Level 3 Hydropedological Assessment for the Elandsfontein Colliery

Emalahleni, Mpumalanga, South Africa

October 2019

CLIENT

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Report Name	**Level 3 Hydropedological Assessment for the Elandsfontein Colliery**
Submitted to	EIMS ENVIRONMENTAL IMPACT MANAGEMENT SERVICES
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Declaration	The Biodiversity Company and its associates operate as independent consultants under the auspice of the South African Council for Natural Scientific Professions. We declare that we have no affiliation with or vested financial interests in the proponent, other than for work performed under the Environmental Impact Assessment Regulations, 2017. We have no conflicting interests in the undertaking of this activity and have no interests in secondary developments resulting from the authorisation of this project. We have no vested interest in the project, other than to provide a professional service within the constraints of the project (timing, time and budget) based on the principals of science.

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Declaration

I, Ivan Baker declare that:

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

Ivan Baker

Soil Specialist

The Biodiversity Company

October 2019

Declaration

I, Johan van Tol declare that:

- I act as the independent specialist in this application;
- I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant;
- I declare that there are no circumstances that may compromise my objectivity in performing such work;
- I have expertise in conducting the specialist report relevant to this application, including knowledge of the Act, regulations and any guidelines that have relevance to the proposed activity;
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- all the particulars furnished by me in this form are true and correct; and
- I realise that a false declaration is an offence in terms of Regulation 71 and is punishable in terms of Section 24F of the Act.

Prof. Johan van Tol

Soil Specialist

Digital Soils Africa

October 2019

1 Introduction

The Biodiversity Company was commissioned to conduct a level 3 hydropedological assessment as part of the environmental authorisation/licencing and/or permitting process for the relevant mining activities (open cast and underground).

The project will also be undertaken to meet the requirements of the National Environmental Management Act 107 of 1998, specifically Appendix 6. This biodiversity assessment will be informed by the National Environmental Management: Biodiversity Act (NEM:BA) No. 10 of 2004.

A single hydropedological site visit was conducted from the 12^{th} to the 16^{th} of August 2019, This report, after taking into consideration the findings and recommendation provided by the specialist herein, should inform and guide the Environmental Assessment Practitioner (EAP) and regulatory authorities, enabling informed decision making with regards to the proposed activity.

2 Aims and Objectives

The aim of the assessment was to determine the current state of the associated water resources in the area of study. This was achieved through the following:

- Identification of soil profiles and morphology;
- Determining the Saturated Hydraulic Conductivity (*Ks*) of bedrock;
- Undisturbed sampling of all soil horizons for each land type;
- Conceptualising impacts towards hillslope hydrology;
- Using results from laboratory tests on undisturbed samples for the parameterisation of the relevant modelling software;
- Quantifying the loss of interflow towards watercourses; and
- The prescription of mitigation measures and recommendations for identified risks.

3 Knowledge Gaps

The following aspects were considered as limitations;

- Only the slopes affected by the proposed mining areas have been assessed;
- No surface impacts (i.e. haul roads, infrastructure, shafts, evaporation ponds etc) have been included into this report;
- Access could not be gained at observation 8 and 9 (i.e. Sampling sites);
- It has been assumed that the mining areas provided to the consultant are correct;
- The GPS used for ground truthing is accurate to within five meters. Therefore, the wetland and the observation site's delineation plotted digitally may be offset by at up to five meters to either side; and

- Geohydrological modelling was not part of the hydropedological assessments.

4 Literature Review

4.1 Hydropedological Flow Paths

Given that hydropedology is a relatively new field, a short literature review has been added on this interdisciplinary research field. This literature is an excerpt from van Tol *et al.,* (2017).

Soil physical properties and hydrology play significant roles in the fundamentals of hydropedology. Physical properties including porosity, hydraulic conductivity, infiltration etc. determine micro preferential flow paths through a soil profile. The hydrology in turn is responsible for the formation of various morphological processes in soil, including mottling, colouration and the accumulation of carbonate.

These processes are used to construct models illustrating sub-surface flow paths, storage and interconnection between these flow paths. Hydropedology can therefore be used for a variety of functions. These functions include process-based modelling, digital soil mapping, pollution control management, impact of land use change on water resources, wetland protection, characterising ground and sub-surface flows as well as wetland protection and rehabilitation, of which the latter will be the main focus during this report (see Figure 1). The latter mentioned enables effective water resource management regarding wetlands and sub-surface flows in general.

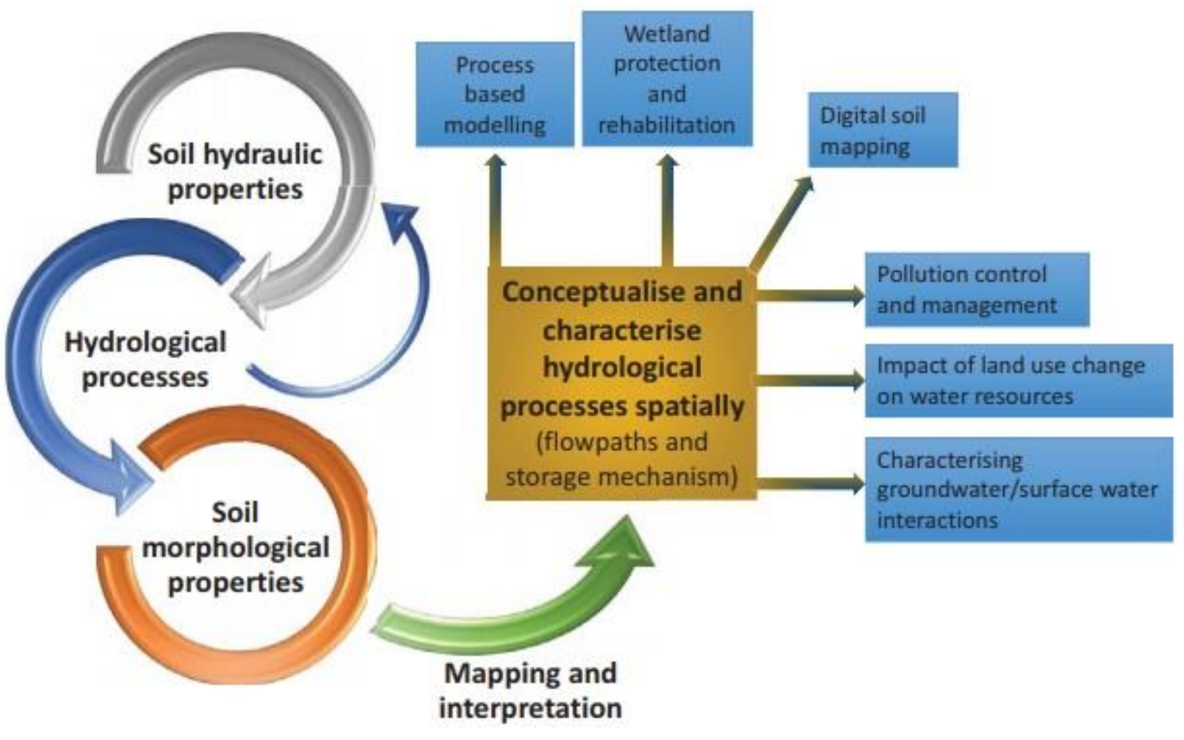

Figure 1: Illustration of the interactive nature of hydropedology and its potential applications (van Tol et al., 2017).

As can be seen in Figure 2, the hydropedological behaviour of soil types can differ significantly. Figure 2 (a) illustrates a typical red coloured soil (top- and sub-soil. This soil type will typically have a vertical flow path throughput the soil profile. Water will therefore infiltrate the top-soil and freely drain into the profile to such an extent that the water rapidly reaches the bedrock. After reaching this layer, water will penetrate the ground water source or be transported horizontally towards lower laying areas. This soil type is known as a recharge soil, given its ability to recharge ground and surface water sources.

Figure 2 (b) illustrates interflow soils. Lateral flows are dominant in this soil type and occurs due to differences in the hydraulic conductivity of soil horizons. The “sp” soil horizon restricts vertical movement and promotes lateral flows at the A/B interface. The lighter colour in this profile indicates leaching which is caused by lateral flows which often occurs on top of a bedrock layer due to the impermeable nature thereof. Mottles often occurs above this impermeable layer due to fluctuating water levels, see the magnified illustration in Figure 2 (b-i).

Figure 2 (c) illustrates responsive soils. This hydropedological soil type is characterised (in this case) by a dark top-soil and a grey coloured sub-soil. Other indicators include mottling and gleying. These soil types are saturated for very long periods. Therefore, rainfall is unlikely to infiltrate this layer and would likely be carried off via overland flow and are mostly fed by lateral sub-surface flows. Shallow soils are equally responsive in the sense that the soil profile will rapidly be saturated during precipitation, after which rainfall will be carried off by means of overland flows.

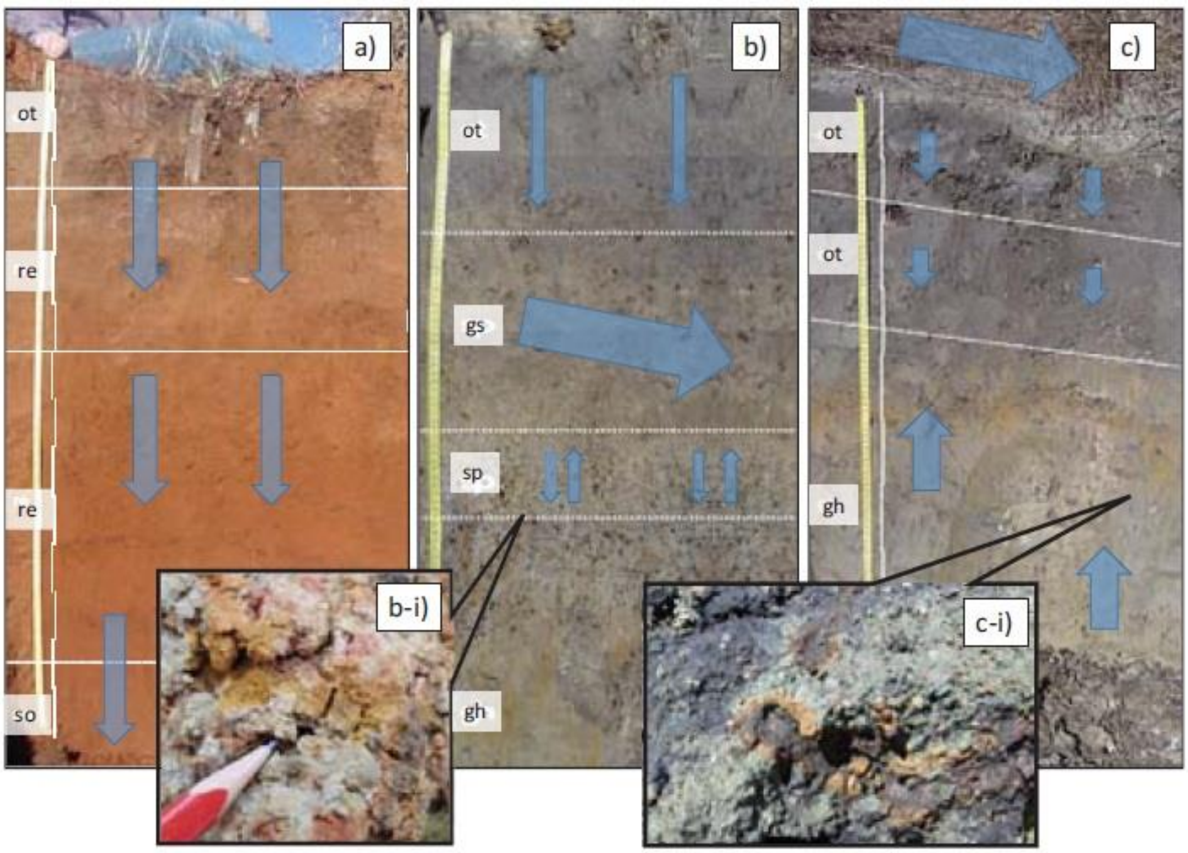

Figure 2: Illustration of different hydropedological soil types (van Tol et al., 2017).

A typical example of the hydropedological processes through a hillslope is illustrated in Figure 3. In this example, a recharge soil type is located at the upper reaches of the slope. Rainfall infiltrates this soil type and percolates vertically towards the bedrock. Water then, infiltrate into this bedrock given the permeability thereof and could now recharge groundwater or return to the soil in lower lying positions. The second soil type (the interflow zone) indicates lateral flows at the A/B interface and again at the soil/bedrock interface which feeds the responsive zone. The responsive zone is then simultaneously fed by lateral sub-surface flows and ground water recharge.

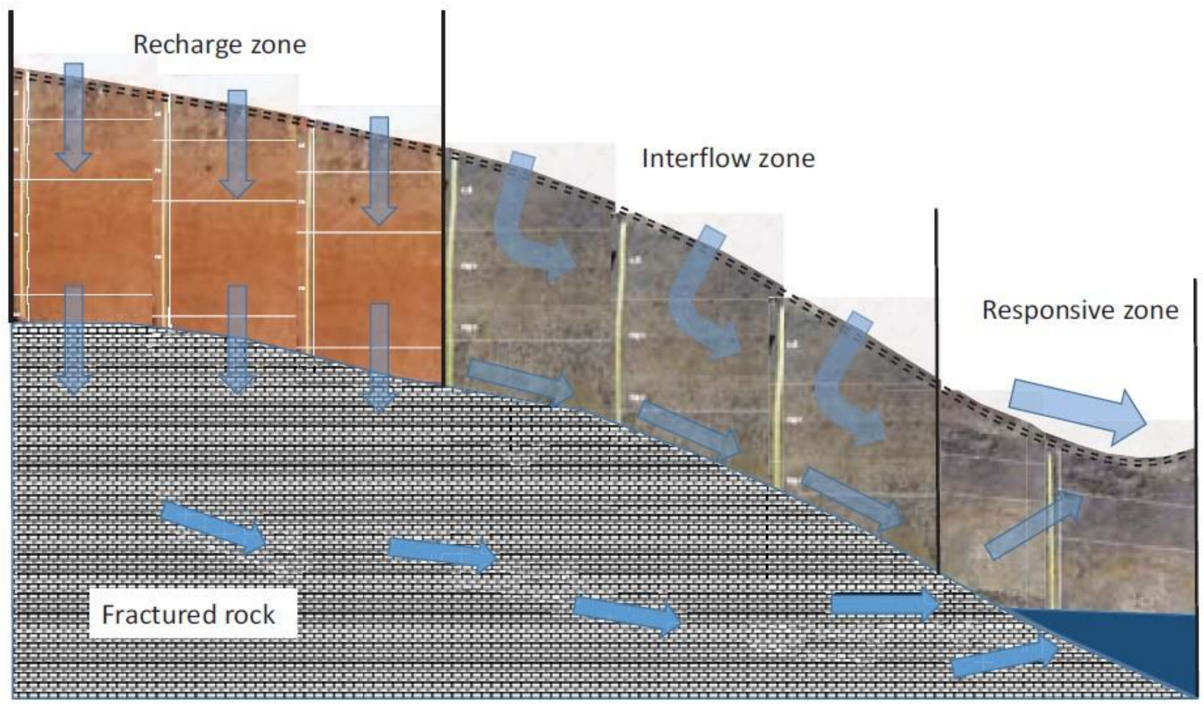

Figure 3: Theoretical example of various sub-surface flow paths (van Tol et al., 2017).

The methodology of van Tol *et al.,* (2017) has since been updated to include a "stagnant" hydropedological type. According to van *Tol et al.,* (2019), four different hydropedological types exist, namely Recharge, Interflow, Responsive and Stagnating hydropedological types. These soil types are divided into seven subgroups depending on the morphology of the relevant soil form. The latest addition to this methodology, as mentioned, is known as a stagnating hydropedological type.

This soil type is characterised by restrictive movement of water through profiles (both laterally and vertically) and is dominated by evapotranspiration. The A- and B-horizon of such a soil type usually has a high permeability with morphological indicators indicating very little movement through the profile. Lime and iron concretions as well as cementation of silica are typical indicators of such a soil form.

5 Project Area

The project area is located approximately 14 km south-west of Emalahleni and approximately 13 km south-east of Balmoral, Mpumalanga, South Africa (see Figure 4). The dominant land uses surrounding the project area includes watercourses, cultivation, urban sprawls and mining.

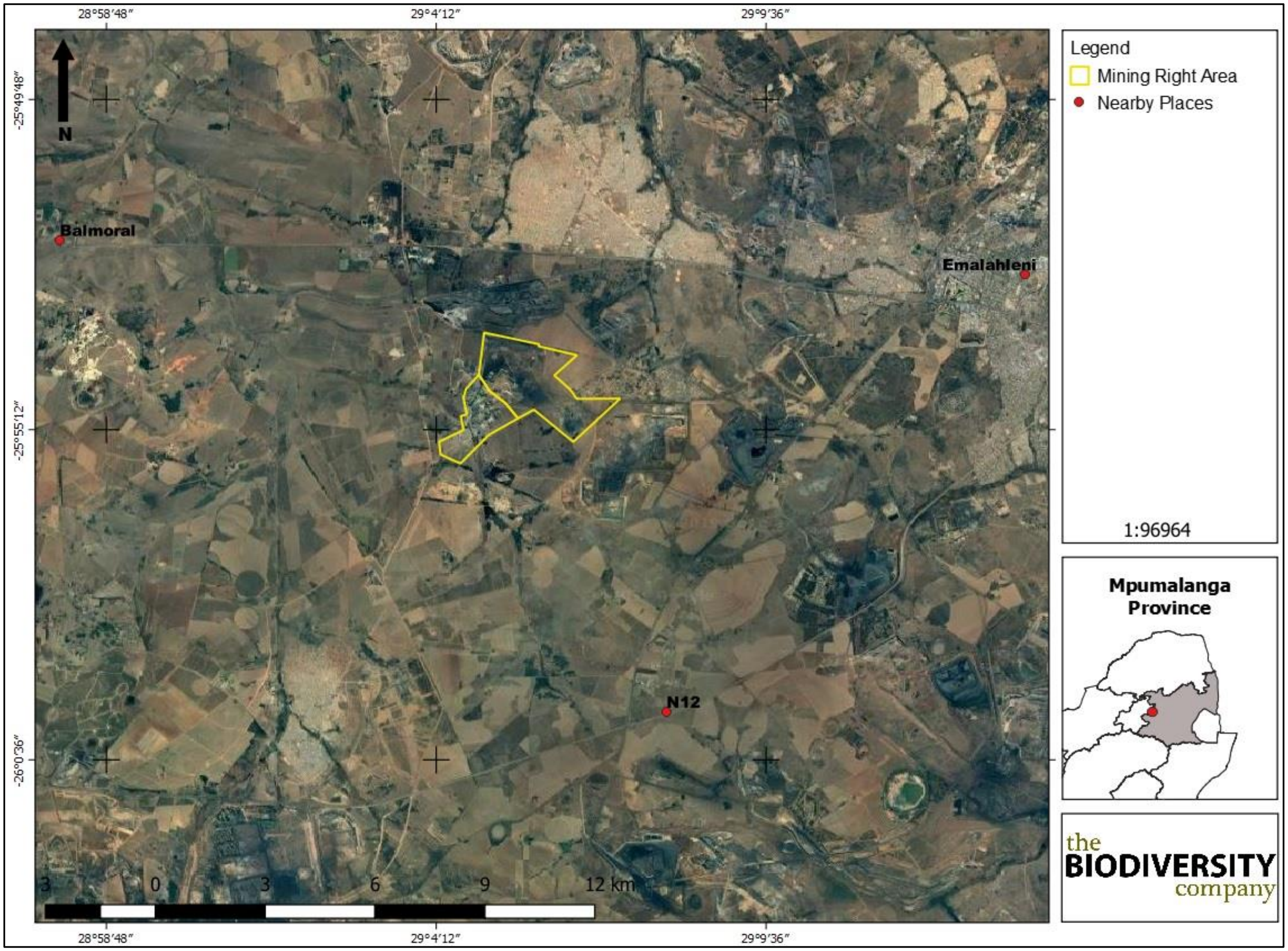

Figure 4: Locality map of the project area

5.1 Vegetation Types

The MRA is located within two vegetation types, including the Rand Highveld Grassland (Gm 11) Eastern Highveld Grassland (Gm 12). The distribution of the Rand Highveld Grassland ranges between the North-West, Gauteng, Free State and Mpumalanga provinces. This vegetation type can be found between rocky ridges specifically between Witbank and Pretoria. The Rand Highveld Grassland extends into these ridges in the Stoffberg area as well as west of Krugersdorp stretching all the way to Potchefstroom. The preferred altitude for this vegetation type is between 1300m and 1635m above sea level (Mucina & Rutherford, 2006). -

Grass species commonly found in these regions include the genera *Themeda. Eragrostis, Elionurus* and *Heteropogon*. The diversity of herbs is high in these regions with rocky ridges and hills being colonized by sparse woodlands accompanied by a rich suite of shrubs with the genus *Rhus* making up the bulk thereof (Mucina & Rutherford, 2006). The sparse woodlands in this vegetation type includes species like *Protea caffra* subsp., *Caffra, Acacia caffra, P. Welwitschii* etc.

The project area falls within the Eastern Highveld Grassland (Gm 12) vegetation type. This vegetation type is located in the Gauteng and Mpumalanga province within the plains between Belfast and Johannesburg. This vegetation type also extends to Bethal, the western areas of Piet Retief and Ermelo. The altitude in which this vegetation type occurs ranges between 1 520 meters above sea level to 1 780 meters above sea level (Mucina & Rutherford, 2006).

The vegetation of this vegetation type is characterised by short and dense grasslands that occur in moderately undulating plains which include low hills and pan depressions (Mucina & Rutherford, 2006). Small scattered rocky outcrops are common in this area with wiry, sour grasses accompanied by some woody species which include *Celtis africana, Parinari capensis, Protea caffra* etc.

The conservation status of the Gm 12 vegetation type is endangered with a target percentage of 24. Half of the area is already transformed into agriculture, mining, urban etc. with a handful of conservation areas still up and running. These include Holkranse, Nooitgedacht Dam and Morgenstond (just to name a few) (Mucina & Rutherford, 2006).

5.2 Soils and Geology

According to the land type database (Land Type Survey Staff, 1972 - 2006), the project area is characterised by the Bb 13 and the Ba 5 land types. Figure 5 illustrates the respective terrain units relevant to the Bb 13 land type with the expected soils illustrated in Table 1. Figure 6 illustrates the respective terrain units relevant to the Ba 5 land type with the expected soils illustrated in Table 2.

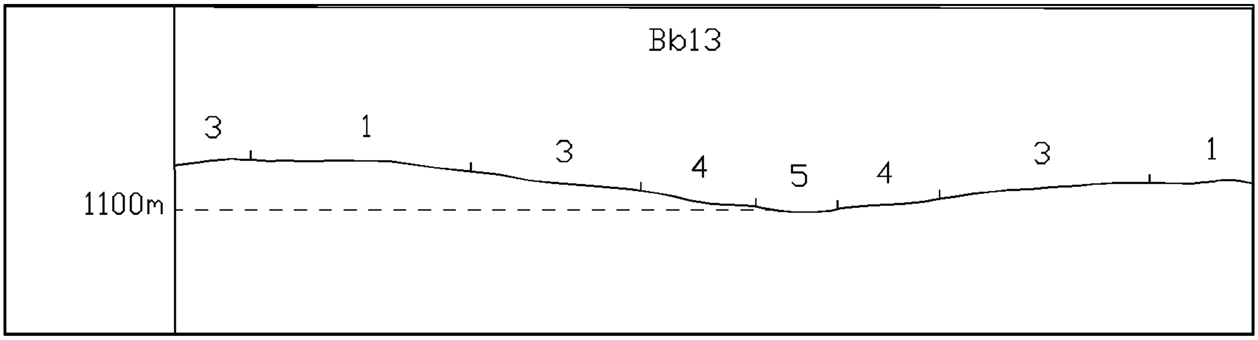

Figure 5: Illustration of land type Bb 13 terrain units (Land Type Survey Staff, 1972 - 2006)

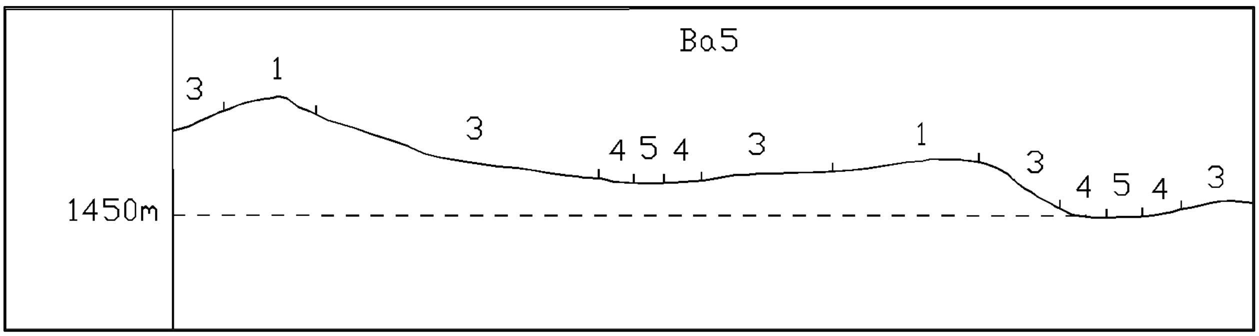

Figure 6: Illustration of land type Ba 5 terrain units (Land Type Survey Staff, 1972 - 2006)

Table 1: Soils expected at the respective terrain units within the Bb 13 land type (Land Type Survey Staff, 1972 - 2006)

Terrain units							
1 (40%)		**3 (45%)**		**4 (10%)**		**5 (5%)**	
Clovelly	45	Avalon	35	Avalon	30	Karspruit	40
Glencoe	25	Clovelly	35	Longlands	25	Kroonsdad	30
Hutton	15	Hutton	10	Kroonstad	15	Furnwood	20
Avalon	15	Glencoe	10	Glencoe	10	Longlands	10
		Longlands	5	Wasbank	10		
		Kroonstad	5	Furnwood	10		

Table 2: Soils expected at the respective terrain units within the Ba 5 land type (Land Type Survey Staff, 1972 - 2006)

Terrain units							
1 (20%)		**3 (60%)**		**4 (15%)**		**5 (5%)**	
Hutton	60	Hutton	40	Hutton	25	Rensburg	50
Glenrosa	20	Avalon	15	Avalon	15	Katspruit	30
Clovelly	10	Glencoe	10	Longlands	15	Swartland	20
		Glenrosa	10	Kroonstad	10		
		Clovelly	5	Bonheim	10		
		Longlands	5	Clovelly	10		
		Swartland	5	Swartland	5		
		Wasbank	5	Glencoe	5		
		Mispha	5	Wasbank	5		

The geology of this vegetation type is characterised by the Pretoria group and the Witwatersrand Subgroup's quartzite ridges as well as the Rooiberg Group's Selons River Formation which is from the Transvaal Supergroup. The parent geology from this vegetation type supports shallow soils like Glenrosa and Mispah which typically forms on slopes and ridges where topsoil is likely to wash off (Mucina & Rutherford, 2006).

5.3 Climate

The climate for the Rand Highveld Grassland is characterised by a summer rainfall with a mean annual precipitation of 654mm which is slightly lower in the western parts of this vegetation type see (Figure 7). These areas are known to have warm-temperate conditions with dry winters. The likelihood of frost however is greater in the western parts with the incidence of frost ranging from 30 to 40 days compared to the east which has a frost incidence of 10 to 35 days (Mucina & Rutherford, 2006). This vegetation type is also classified as endangered even though very little conservation has been done for this vegetation type.

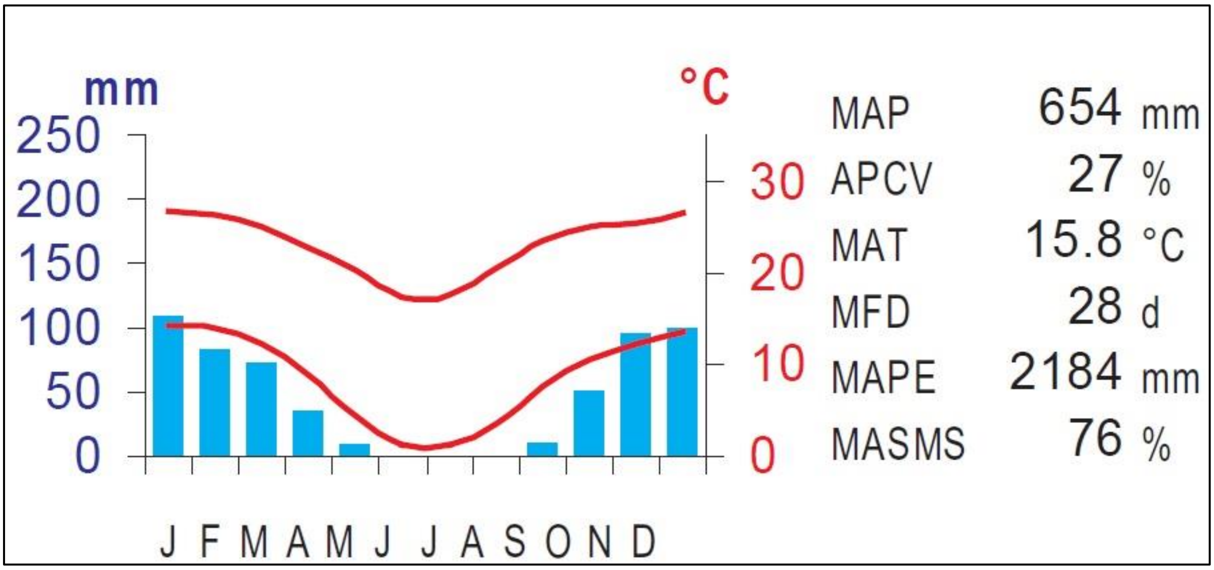

Figure 7: Climate for the Rand Highveld Grassland (Mucina & Rutherford, 2006)

5.4 River lines and Mpumalanga Highveld Grassland Wetlands

Various non-perennial and perennial streams have been identified within the proposed project area by means of the "2529" quarter degree square topographical river line data set. The Mpumalanga Highveld Grassland Wetland Layer indicates an additional wetland within the MRA, namely a floodplain wetland with various other wetland types located within the MRA's surroundings (see Figure 8).

5.5 NFEPA Wetlands

Two types of NFEPA wetlands were identified within the MRA, namely channelled valley bottom wetlands as well as seeps (see Figure 9). The channelled valley bottom wetlands are classified as natural and the seeps are classified as artificial.

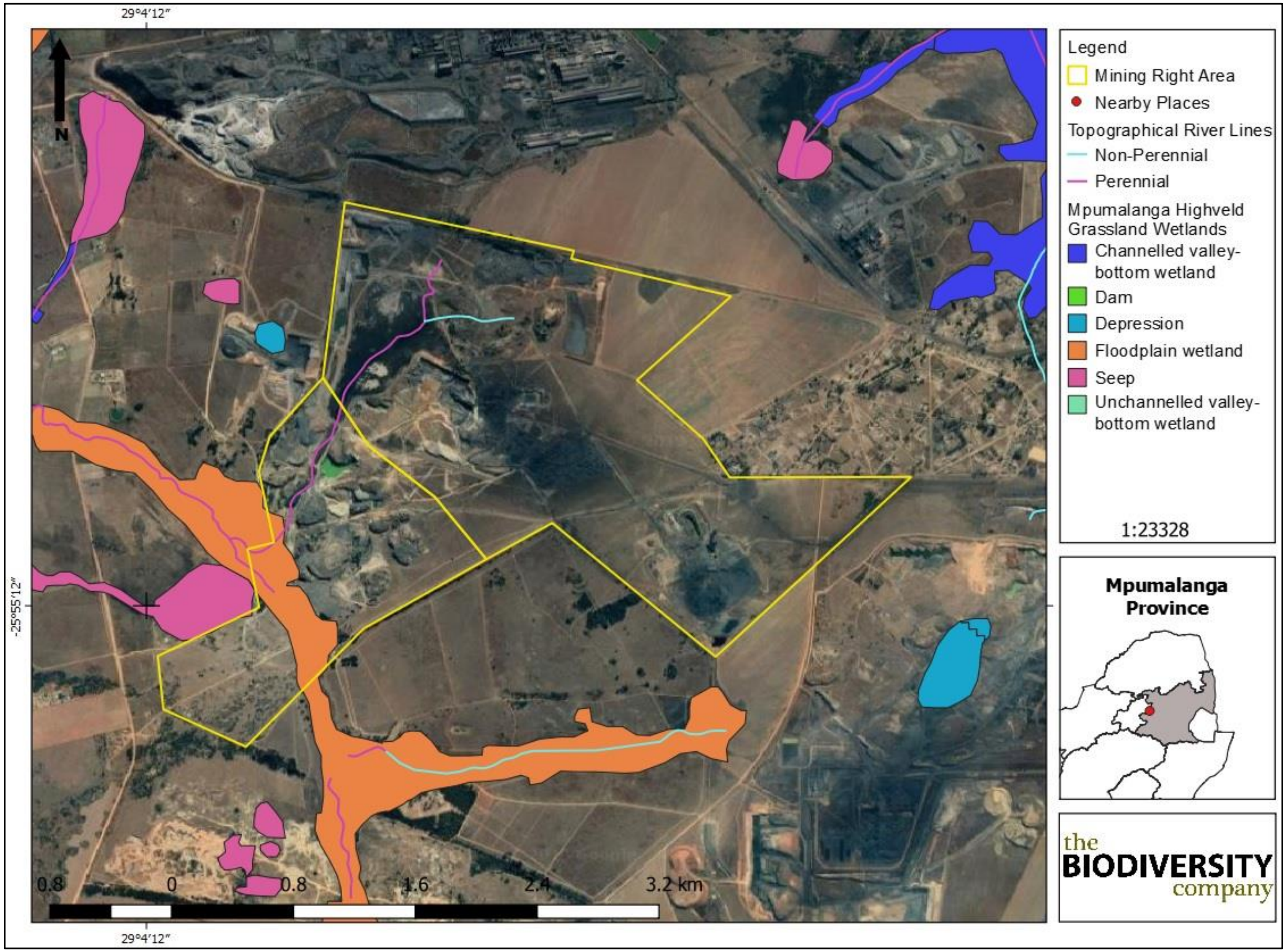

Figure 8: Illustration of topographical river lines and the Mpumalanga Highveld Grassland Wetlands

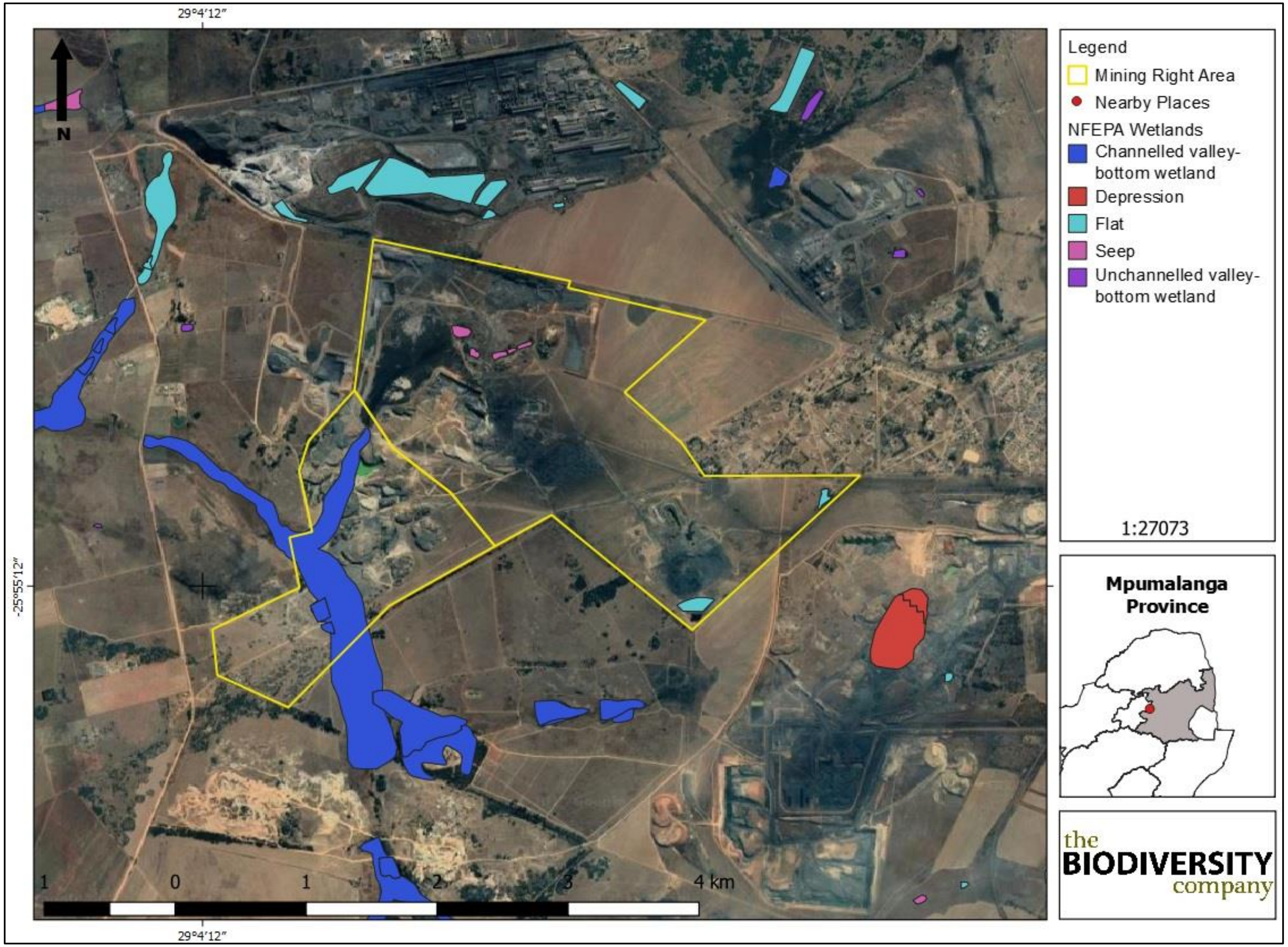

Figure 9: NFEPA wetlands within the project area and its surroundings

6 Methodology

6.1 Desktop assessment

The following information sources were considered for the desktop assessment;

- Aerial imagery (Google Earth Pro);
- Land Type Data (Land Type Survey Staff, 1972 - 2006)
- Contour data (5 m); and
- Mucina & Rutherford (2006).

6.2 Field Procedure

The slopes within the project area has been assessed during the desktop assessment to identify possible transects that will represent typical terrain and soil distribution patterns. These locations where then altered slightly during the survey depending on the extent of vegetation, slopes, access and any features that will improve the accuracy of data acquired. A total of four transects were identified in which five pits in total have been excavated up to refusal (see Figure 10 and Figure 7). Access could not be gained at Observation 8 and 9. Therefore, three pits have been added (“added pit 1, 2 and 3”) to resemble the soil profiles relevant to Observation 8 and 9. These added pits are based on similar land types, topography, slope and vegetation characteristics than Observation 7, 8 and 9 to ensure accuracy.

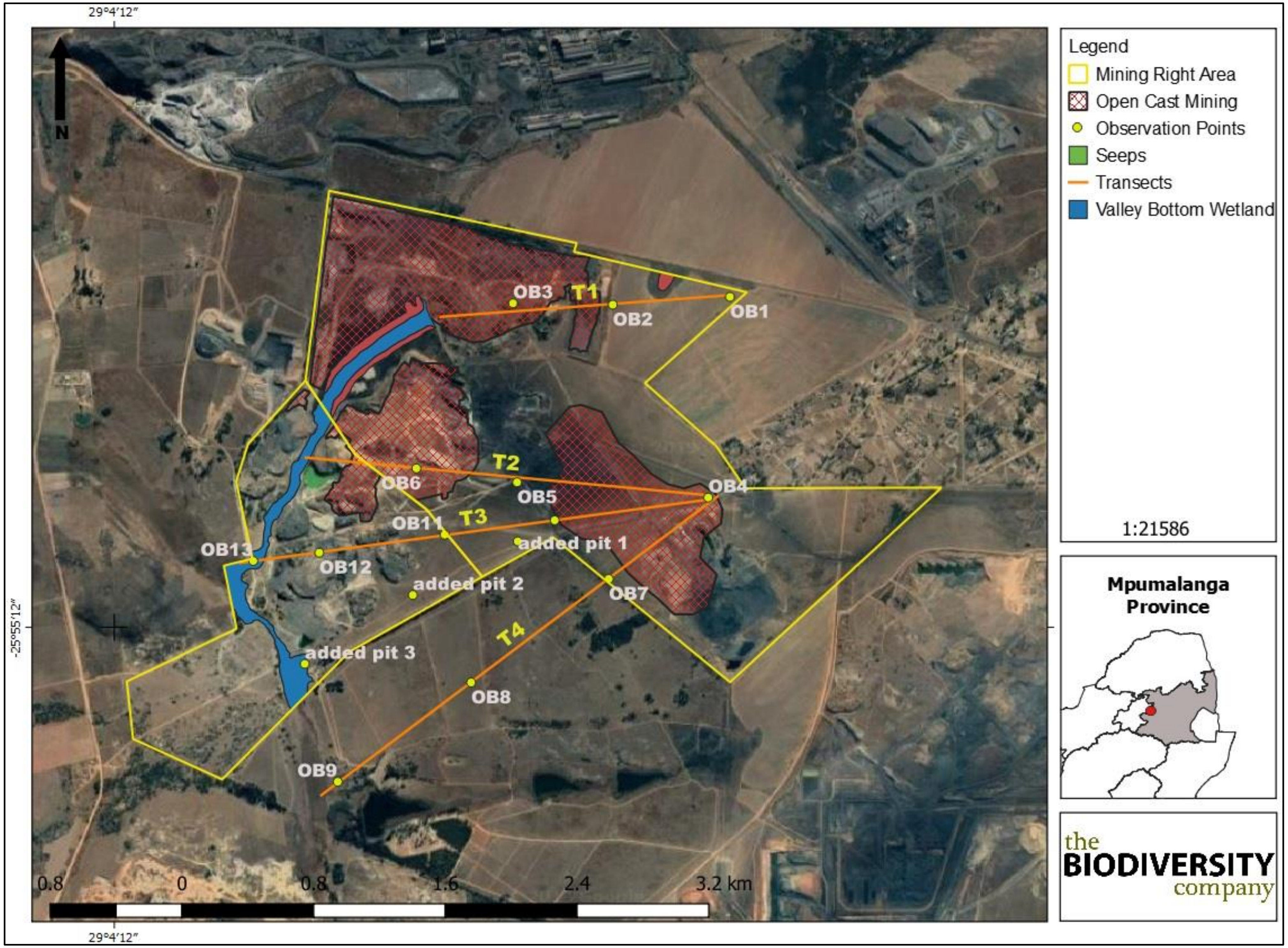

Figure 10: Transects and Sampling Sites relevant to open cast mining areas

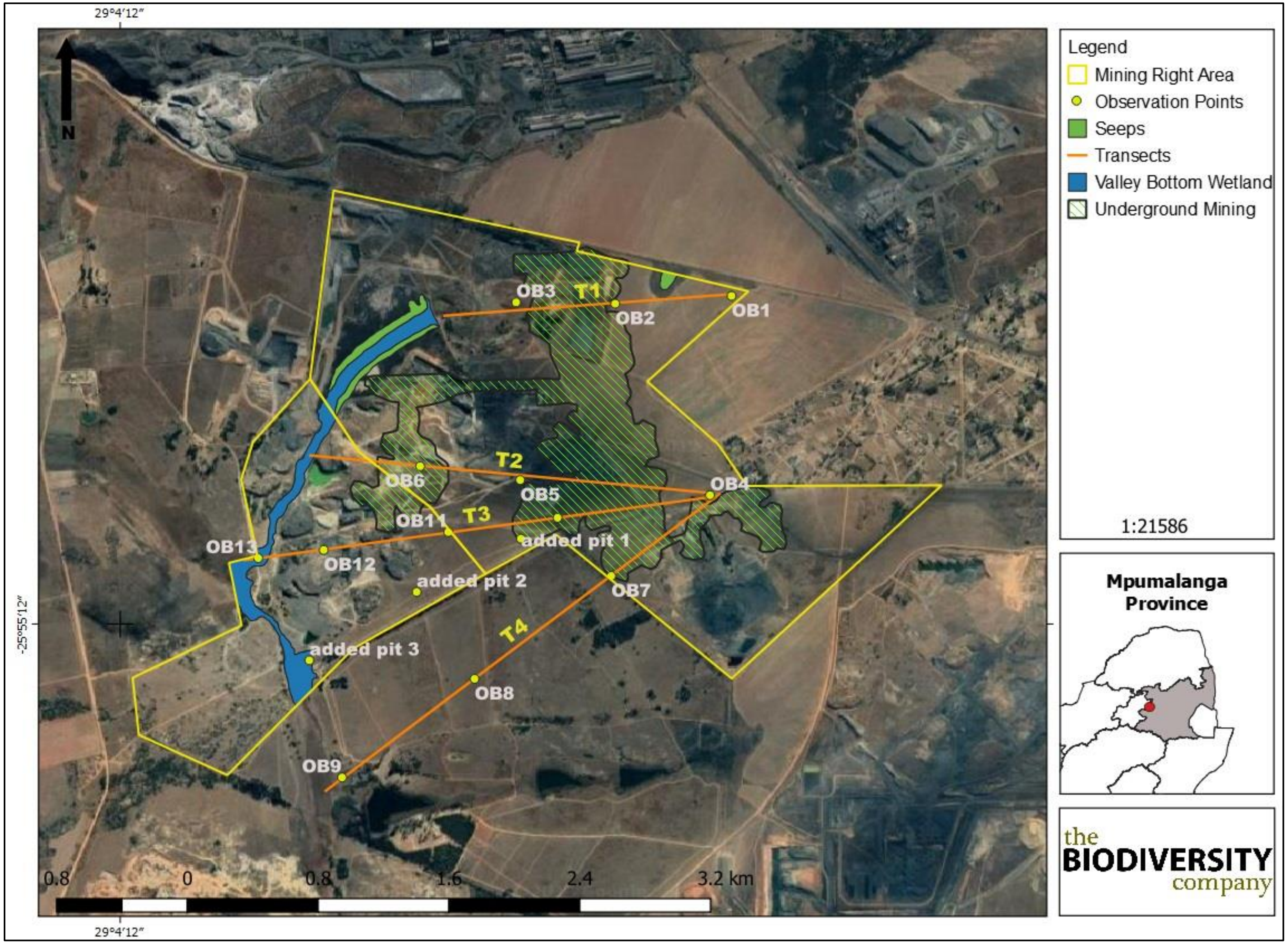

Figure 11: Transects and Sampling Sites relevant to underground mining areas

6.2.1 Identification of Soil Types and Hydrological Soil Types

Soil types have been identified according to the South African soil classification (Soil Classification Working Group, 1991) after which the link between soil forms and hydropedological response were established (van Tol & Le Roux, 2019), and the soils regrouped into various hydropedological soil types as shown in Table 3.

Table 3: Hydrological soil types of the studied hillslopes (van Tol et al., 2019)

Hydrological Soil Type	Description	Subgroup	Symbol
Recharge	Soils without any morphological indication of saturation. Vertical flow through and out the profile into the underlying bedrock is the dominant flow direction. These soils can either be shallow on fractured rock with limited contribution to evapotranspiration or deep freely drained soils with significant contribution to evapotranspiration.	Shallow	
		Deep	
Interflow (A/B)	Duplex soils where the textural discontinuity facilitates build-up of water in the topsoil. Duration of drainable water depends on rate of ET, position in the hillslope (lateral addition/release) and slope (discharge in a predominantly lateral direction).	A/B	
Interflow (Soil/Bedrock)	Soils overlying relatively impermeable bedrock. Hydromorphic properties signify temporal build of water on the soil/bedrock interface and slow discharge in a predominantly lateral direction.	Soil/Bedrock	
Responsive (Shallow)	Shallow soils overlying relatively impermeable bedrock. Limited storage capacity results in the generation of overland flow after rain events.	Shallow	
Responsive (Saturated)	Soils with morphological evidence of long periods of saturation. These soils are close to saturation during rainy seasons and promote the generation of overland flow due to saturation excess.	Saturated	
Stagnating	In these soils outflow of water is limited or restricted. The A and/or B horizons are permeable but morphological indicators suggest that recharge and interflow are not dominant. These includes soils with carbonate accumulations in the subsoil, accumulation and cementation by silica, and precipitation of iron as concretions and layers. These soils are frequently observed in climate regions with a very high evapotranspiration demand. Although infiltration occurs readily, the dominant hydrological flow path in the soil is upward, driven by evapotranspiration.		

6.2.2 Undisturbed Sampling

Undisturbed samples were collected for each of the diagnostic horizons. These samples were sent to *Van's lab* (Pty) Ltd. in Bloemfontein to determine the particle size distribution, saturated hydraulic conductivity (*Ks*), bulk density, and water retention characteristics. A cylindric Poly Vinyl Chloride (PVC) is gently inserted laterally into a diagnostic soil type to extract an undisturbed sample of the relevant soil type. Wooden lids are then taped to the pipe to ensure that the sample stays intact.

6.2.3 *In-Situ* Testing of Hydraulic Conductivity

In-situ Ks was tested by means of a single ring infiltrometer within the excavated pits. These tests are vital for the sections of the profile undisturbed sampling is not possible due to the physical properties of such a layer, i.e. bedrock.

A single ring infiltrometer consists of a metal sheet driven into a soil profile which is used as a constant head test. Water is poured into the sheet up to a specific mark in the inside of the sheet that resembles the upper part of a line set to measure the drop of water in a one-centimetre interval. The time the water takes to infiltrate a centimetre (from the upper mark to the bottom mark) is taken several times, until the infiltration rate remains close to constant (differing no more than 10% of the previous infiltration time). For soil profiles too deep to excavate up to the refusal layer, *Ks* was tested by means of a 55 mm diameter PVC pipe which were inserted into the auger hole. The conductivity was then calculated using:

$$K = \frac{r^2 \ln\left(\frac{L}{R}\right)}{2LT_0}$$

Where *K* = hydraulic conductivity; *r* = radius of pipe; *L* = length of saturated portion of the perforated area; *R* = radius of perforated area (the same as *r* in this experiment and T_0 = basic time lag.

6.3 Modelling

The aim of the modelling exercise was to quantify hydrologic processes and how they will be impacted upon by the proposed development. The conceptual models of hillslope hydrological responses developed from soil morphological properties guided the modelling approach. For assessment of the impact of open cast pit on hydropedological processes the Catchment Model Framework (CMF) model was used (Kraft *et al*., 2011). CMF is essentially a toolbox to configure a wide range of different model structures based on the finite volume approach (Figure 12). Water fluxes through the landscape are presented as a network of storages and boundary conditions in CMF. Flux governing equations can be assigned to link the storage units with the next one. These equations can be fairly simple e.g. linear storage or tipping bucket approaches or more complex e.g. solving of Kinematic Wave or Richards equation. The compounds of the model are assembled using the scripting language Python.

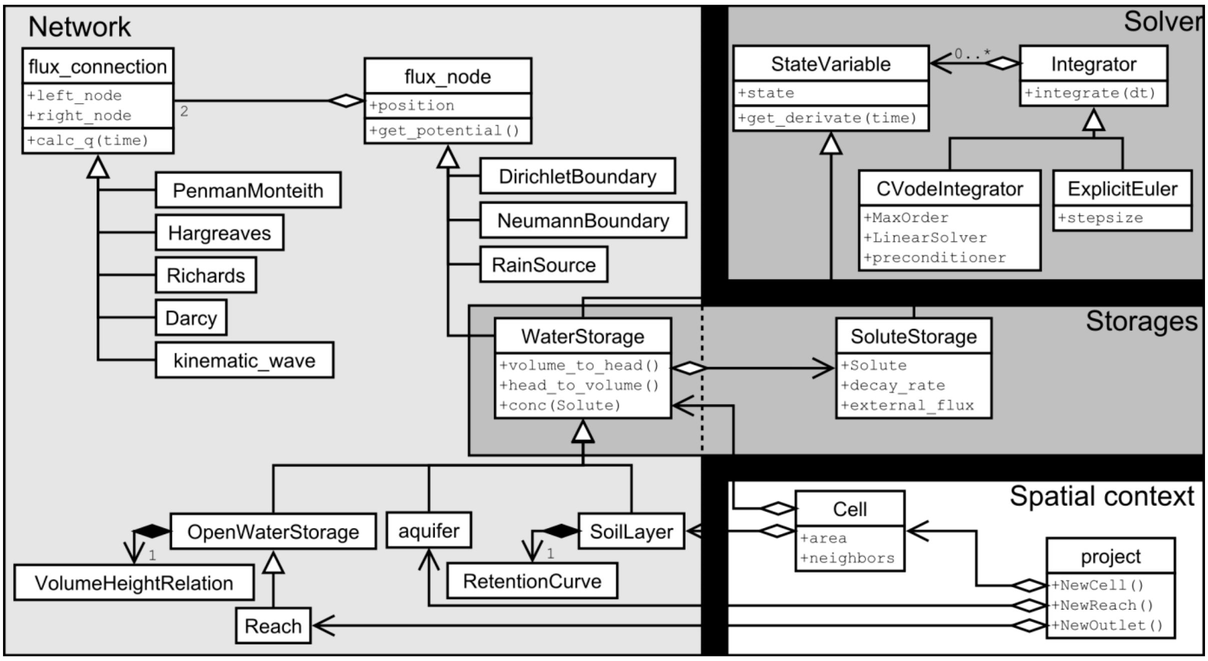

Figure 12: Simplified class representation of the Catchment Modelling Framework and its components (Kraft et al., 2011).

In this study, a large portion is already disturbed by development. This resulted in considerable disturbance of natural flow paths associated with the mixing and/or compaction of soil horizons. Hydrological modelling of these areas to mimic natural flowpaths are therefore not possible due to the alteration of these pathways. The modelling therefore only focussed on one transect which is largely undeveloped. The simulated transect lies between T3 and T4 in Figure 11.

The soil distribution pattern of the transect were configured in CMF and parameterised using measured data from the field and laboratory analysis. The topography (surface elevations) was obtained from Google Earth and included in the configuration of the transects. The Van Genuchten-Maulem hydraulic model was used for sub-surface flows. Relevant Van Genuchten parameters were derived from measured hydraulic properties in combination with PedoTransfer Functions in Rosetta (Schaap et al., 2001).

The slope was initially saturated by applying 100 mm rain per day for 10 consecutive days to the surface boundary. The slope was then allowed to drain for 20 days under low evaporative demands where after 50 mm rain was applied. The slope was then allowed to dry for another 30 days for 30 mm of rain to be added. Water content and fluxes were evaluated from the onset of rain free drainage (day 11) until drainage ceased following the 30 mm event (roughly day 80). This approach was repeated for natural and 'developed' conditions. For the latter, the relative location and coverage of the open cast pit was considered in the model setup (Figure 13b). The assumption was that there is a *'no flow'* boundary below the open cast pit i.e. the area above the lower boundary of the open cast pit does not contribute to the water fluxes downslope. The transect was therefore shortened to exclude the soils in/above the open cast pits. The overall objective of the hydrological simulations was to compare the lateral flows into the stream from the bottom of the slope as well as well as the water content in the valley bottom under the two scenarios.

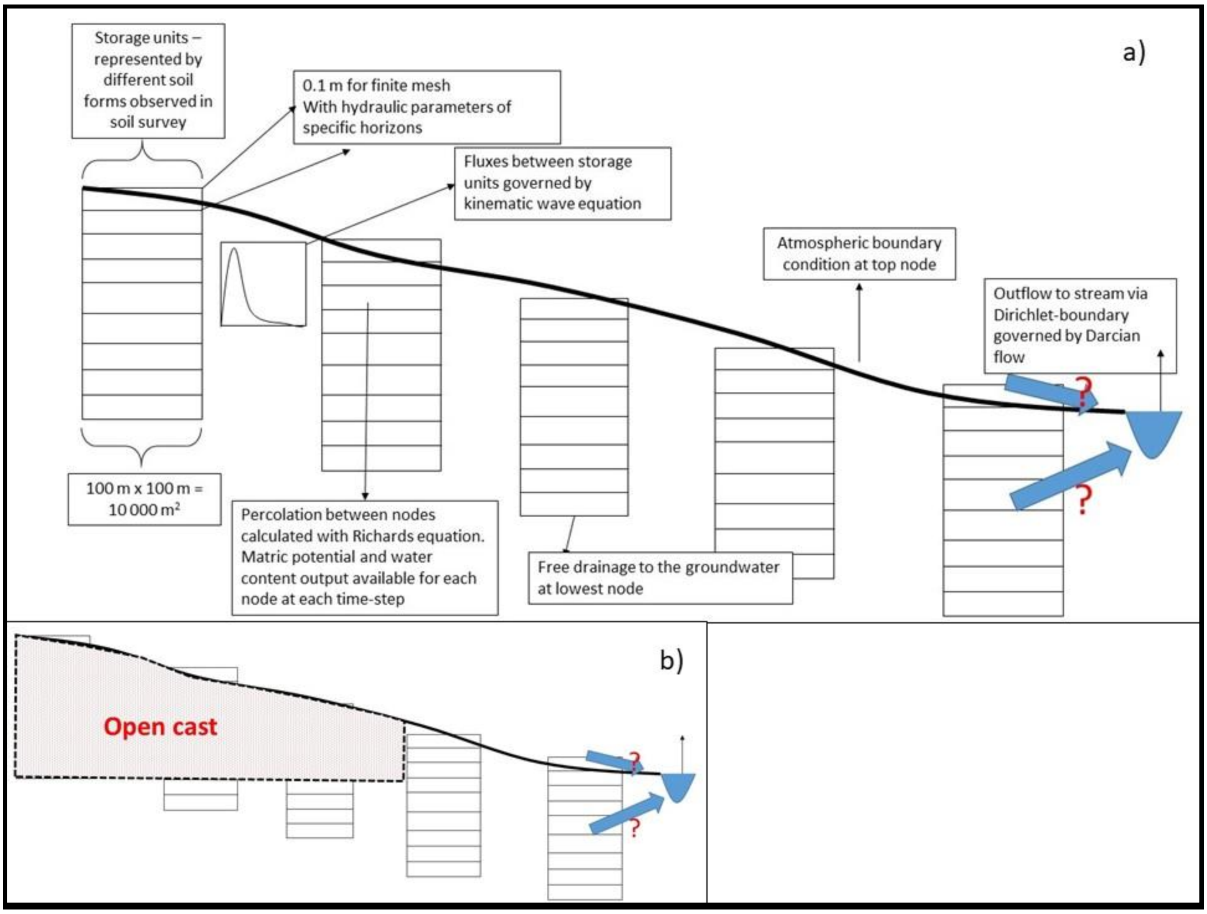

Figure 13: Modelling set-up under natural conditions used to quantify the impact of the proposed pit on surface and subsurface flows; a) natural conditions and b) after the proposed development (adapted from Van Tol et al., 2019).

7 Results and Discussions

7.1 Hillslope Hydrology

The hydropedology survey was conducted in August 2019. The survey was conducted to obtain information required to conceptualise the dominant behaviour of representative hillslopes as well as to provide data for the hydropedological modelling. Four transects were traversed to acquire information regarding the hillslope hydrology, the hydropedological type properties as well as physical properties (i.e. permeability, bulk density, wilting point and texture). The hydropedological types classified during the site assessment are illustrated in Figure 10 and Figure 7.

7.1.1 Transect 1

The hydropedological behaviour of transect 1 is illustrated in a conceptual hydrological response model (see Figure 17). The processes involved within this slope is described according to the number assigned to the relevant hydrological response.

7.1.1.1 Hydropedological Type #1

Observation 1 is located on the crest of the slope relevant to Transect 1 and has been classified as a Carolina soil form, which consists of an Orthic topsoil on top of a Yellow Brown Apedal horizon which in turn overlays a Hard Rock layer (see Figure 14). This soil form has been identified as a deep recharge hydropedological type, which ensures infiltration through the profile and into the bedrock layer.

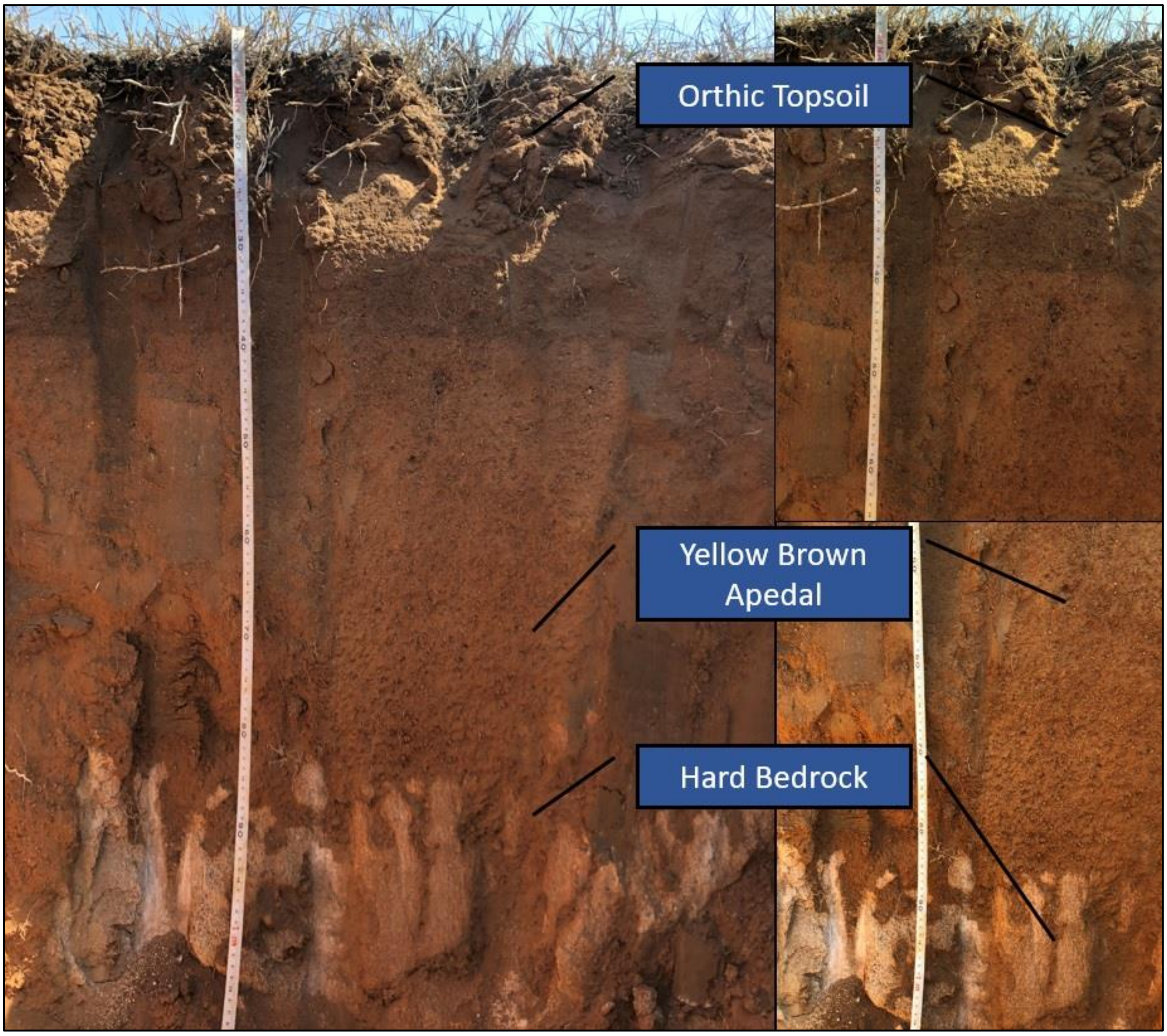

Figure 14: Recharge (soil/bedrock) (Carolina) hydropedological type identified

7.1.1.2 Hydropedological Type #2

Observation 2 is located within the mid-slope terrain unit of transect 1. The soil form relevant to observation 2 has been classified as a Bainsvlei soil form, which consists of an Orthic topsoil on top of a Red Apedal horizon which in turn is underlain by unspecified material with signs of wetness (see Figure 15). The latter mentioned is characterised by a high concentration plinthite-like soft concretions which is evidence of fluctuating levels of saturation and a degree of interflow within this horizon.

Given the fact that no signs of wetness were identified within the first subsoil (the Red Apedal horizon), this soil form has been identified as an interflow (between soil and bedrock) hydropedological type. It is worth noting that this soil profile is characterised by a depth of 230 cm. This soil form has been identified as a Bloemdal soil form given the presence of an unspecified material with signs of wetness.

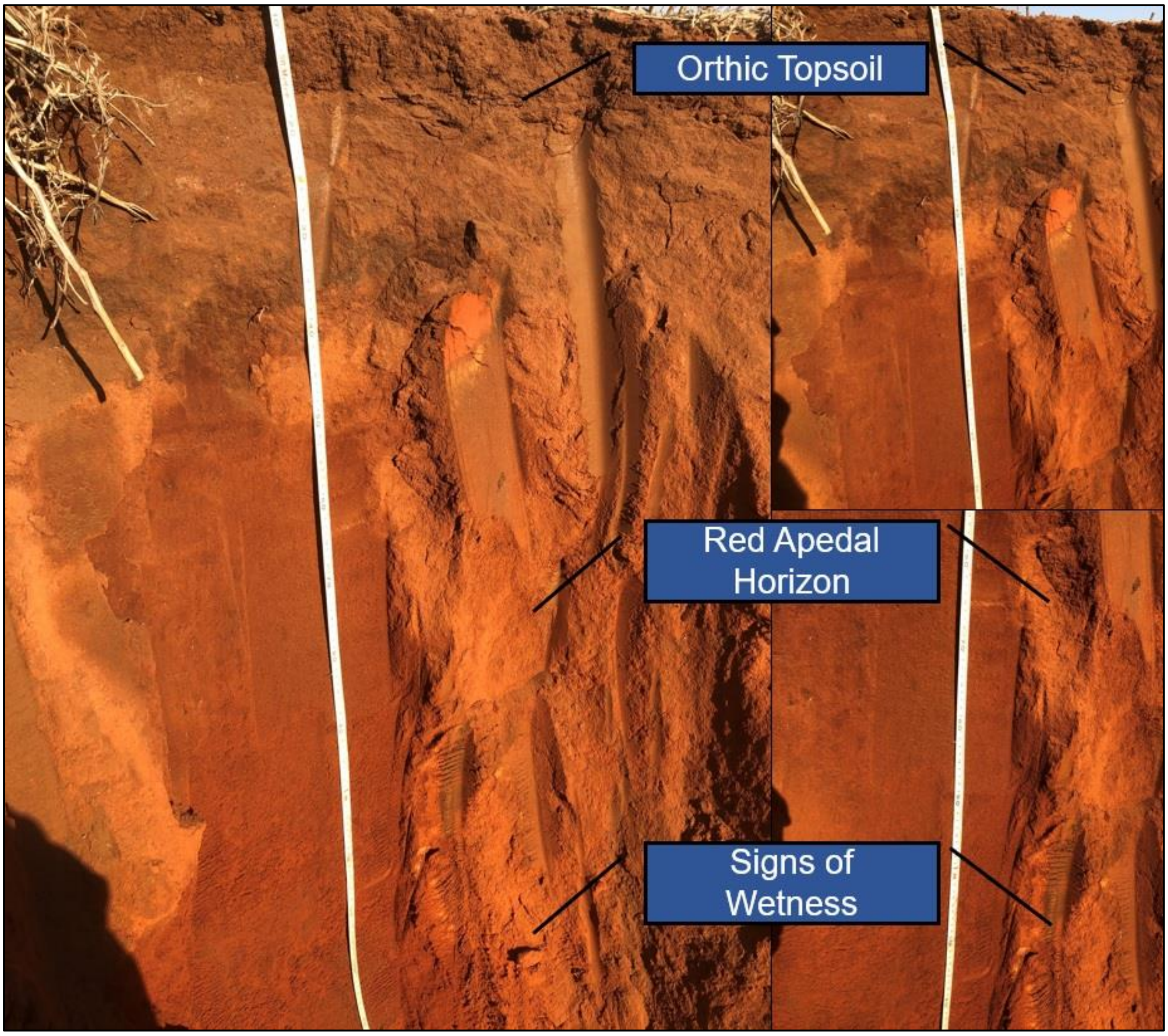

Figure 15: Interflow (soil/bedrock) (Bainsvlei) hydropedological type identified in observation 2, transect 1

7.1.1.3 Hydropedological Type #3

The entire portion of the hillslope from Observation 2 downwards is characterised by disturbances from mining activities. The soil form identified within this section is a Transported Technosol (and more specifically a Witbank soil form) due to the presence of artificial material transported and deposited within this area (see Figure 16).

The material within this soil profile has no diagnostic properties and are mixed together with other soils, waste rock and is compacted severely. A rock-hard soil profile rendered the soil impossible to sample with no morphology indicating dominant flow paths. The lack of morphological indicators and the compaction of the Witbank soil form has rendered the dominant flow paths overland flow, which also is evident from a high concentration of drains and gullies that have formed from significant surface run-off.

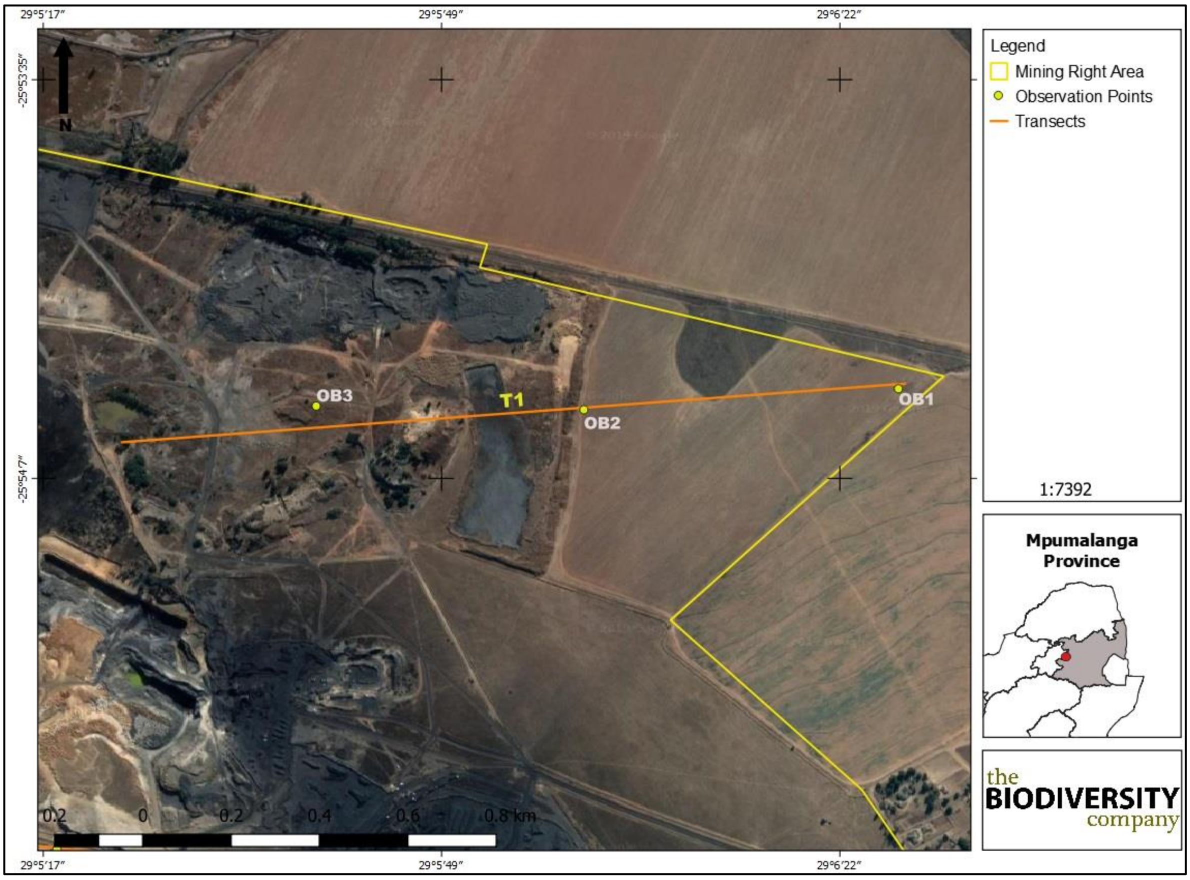

Figure 16: Extent of disturbed areas (Witbank soil form)

7.1.1.4 Transition "A"

Deep recharge seeps out into the following hydropedological type, which is an interflow (between soil and bedrock) hydropedological type. An influx of sub-surface flow to the bedrock interface joins up with infiltration of precipitation to ensure a steady interflow between soil and bedrock.

7.1.1.5 Transition "B"

A high degree of modification, inputs of Technosols and severe compaction have resulted in an extremely low *Ks*, which forces interflow up the Witbank soil form after which overland flow dominates.

7.1.1.6 Transition "C"

Overland flow from the previous hydropedological type (Witbank) is transitioned into the watercourse downslope from Transect 1. The dominance of overland flow is emphasised by the concentrations of drains and gullies. It is the specialist's opinion that very little water from the hillslope will reach the watercourse, with the dominant influx towards the watercourse being during precipitation events. Additionally, inputs from waste impoundments and mining areas adjacent to the watercourse will provide fortuitous inputs.

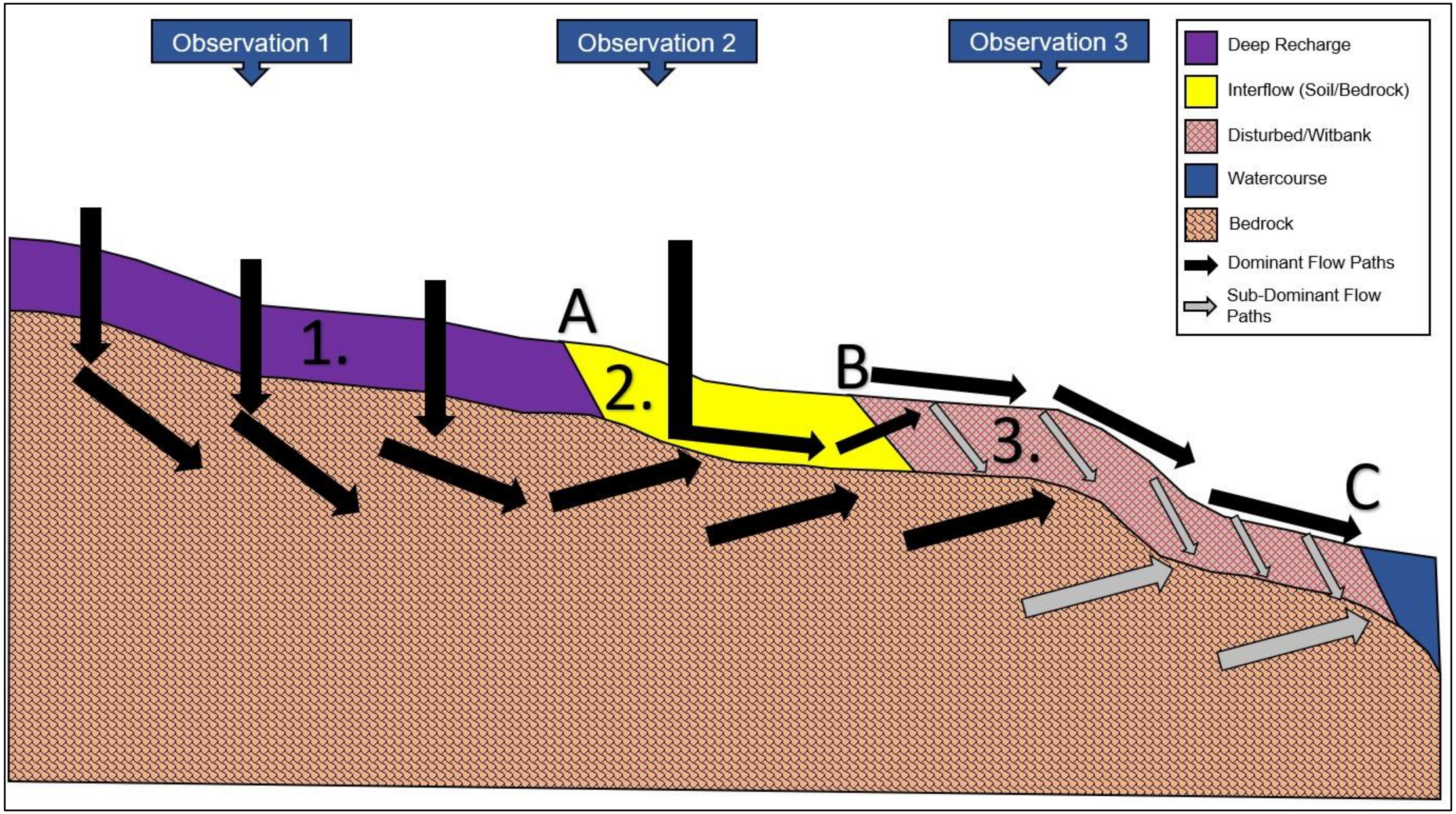

Figure 17: Conceptual hydropedological response model of transect 1 (in current state)

7.1.2 Transect 2

The hydropedological behaviour of transect 2 is illustrated in a conceptual hydrological response model (see Figure 19). The processes involved within this slope is described according to the number assigned to the relevant hydrological response.

7.1.2.1 Hydropedological Type #1

Observation 4 is located on the crest of the slope relevant to Transect 2. This soil form constitutes a recharge (shallow) hydropedological type given the high *in-situ Ks* and the lack of wetness. The *in-situ Ks* has been calculated at 24 mm/h, which ensures a high recharge volume. It is worth noting that this soil profile is very shallow with a depth of only 30 cm.

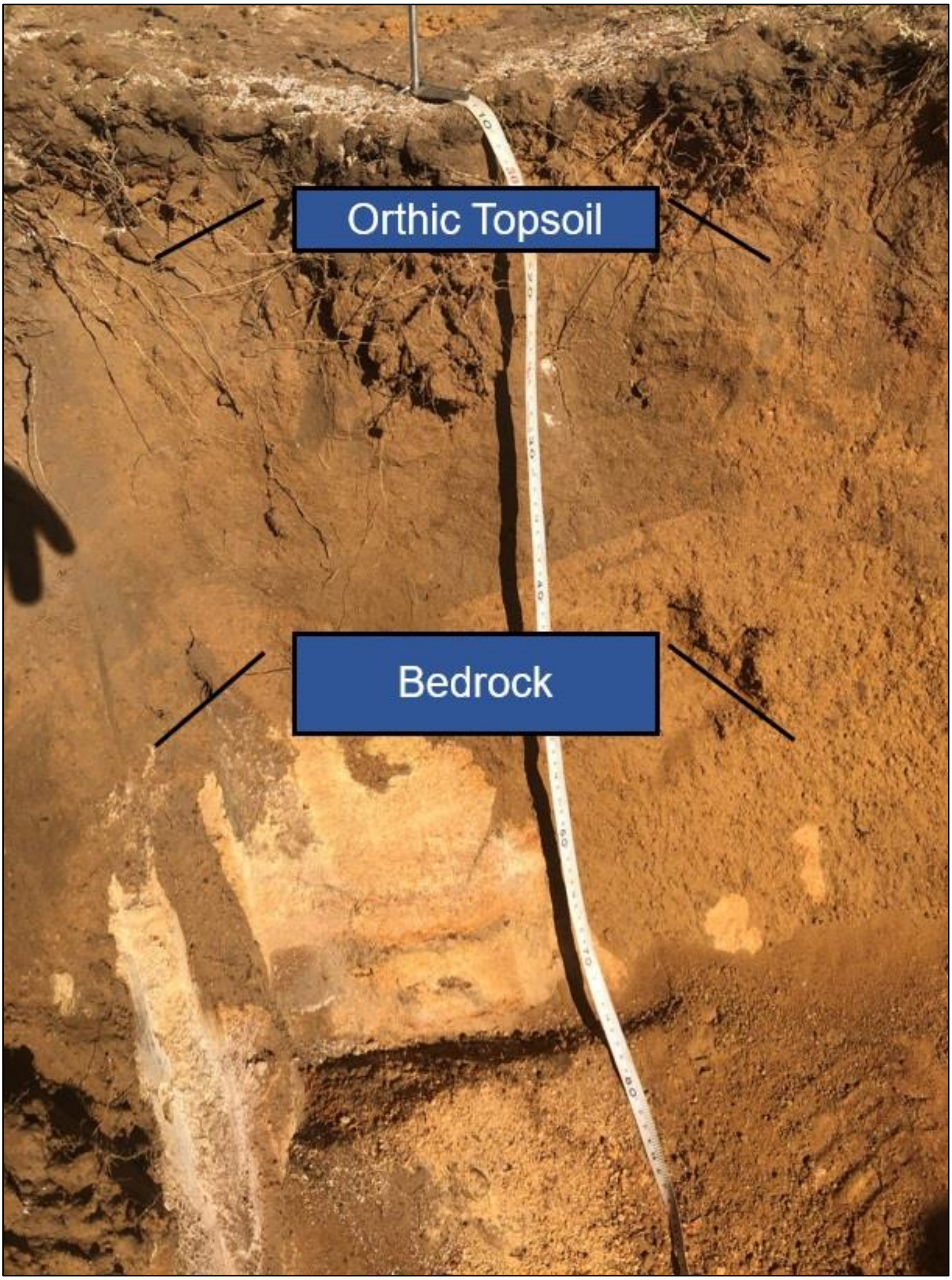

Figure 18: Recharge (shallow) (Mispah) hydropedological type identified in observation 4, transect 2

7.1.2.2 Hydropedological Type #2

The second hydropedological type is characterised by current open cast mining activities, which increases compaction, alters soil dynamics and therefore decreases infiltration.

Overland flow also is deemed to be insignificant given the gentle slope as well as the dammed topography of the open cast pit, which ultimately ensures that evaporation is the dominant flow path. This feature therefore already has affected the hillslope hydrology, which affects all portions upslope of the open cast pit.

7.1.2.3 Hydropedological Type #3

The third hydropedological type is characterised by a deep Carolina soil form, which has been described in Section 7.1.1 (Transect 1). This soil form constitutes a deep recharge hydropedological type due to the lack of signs of wetness.

7.1.2.4 Hydropedological Type #4

The fourth hydropedological type has been identified as an interflow (soil/bedrock) hydropedological type due to the presence of a Bainsvlei soil form, which has been described in Section 7.1.1 (Transect 1).

7.1.2.5 Hydropedological Type #5

The fourth hydropedological type has been identified as an overland flow hydropedological type due to the presence of a Witbank soil form, which has been described in Section 7.1.1 (Transect 1).

7.1.2.6 Transition "A"

A large fraction of the shallow recharge seeps out into the open cast pit, after which evaporation of moisture takes place. Additionally, a large portion of sub-surface water that would have passed underneath the open cast pit now is subject to evaporation due to a decrease in soil depth.

7.1.2.7 Transition "B"

Very little interflow/overland flow reaches the third hydropedological type due to the disturbances from the open cast pit.

7.1.2.8 Transition "C"

Deep recharge seeps out into the next hydropedological type and is channelled across the bedrock interface together with infiltrated precipitation.

7.1.2.9 Transition "D"

Interflow is forced up the Witbank soil profile, after which overland flow and evaporation becomes dominant.

7.1.2.10 Transition "D"

Interflow is forced up the Witbank soil profile, after which overland flow and evaporation becomes dominant.

7.1.2.11 Transition "E"

Interflow is forced up the Witbank soil profile, after which overland flow and evaporation becomes dominant. Overland flow will enter the watercourse together with a small degree of recharge from the bedrock. It is the specialist's opinion that very little water from the hillslope will reach the watercourse due to disturbances.

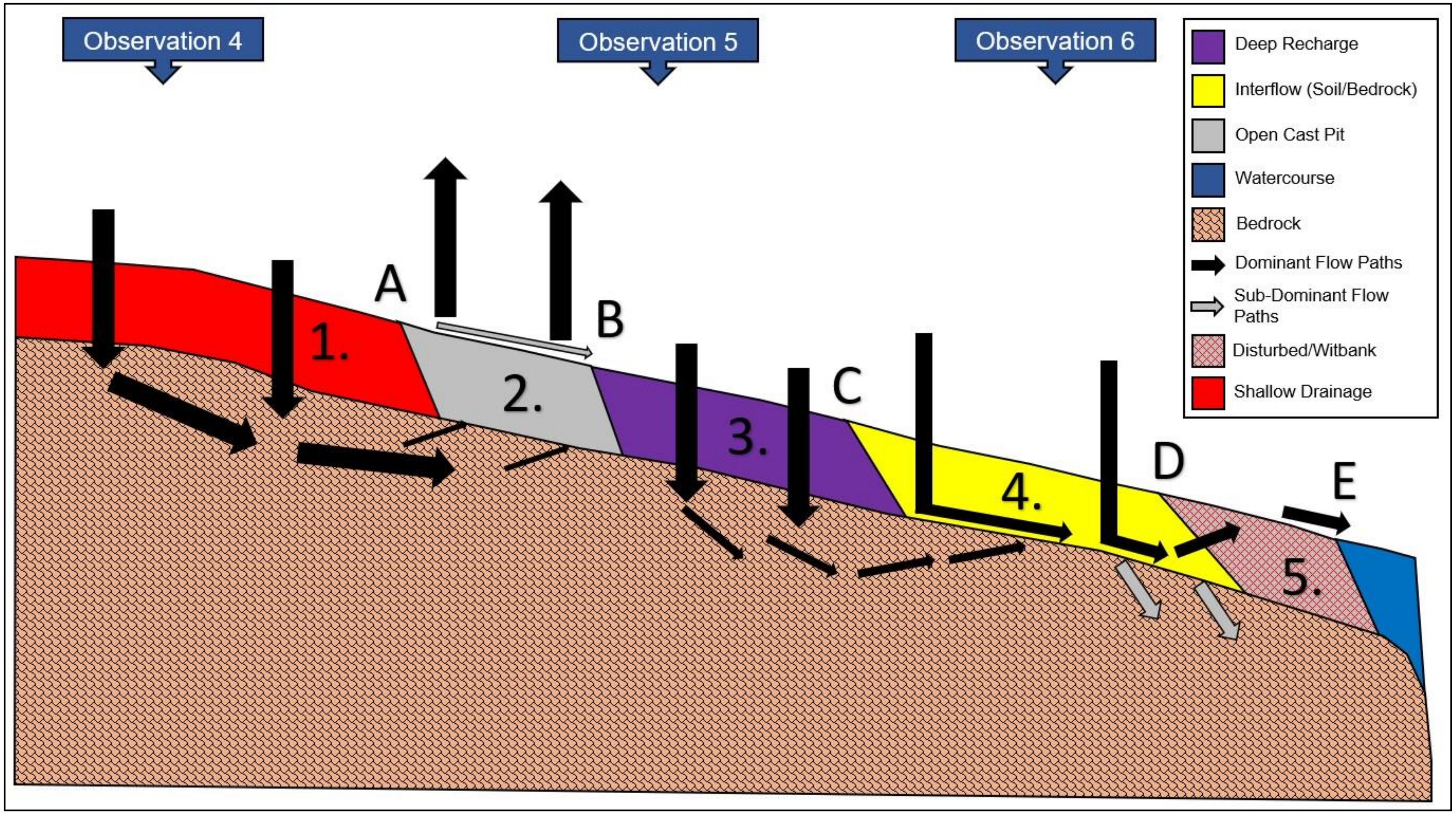

Figure 19: Conceptual hydropedological response model of transect 2 (in current state).

7.1.3 Transect 3

The hydropedological behaviour of transect 3 is illustrated in a conceptual hydrological response model (see Figure 19). The processes involved within this slope is described according to the number assigned to the relevant hydrological response.

7.1.3.1 Hydropedological Type #1

Observation 4 is located on the crest of the slope relevant to Transect 3 and has already been described in Section 7.1.2 (Transect 2). This soil form has been identified as a Mispah soil form and a shallow recharge hydropedological type.

7.1.3.2 Hydropedological Type #2

Observation 10 is located on the mid-slope of the slope relevant to Transect 3 and has already been described in Section 7.1.2 (Transect 2). This soil form has been identified as a Carolina soil form and a deep recharge hydropedological type.

7.1.3.3 Hydropedological Type #3

Observation 11 is located on the toe of the slope relevant to Transect 3 and has already been described in Section 7.1.2 (Transect 2). This soil form has been identified as a Witbank soil form and an overland flow hydropedological type.

7.1.3.4 Hydropedological Type #4

The fourth hydropedological type has been identified as an interflow (soil/bedrock) hydropedological type due to the presence of a Mispah soil form characterised by signs of wetness on the bedrock interface.

7.1.3.5 Transition “A”

Shallow recharge seeps into the Witbank soil form and either evaporates, or, to a lesser extent is channelled across the bedrock layer. Overland flow will be dominant during precipitation events. A degree of recharge will also feed back directly into the final interflow hydropedological type.

7.1.3.6 Transition “B”

Overland flow, interflow and recharge feeds back into the final hydropedological type to ensure an interflow between bedrock and soil. It is the specialist’s opinion that some of the sub-surface flows from the hillslope reaches the watercourse due to the fact that signs of wetness have been identified in a shallow soil profile 50 cm in depth.

7.1.3.7 Transition “B”

Shallow interflow (between soil and bedrock) gradually feeds into the watercourse.

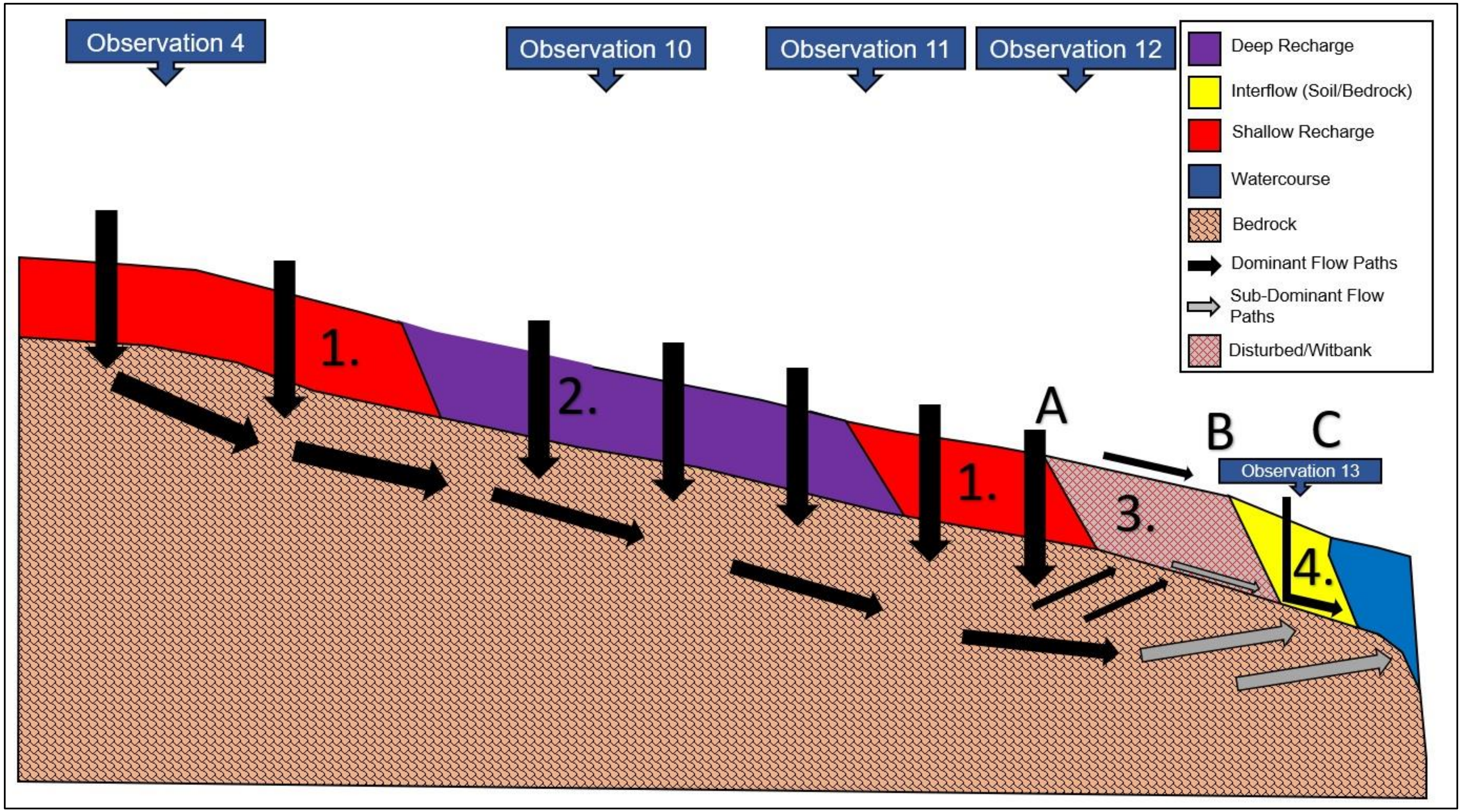

Figure 20: Conceptual hydropedological response model of transect 3 (in current state)

7.1.4 Transect 4

The hydropedological behaviour of transect 4 is illustrated in a conceptual hydrological response model (see Figure 19). The processes involved within this slope is described according to the number assigned to the relevant hydrological response.

7.1.4.1 Hydropedological Type #1

Observation 4 is located on the crest of the slope relevant to Transect 4 and has already been described in Section 7.1.2 (Transect 2). This soil form has been identified as a Mispah soil form and a shallow recharge hydropedological type.

7.1.4.2 Hydropedological Type #2

Observation 7 is located on the mid-slope of the slope relevant to Transect 4 and has already been described in Section 7.1.1 (Transect 1). This soil form has been identified as a Bainsvlei soil form and an interflow (soil/bedrock) hydropedological type.

7.1.4.3 Hydropedological Type #3

Added pit "3" is located on the toe of the slope relevant to Transect 4 and has already been described in Section 7.1.1 (Transect 1). This soil form has been identified as a Carolina soil form and a deep recharge hydropedological type.

7.1.4.4 Transition "A"

Shallow recharge seeps into interflow (soil/bedrock) hydropedological type to join up with infiltrated precipitation. Sub-surface flows then are channelled over the bedrock interface.

7.1.4.5 Transition "B"

Interflow reaches the next hydropedological type (shallow recharge) and infiltrates to recharge reserves within and below the bedrock layer.

7.1.4.6 Transition "C"

No interaction occurs between shallow and deep recharge zones.

7.1.4.7 Transition "D"

Recharge feeds back into the watercourse directly from the bedrock layer and/or the groundwater aquifer.

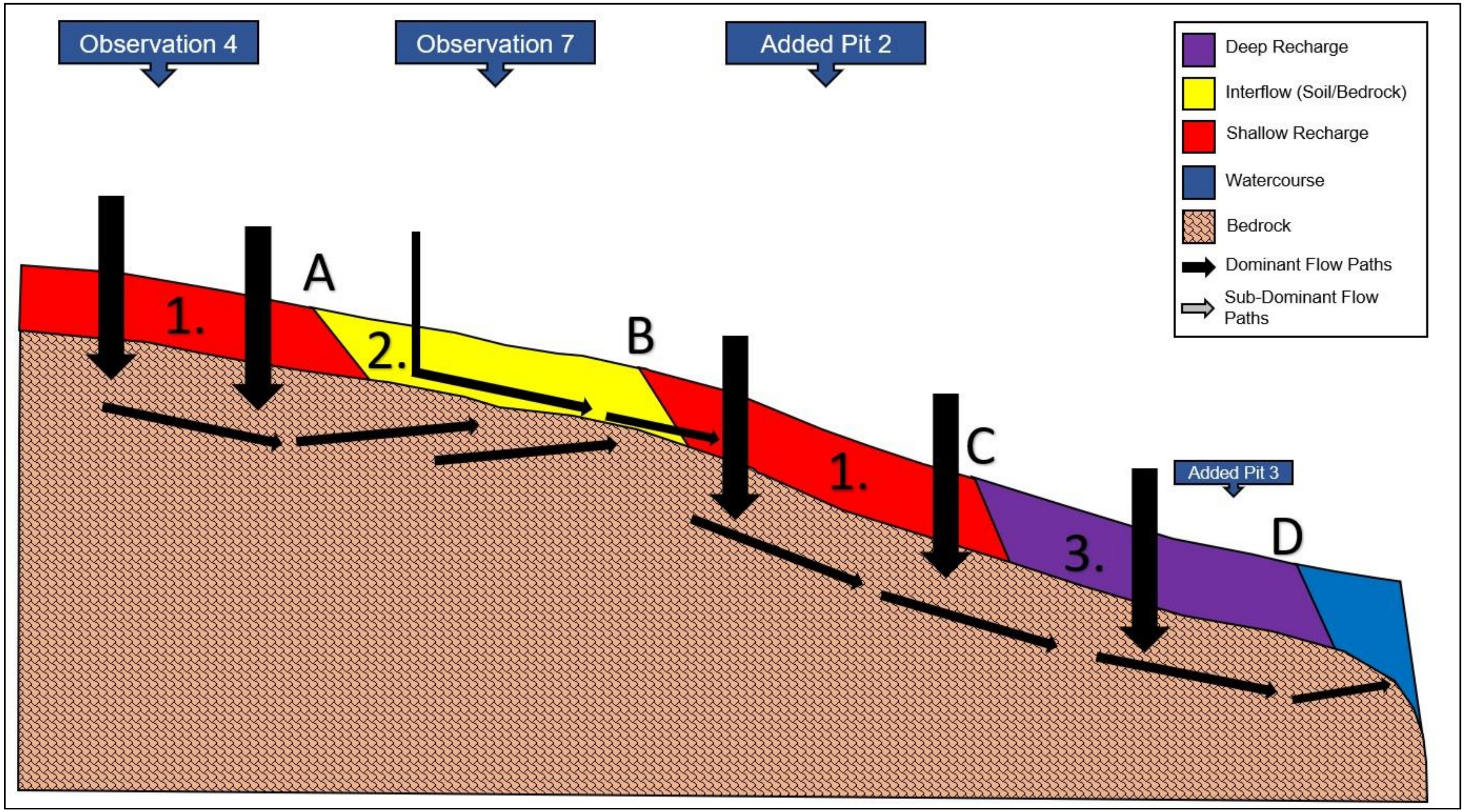

Figure 21: Conceptual hydropedological response model of transect 4 (in current state)

7.2 Conceptual Impacts

The following sections describe the conceptual impacts towards the hillslope hydrology by means of the proposed activities.

7.2.1 Transect 1

It has been anticipated that disturbances within the lower regions of the slope relevant to transect 1 will result in overland flow being the dominant flow path. Evaporation will be dominant at the transition between the interflow zone and the Witbank soil form with overland flow occurring during rainfall events (see Figure 22 and Figure 23). The predominant loss from the proposed open cast mining activities will be that of overland flow during rainfall events, which, by means of stormwater systems can be reintroduced via overland flow as is currently the situation. The proposed underground mining will have very little to no effect on the hillslope hydrology of Transect 1, with the odd chance of subsidence and fracturing of rock occurring.

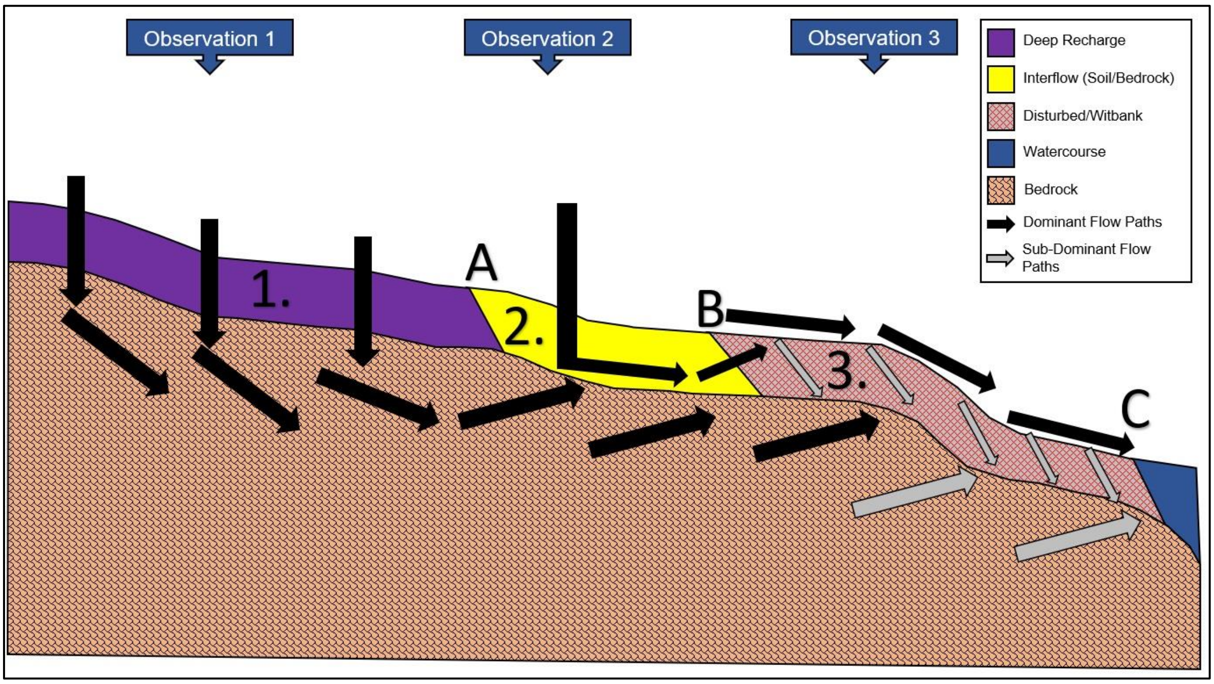

Figure 22: Conceptualisation of the hillslope hydrology relevant to Transect 1 (current state)

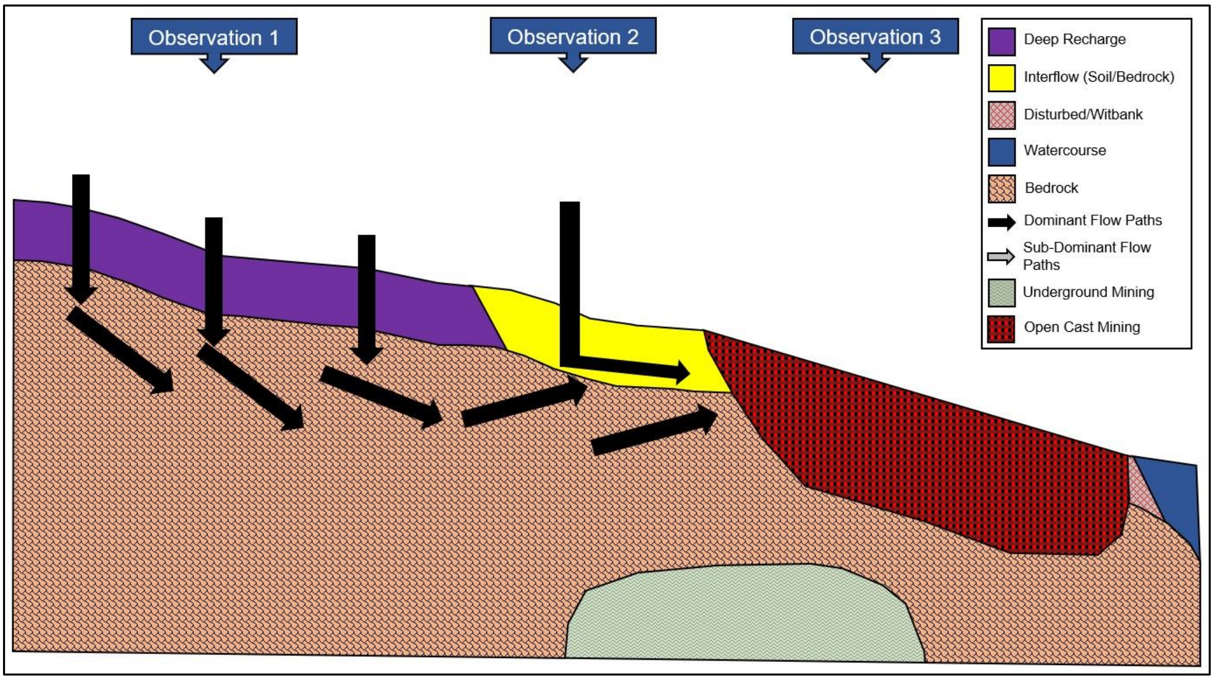

Figure 23: Conceptualisation of the hillslope hydrology relevant to Transect 1 (proposed state)

7.2.2 Transect 2

It is the specialist's opinion that the first open cast pit will have very little effect on the hillslope hydrology due to the current presence of an open cast pit that has resulted in the loss of interflow entering the system. Some degree of overland flow during precipitation events will be lost, which can be mitigated with ease (Figure 24 and Figure 25). Ultimately, even though the second pit at the lower regions of the slope will completely intercept interflow as well as the bulk of the recharge water seeping into the interflow zone, very little change in interflow to the watercourse will be caused by the proposed open cast mining activities.

The latter mentioned can mainly be described to the current extent of disturbances which renders the hillslope hydrology ineffective. The proposed underground mining will have very little to no effect on the hillslope hydrology of Transect 2, with the odd chance of subsidence and fracturing of rock occurring.

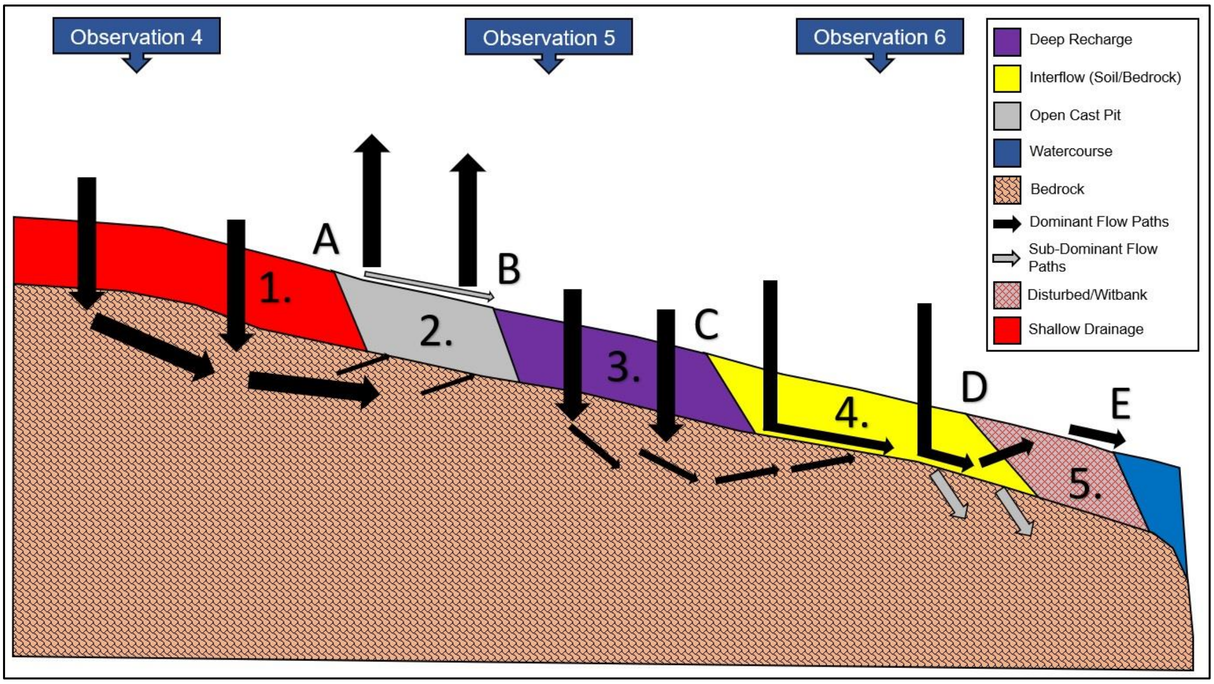

Figure 24: Conceptualisation of the hillslope hydrology relevant to Transect 2 (current state)

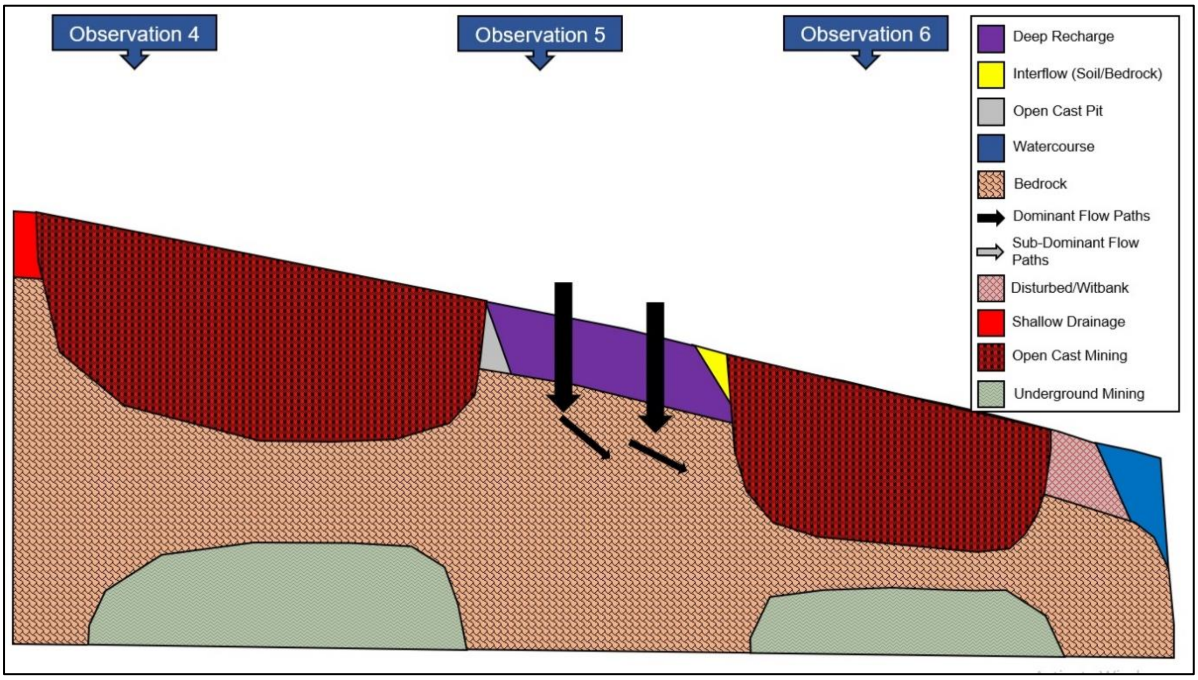

Figure 25: Conceptualisation of the hillslope hydrology relevant to Transect 2 (proposed state)

7.2.3 Transect 3

For this transect, recharge (deep and shallow) is dominant throughout the hillslope. It also has been determined, that regardless of the extent of current disturbances, some of the recharge water seeps out at the bottom of the current disturbed area, which results in shallow interflow (see Figure 26 and Figure 27). This interflow is anticipated to be rather significant to overcome evapotranspiration rates in such a shallow profile (50 cm in depth).

The proposed underground mining will have very little to no effect on the hillslope hydrology of Transect 3, with the odd chance of subsidence and fracturing of rock occurring.

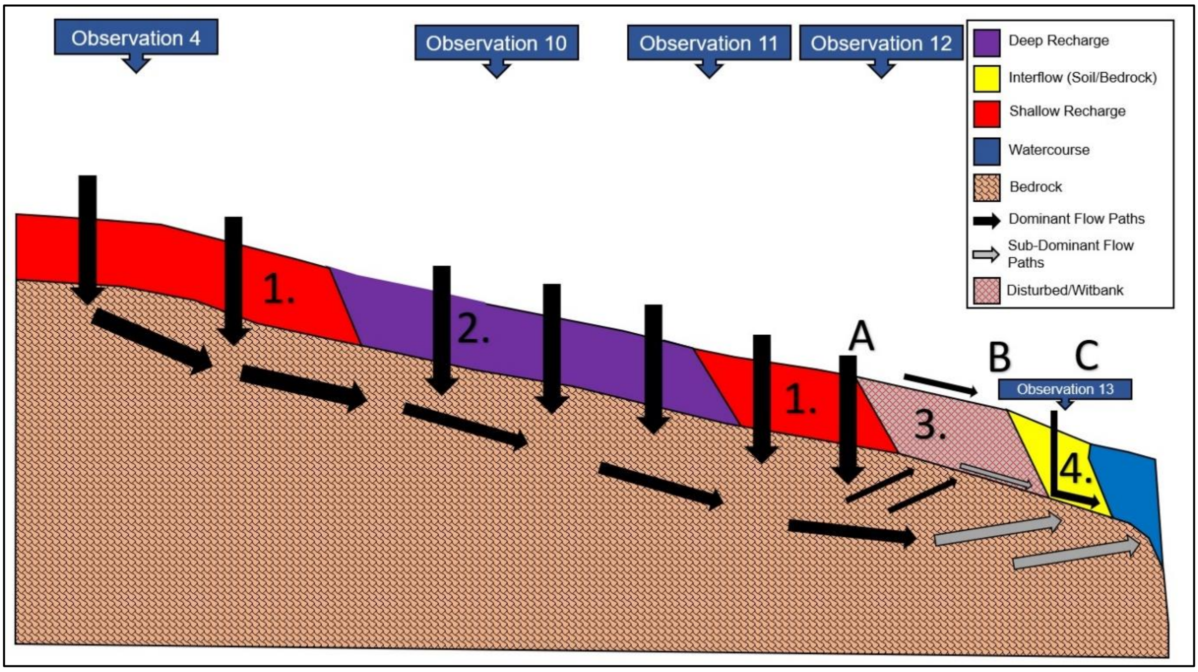

Figure 26: Conceptualisation of the hillslope hydrology relevant to Transect 3 (current state)

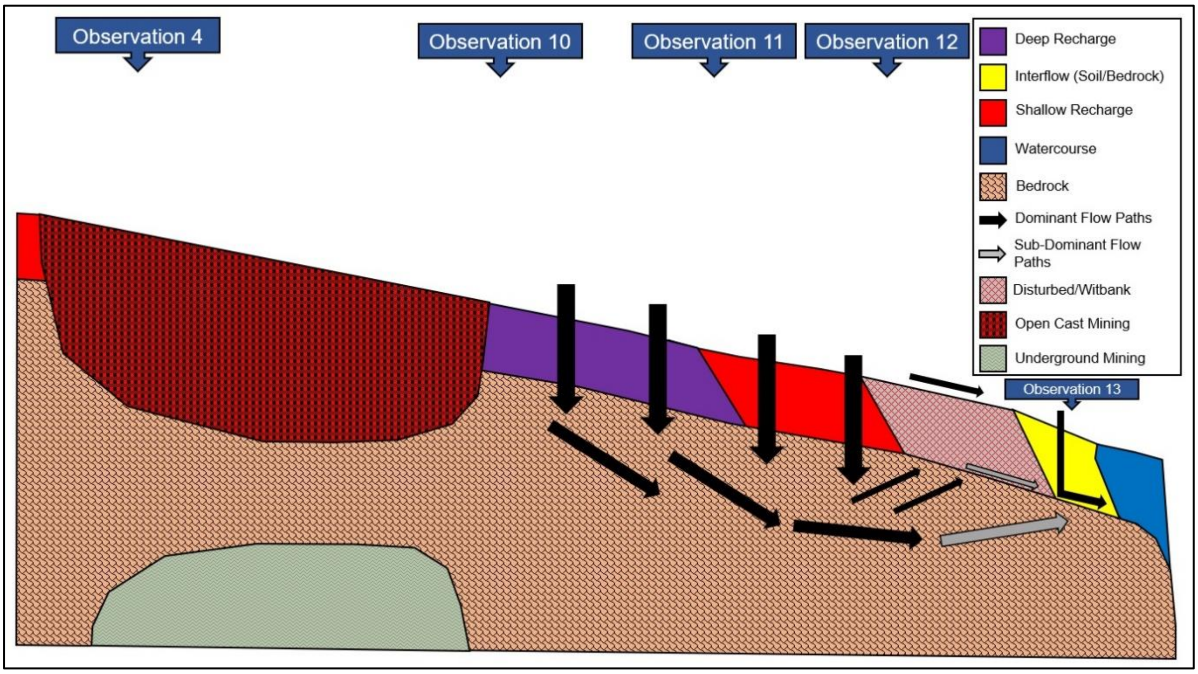

Figure 27: Conceptualisation of the hillslope hydrology relevant to Transect 3 (proposed state)

7.2.4 Transect 4

Only approximately 25% of the slope will be affected by the proposed open cast mining activities, and, given the fact that the proposed open cast pit will be at the crest of the hillslope, low to moderate losses are expected. The hillslope is in a natural condition without any disturbed areas (Technosols, mining activities, disturbed areas etc) (see Figure 28 and Figure 29).

The proposed underground mining will have very little to no effect on the hillslope hydrology of Transect 4, with the odd chance of subsidence and fracturing of rock occurring.

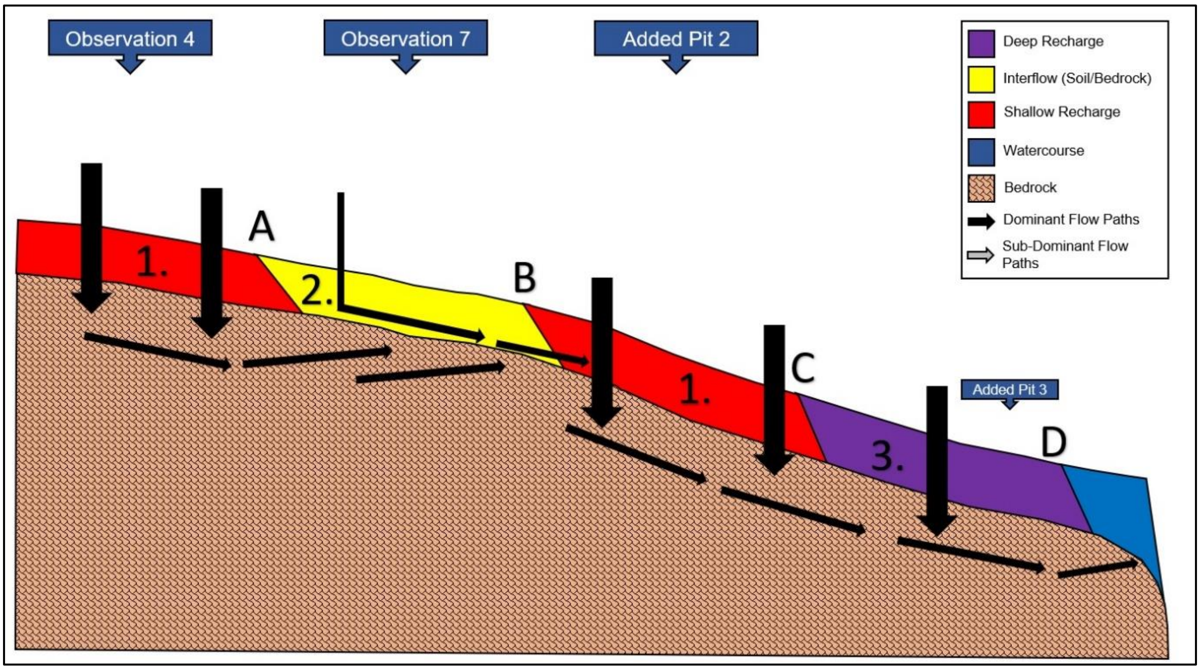

Figure 28: Conceptualisation of the hillslope hydrology relevant to Transect 4 (current state)

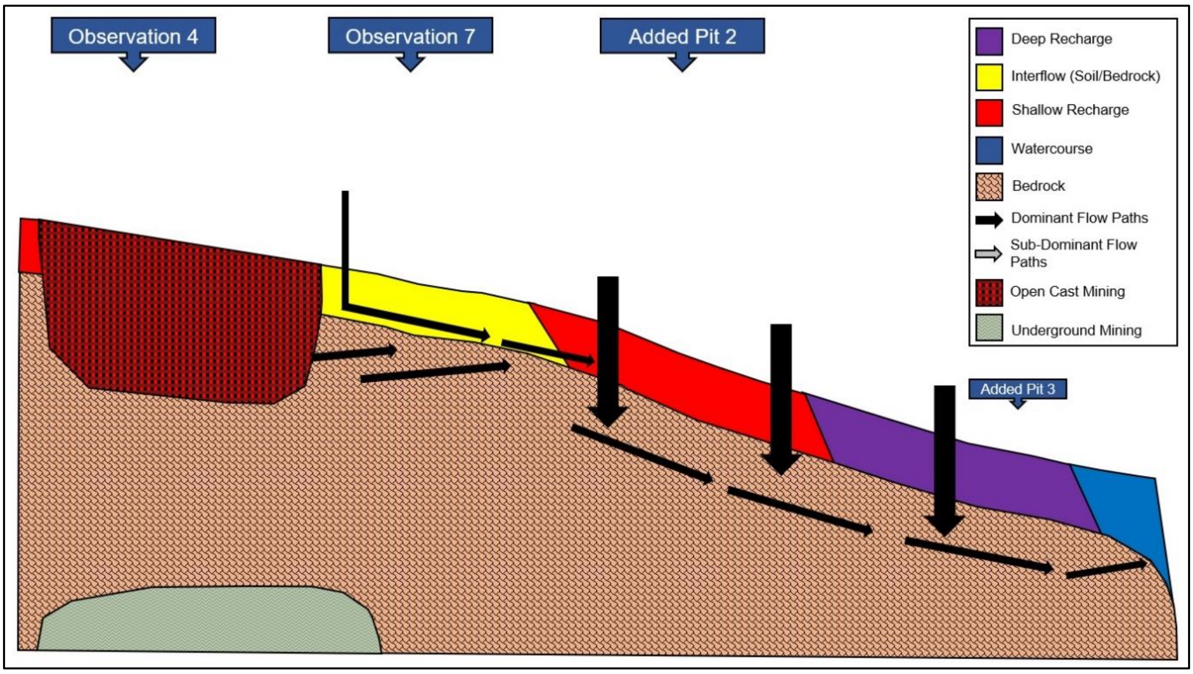

Figure 29: Conceptualisation of the hillslope hydrology relevant to Transect 4 (proposed state)

7.3 Laboratory Results

The hydraulic parameters from *in-situ* and laboratory measurements of the dominant horizons are presented in (Table 4), with the van Genuchten parameters estimated in Rosetta presented in Table 5.

Table 4: Selected hydraulic properties for representative horizons

	Obs	Soil form	Horizons	Depth (mm)	Sand (%)	Silt (%)	Clay (%)	Db (g.cm^{-3})	DUL (mm.mm^{-1})	Ks (mm.h^{-1})
Transect 3&4	4	Ms	ot	300	85.7	6.0	10.0	1.44	0.26	156.0
			R	300+						5.1
	7	Bv	ot	400	85.7	6.0	10.0	1.44	0.26	156.0
			re	2300	76.0	10.8	14.2	1.45	0.25	66.5
			sp	2500	45.0	10.8	45.2	1.45	0.25	6.7
	Pit 2	Gc	ot	300	71.8	10.4	17.8	1.52	0.24	87.4
			ye	1200	66.7	13.0	21.8	1.49	0.31	14.9
			hp	1200+						5.1
	Pit 3	Ca	ot	200	71.8	10.4	17.8	1.52	0.24	87.4
			ye	1200	66.7	13.0	21.8	1.49	0.31	14.9
			R	1200+						5.1

Table 5: Van Genucthen parameters for representative horizons

	Obs	Soil form	Horizons	Depth (mm)	Θr (mm.mm^{-1})	Θs (mm.mm^{-1})	α	n	λ
Transect 3&4	4	Ms	ot	300	0.05	0.42	0.00147	1.44	0.5
			R	300+	0.04	0.26	0.00427	1.14	0.5
	7	Bv	ot	400	0.05	0.42	0.00147	1.44	0.5
			re	2300	0.05	0.42	0.00184	1.42	0.5
			sp	2500	0.09	0.44	0.00228	1.26	0.5
	Pit 2	Gc	ot	300	0.06	0.40	0.00241	1.37	0.5
			ye	1200	0.06	0.42	0.00128	1.34	0.5
			hp	1200+	0.04	0.26	0.00427	1.14	0.5
	Pit 3	Ca	ot	200	0.06	0.40	0.00241	1.37	0.5
			ye	1200	0.06	0.42	0.00128	1.34	0.5
			R	1200+	0.04	0.26	0.00427	1.14	0.5

7.4 Modelling Results

The proposed open cast pit is located on the crest position, largely covered by shallow recharge soils. Due to the location and the hydropedological type, differences in total outflow and lateral flows between natural and developed scenarios were not expected for this slope. This is clearly illustrated in Figure 30 and Figure 31, where virtually no differences were simulated.

The only difference between the natural and developed state was observed in the soil water contents (expressed as matric potential), directly below the open cast pit (Figure 32). Here the soils under the natural state will be slightly wetter than under the developed state. This is due to lateral flows from upslope which will maintain soil water longer under the natural state compared to the developed state (when the upslope section is removed due to mining). Approximately 300 m below the proposed development, the simulated soil water contents area however identical (Figure 33).

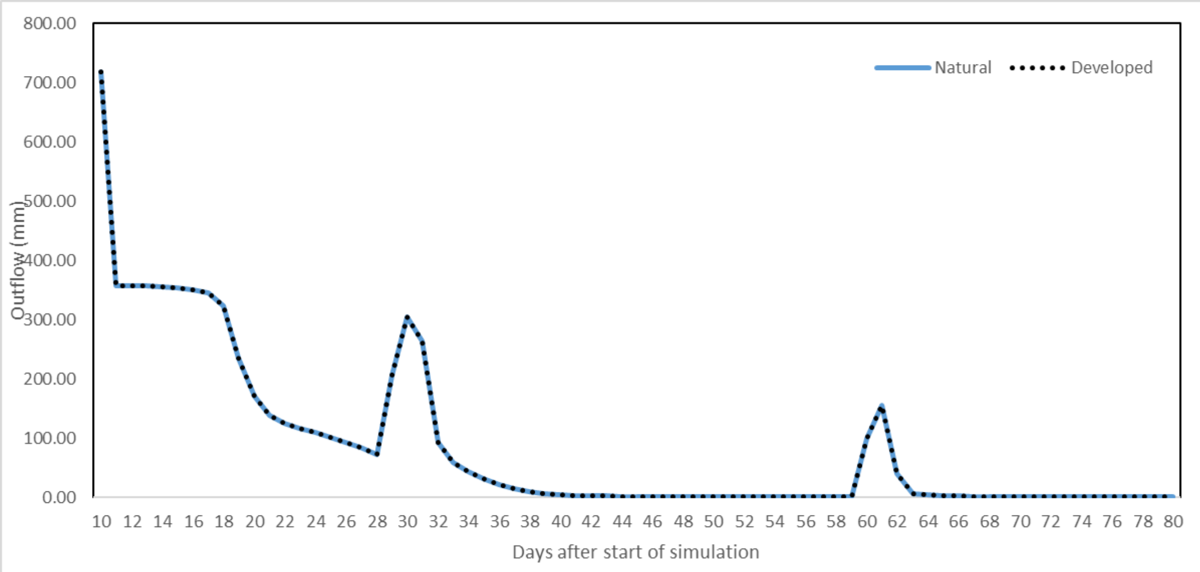

Figure 30: Simulated outflow (mm) from the transect under natural and developed conditions.

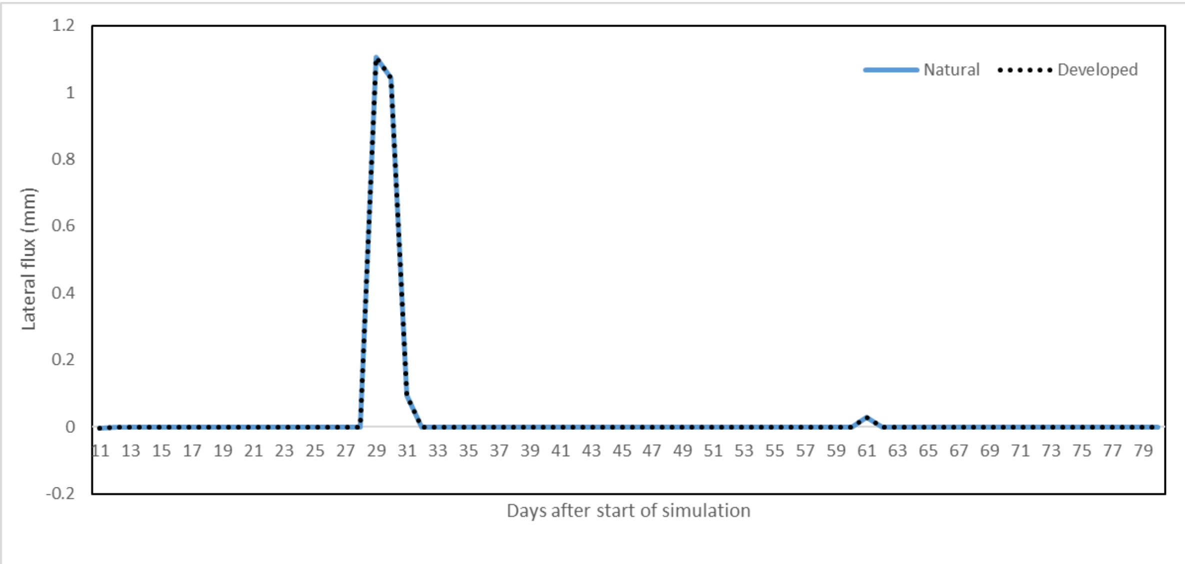

Figure 31: Simulated lateral fluxes (mm) from the transect under natural and developed conditions.

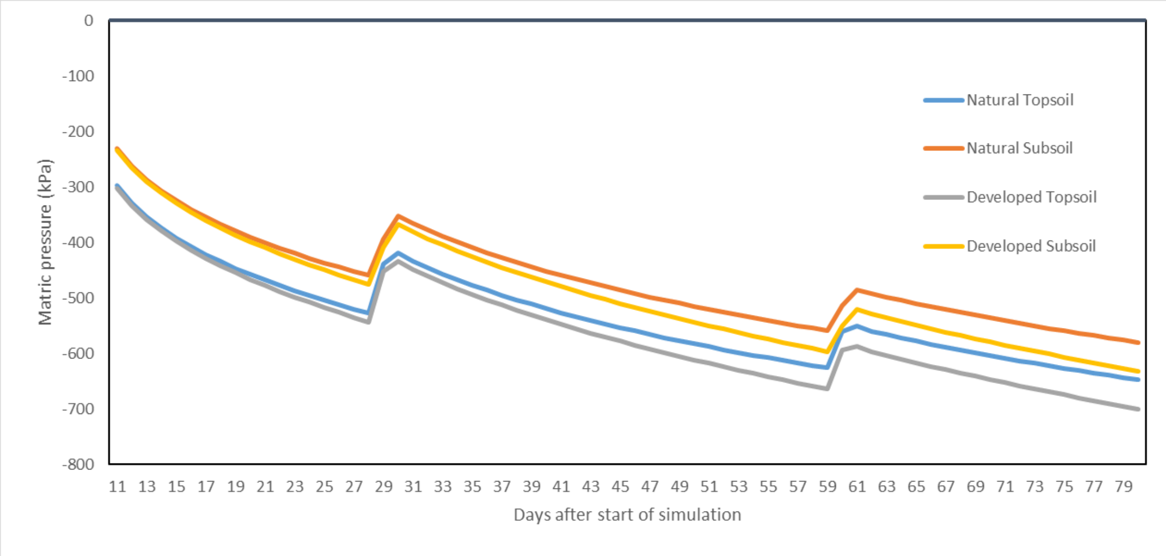

Figure 32: Simulated matric potential of top and subsoils under natural and developed conditions, directly below the proposed pit.

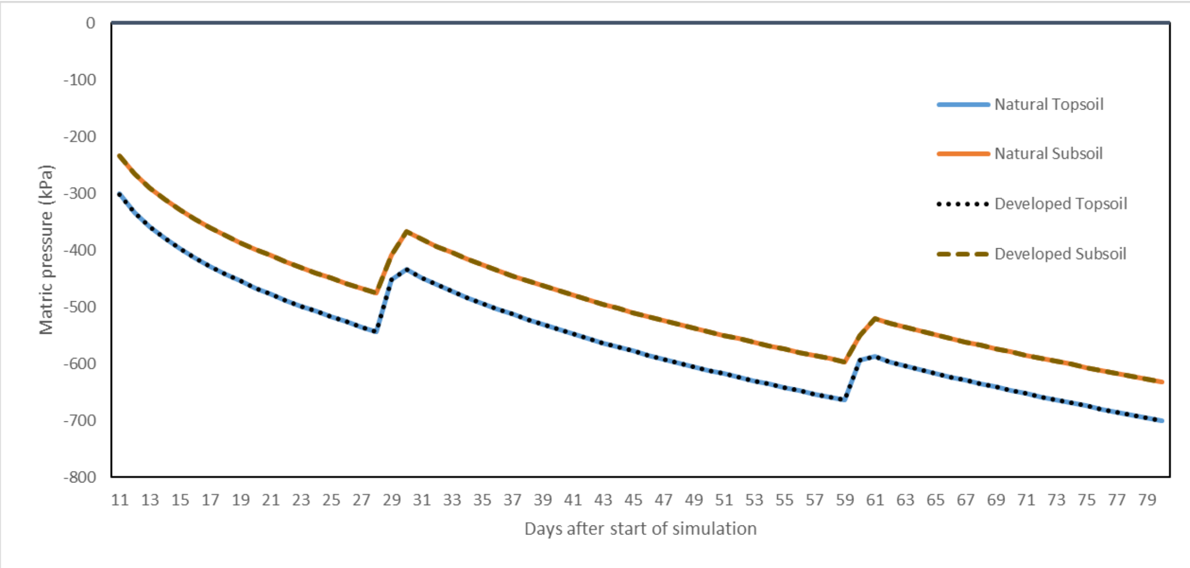

Figure 33: Simulated matric potential of top and subsoils under natural and developed conditions, approximately 300 m below the proposed pit.

The hydrological simulations therefore suggest the proposed development will have very little impact on the water regimes of the wetland and on water released to the stream.

8 Recommendations and Conclusions

This report presents findings from a hydropedological survey of four transects to assess the potential impact of open cast mining on vadose zone processes. The soil morphological interpretations were supplemented by measurements of hydraulic properties and simulations of key hydrological processes through the hillslopes.

Large portions of the studied area are already impacted upon by current mining activities. These modifications have altered natural flow paths of and complicates hydropedological interpretations in relation to proposed future developments. With this being said, it is worth noting that the recharge soils occupy long sections of the slopes, especially those areas where the proposed pit will be located. Conceptually, the impact of the development on lateral flow paths through the vadose zone will therefore be insignificant. This conceptual understanding was supported by hydrological simulations of one slope which was not yet impacted by development. The simulations indicate that the proposed development will only result in drying of the soils directly below the open cast pit. Approximately 300 m downslope of the pit, differences in soil water contents were not observed. Similarly, there was no difference in the outflow and lateral flux to the stream between the natural and developed state.

With large areas being occupied by recharge soils, the geohydrological study should advise on the impact of the proposed development on the contribution of groundwater to streamflow and wetland water regimes.

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REPORT

Geo Soil & Water CC

ELANDSFONTEIN COLLIERY - SURFACE WATER SPECIALIST STUDY (BASELINE HYDROLOGY)

Submitted to:

Geo Soil Water

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Boardwalk Office Park,

107 Haymeadow Dr,

Faerie Glen,

Pretoria

Report Number:

B585_ElandsfonteinSurfaceWaterSpecialistStudy_Rev1

21 November 2019

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1. INTRODUCTION

Geo Soil & Water cc (GSW) commissioned BEAL Consulting Engineering (BEAL) to conduct a surface water specialist study for Elandsfontein Colliery. This report details the results of the study, as well as recommendations emanating from the work done.

1.1 Study Objectives

The study objectives are as follows:

- Baseline hydrological analysis
- Floodlines and buffer zones

This report constitutes the outcome of the specialist studies undertaken related to the environmental impact of Elandsfontein Colliery.

1.2 Battery Limits

The battery limits of the study are shown in Figure 1. All work is confined to this area unless otherwise specified.

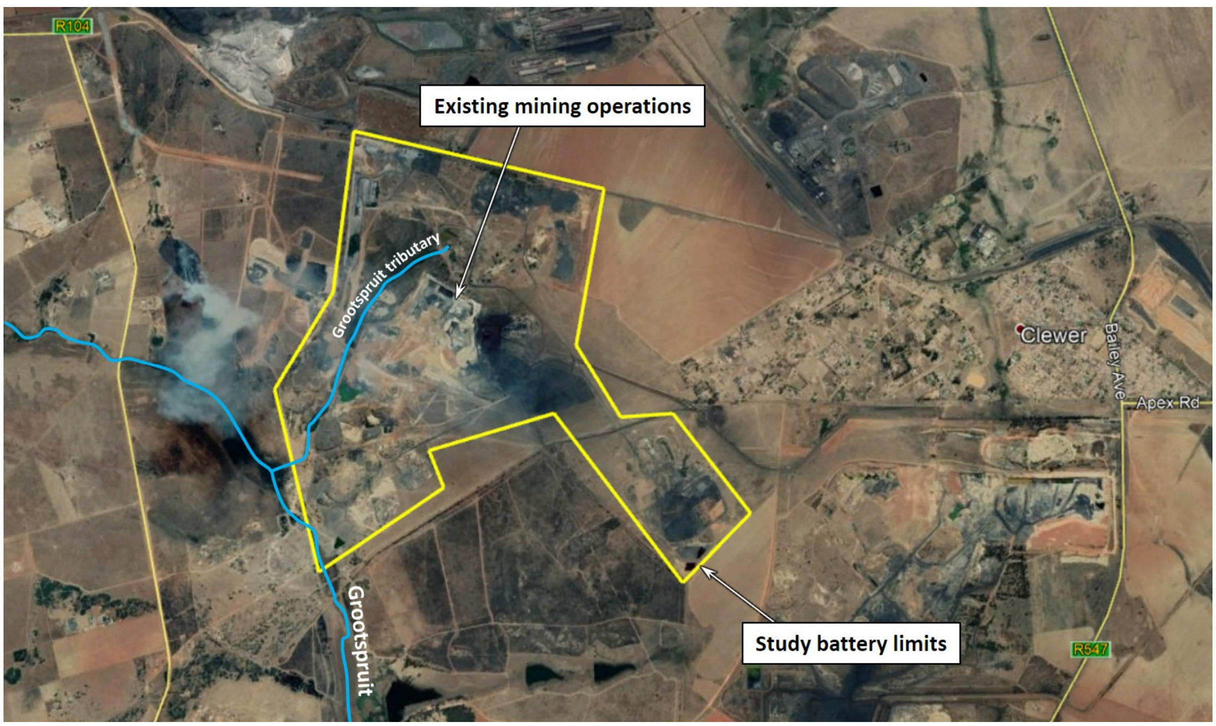

Figure 1: Study Areas

2. REGIONAL SETTING

Elandsfontein colliery is in the Mpumalanga Province of South Africa, in the upper reaches of the Olifants River catchment. The Grootspruit is a tributary of the Saalklapspruit, which is a tributary of the Wilge River. The Wilge-Olifants river confluence is downstream of Witbank Dam, but upstream of Loskop and Flag Boshielo Dams.

The Loskop and Flag Boshielo dams are located downstream of Witbank Dam and are an important source of domestic, irrigation and industrial water to their surrounding areas. The Olifants River is an international river, flowing through the Kruger National Park and into Mozambique. With the Olifants River flowing through the Kruger National Park, provision for meeting ecological requirements is one of the controlling factors for managing water resources throughout the Olifants River catchment.

The Wilge River catchment measures 4 360 km². The mean annual precipitation in this catchment is generally uniform with an average precipitation of approximately 670 mm, varying between 650 mm and 750 mm.

The mean annual evaporation (S-Pan) varies between 1 677 mm in the south western regions of the catchment and 1 800 mm in the north western regions of the catchment.

The natural vegetation in the catchment is predominantly grassland. Extensive irrigated and dry-land agricultural activities are prevalent, along with various forms of livestock farming. Power stations and mining activities occur in the Wilge River catchment, as do a number of small towns. These include Delmas, Bronkhorstspruit, Lionelton, Kendal, and New Largo.

3. LOCAL SETTING

The mining rights area is located in quaternary catchment B20G. The mining rights area is located just west of Clewer and approximately 15km west, south west of Emalahleni. Elandsfontein is an operational colliery with significant development within the mining rights area.

A small tributary of the Grootspruit flows in a south westerly direction through the mining rights area. It's confluence with the Grootspruit is just to the west of the mining rights area. The Grootspruit flows from south to north along the western boundary of the mining rights area before turning west to meet the Saalklapspruit, approximately 5 km west of the mining right area.

The Grootspruit and its tributary are heavily reeded in places. Both river floodplains are highly impacted by mining related activities and poorly constructed/informal road crossings. Both rivers are marked as perennial streams on the 50 000 topographical sheets.

4. CATCHMENT DESCRIPTION

4.1Grootspruit

Apart from the Elandsfontein mining operations, the Grootspruit catchment is undeveloped and consists mostly of impacted grasslands and dry land agriculture.

The topography is relatively flat. Localised areas have steeper slopes, particularly in the vicinity of the streams. The Grootspruit is dammed with multiple farm dams. The water course has an ill-defined channel in the study area and contains significant reedbeds. The flood plains are not well developed.

4.2Grootspruit Tributary

The Elandsfontein mining operations occur on both sides of this stream along most of its length. The upper reaches are dammed with pollution control and water supply dams.

The natural tributary has a poorly defined water course but is generally heavily reeded. The lower reaches have been modified and the stream is canalised for roughly half its length.

5. BASELINE RAINFALL AND EVAPORATION

5.1Mean Annual Precipitation and Evaporation

The mean annual precipitation of the mining rights area is 706 mm. The mean annual evaporation of the mining rights area is 1 689 mm (S-Pan). The monthly average rainfall, rainfall days, and evaporation rates are presented in Table 1. The Mpumalanga Highveld has distinct wet and dry seasons. 91% of the mining rights area's mean annual rainfall falls between October and April inclusively. 68% of the area's mean annual evaporation occurs in this period (Midgley et al., 1990).

Table 1: Mean Monthly Rainfall, Rain Days and Evaporation data for the mining rights area

Month	Ave Rainfall (mm)	Ave rain days	Ave Evaporation (mm S-Pan)
October	73.6	7.0	182.1
November	119.3	9.6	171.8
December	119.4	9.6	189.2
January	136.1	10.4	185.8
February	95.6	7.3	154.9
March	81.6	6.8	152.9
April	40.6	4.2	117.6
May	17.6	2.0	99.0
June	9.0	0.9	80.4
July	6.4	0.8	88.0
August	8.9	1.1	116.5
September	22.4	2.6	151.0
Mean Annual	**705.8***		**1689**

** Note: The sum of the mean monthly rainfall depths does not necessarily equal the mean annual precipitation.*

5.1.1 Climatic water balance

The Department of Water and Sanitation require a climatic water balance that incorporates a list of years which have the wettest six months of the year, either November to April or May to October. In this case November to April is wetter than May to October. The wettest six months between November and April are listed in Table 2.

Table 2: Wettest years between November and April

Rating	Year	Total rainfall between November and April (mm)
Wettest year	2000	1432
2nd wettest year	1917	1184.6
3rd wettest year	1975	1087.7
4th wettest year	1939	1079.1
5th wettest year	2009	1007.1
6th wettest year	1922	993.9
7th wettest year	1969	980.9
8th wettest year	1942	970.1
9th wettest year	1978	968.9
10th wettest year	1924	948.6

5.1.2 Sources of rainfall data

Daily rainfall data was sourced from the CCWR (Computing Centre for Water Research, Natal University) rainfall database (gauge number 0515382 – Witbank (MAG)). The gauge is located approximately 4 km east of the mining rights area. The CCWR data that was used contains daily records and patched records between September 1905 and December 1967, or over 72 years. An additional 46 years of daily data for Witbank (SAWB gauge number 0515412 2) was purchased from the South African Weather Bureau. The full data set therefore runs from September 1905 to August 2013. The data is considered representative of the mining rights area and is good quality.

5.1.3 Sources of evaporation data

The mean annual evaporation was sourced from the average evaporation for quaternary catchment B20G, documented in the Water Resources of South Africa, 2005 Study (Middleton and Bailey, 2009). Its monthly distribution was sourced from the Water Resources of South Africa Study data set, zone 4A (Midgley et al., 1990). The data is considered representative of the mining rights area.

5.2 Peak Rainfall Data

5.2.1 Maximum Monthly Rainfall Data

The maximum monthly rainfall data was distilled from the daily rainfall record (discussed in section 5.1.2) and is presented in Table 3.

Table 3: Maximum Monthly Rainfall data (mm)

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
192.6	321.8	354.3	374.4	340.5	236.4	135.7	117.4	106.4	81.8	79.5	135.5

5.2.2 Peak 24-hr Rainfall Data

The peak 24-hr rainfall depths are presented in Table 4.

Table 4: Peak 24-hr Rainfall Depths for the minimum Rights Area

Recurrence Interval (year)	24-hour rainfall depth (mm)
2	53
10	83
20	96
50	115
100	130
200	146

The daily rainfall record, discussed in section 5.1.2, was analysed and the annual maximum series was extracted from the data. This annual maximum series was statistically analysed to determine various T-year recurrence interval 24-hour storm depths. A Log Pearson Type III fit was selected as the most appropriate statistical fit. The fit is slightly conservative, but results are appropriate to the region. This fit is shown in Figure 2. The rainfall record is long, consists of good data, is representative of the site, and is suitable be used to calculate peak rainfall.

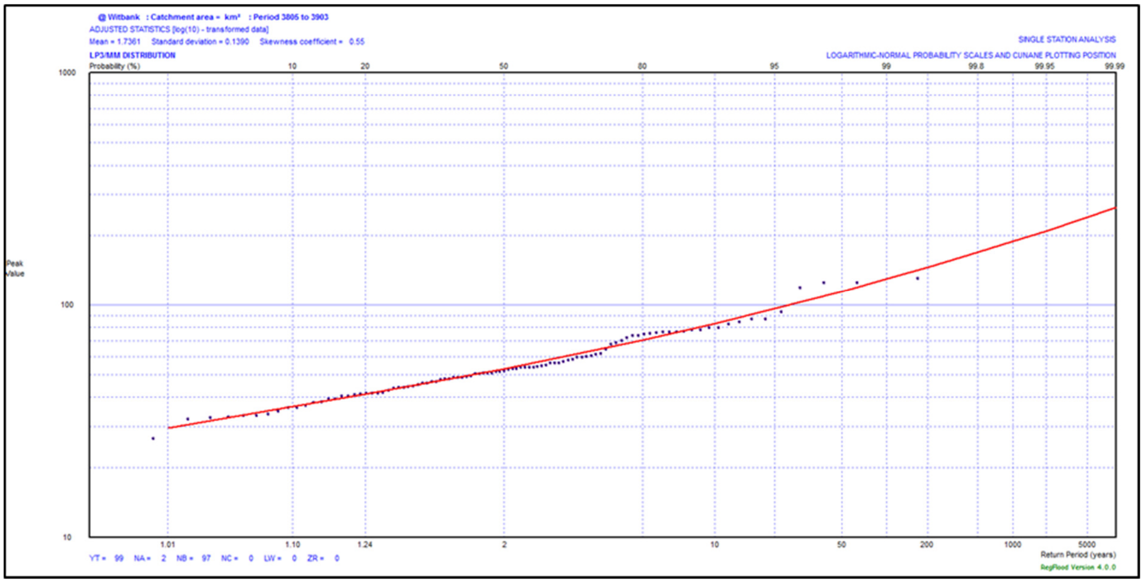

Figure 2: Log Extreme Value Type 1 Statistical Fit to the Annual Maximum Series

6. BASELINE HYDROLOGY

6.1Catchment Delineation

The Grootspruit has an 81.562 km² catchment up to just beyond the mining rights area. The tributary of the Grootspruit has a catchment measuring 8.169 km² up to its confluence with the Grootspruit. The catchment sizes and catchment boundaries are shown in Figure 3.

The mean annual runoffs for the catchments shown in Figure 3 are listed in Table 5.

Table 5: Mean Annual Runoff

Stream	Mean annual run-off (Mm^3/a)
Grootspruit	3.57
Grootspruit tributary	0.36

The mean annual runoff for the quaternary catchments B20G is 22.87 Mm³ (Middleton and Bailey, 2009). The mean annual runoff values in Table 5 were scaled from the quaternary catchment runoff, based on relative catchment size.

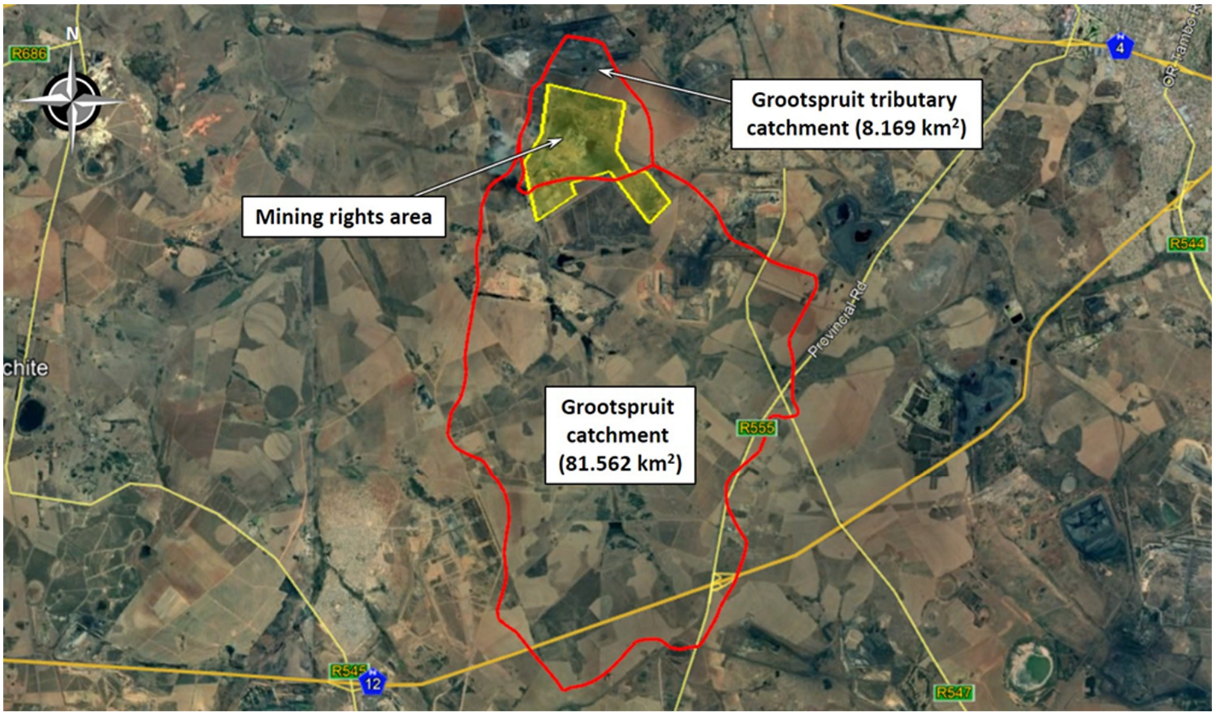

Figure 3: Catchment Delineation

6.2 Normal Dry Weather Flows

Due to the small catchment size of the Grootspruit tributary, dry weather flows are likely to be very low and will often be limited to sub-surface flow only. Average dry weather flows appear high, but these are influenced by storm flow from occasional winter rainfall events and unseen subsurface flow.

The normal dry weather flows are based on the average monthly flows documented in the Water Resources of South Africa, 2005 Study (Middleton and Bailey, 2009) for quaternary catchment B20G. The flows were scaled based on relative catchment size. The dry weather flows are presented in Table 6. The dry weather flows have been highlighted in bold text.

Table 6: Normal Dry Weather Flows in m³/month (Highlighted in Bold Text)

Month	Grootspruit	Grootspruit tributary
Oct	**166 194 m^3**	**16 645 m^3**
Nov	568 599 m^3	56 949 m^3
Dec	516 339 m^3	51 715 m^3
Jan	627 754 m^3	62 874 m^3
Feb	678 305 m^3	67 937 m^3
Mar	560 695 m^3	56 158 m^3
Apr	231 157 m^3	23 152 m^3
May	**88 768 m^3**	**8 891 m^3**
Jun	**49 264 m^3**	**4 934 m^3**
Jul	**33 327 m^3**	**3 338 m^3**
Aug	**26 342 m^3**	**2 638 m^3**
Sep	**26 250 m^3**	**2 629 m^3**

6.3Flood Flow Analysis

The 50-year and 100-year flood peaks for the two streams were calculated and the results are presented in Table 7. The flood peaks were calculated for the catchments shown in Figure 3.

Table 7: Peak Flows in the Rivers and streams

Recurrence interval	Grootspruit	Grootspruit tributary
50-year	246 m^3/s	55 m^3/s
100-year	326 m^3/s	75 m^3/s

The Utility Programs for Drainage software was used to calculate the flood peaks. The Rational Method, Alternative Rational Method, SDF Method and Unit hydrograph Method were used to calculate the flood peaks. The Unit hydrograph Method was selected as the most appropriate flood peak to use for the Grootspruit. The Rational Method was selected as the most appropriate flood peak to use for the Grootspruit tributary.

7. FLOODLINES

7.1Backwater analysis

The backwater analysis was performed using HEC-RAS. Cross sections for the Grootspruit and Grootspruit tributary were taken from survey data supplied by the client.

Both streams are small with ill-defined channels in most areas. Some areas have extensive reedbeds in the channels. The tributary is canalised in some places. The Grootspruit is generally free of trees and woody vegetation. The tributary has a stand of trees on one area that it flows through. The channels mostly consist of grasses, sedges and reed beds. The banks are well vegetated, mainly with grasses. A Manning's n of 0.04 was used within the overbank stations and 0.06 outside of the overbank stations.

The flood peaks presented in Table 7 were used to calculate the floodlines. The 50-year and 100-year floodlines are shown in Figure 4. The accuracy of the survey data cannot be verified. It is assumed that the survey data provided is a true reflection of the topography within the study area. The accuracy of the floodlines is dependent on the accuracy of the survey data.

Figure 4:Floodlines

8. BUFFER ZONES

Section 4a of Government Notice 704 (GN 704) of the South African National Water Act states the following: “No person in control of a mine or activity may locate or place any residue deposit, dam, reservoir, together with any associated structure or any other facility within the 1:100 year flood-line or within a horizontal distance of 100 metres from any watercourse…”.

Section 4b of Government Notice 704 of the South African National Water Act states the following: “No person in control of a mine or activity may … carry on any underground or opencast mining, prospecting or any other operation or activity under or within the 1:50 year flood-line or within a horizontal distance of 100 metres from any watercourse…”

Pollution control dams and stockpiles are required as part of the colliery so Section 4a of GN 704 will apply to these. Section 4b will apply to any opencast pits. The surface water buffer zone therefore is the greater of the 100-year floodline or 100 m from the water course. The buffer zones for the Grootspruit and its tributary are shown in Figure 5.

It must be noted that numerous infrastructures are located within the surface water buffer zones. This infrastructure should be applied to be exempt from the requirements of GN 704 or they should be removed.

Figure 5: Surface Water Buffer Zones

9. REFERENCES

- Middleton, B.J. and Bailey, A.K., Water Resources of South Africa, 2005 study (WR2005), 2009. WRC Report No TT 382/08.
- Midgley, D.C., Pitman, W.V., Middleton, B.J., Surface Water Resources of South Africa, 1990. WRC Report No 298/1.1/94, Volume 1.

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HG-R-20-006-V1

ELANDSFONTEIN COLLIERY IWUL HYDROGEOLOGICAL SPECIALSIT INVESTIGATION AND GROUNDWATER IMPACT ASSESSMENT

March 2020

Conducted on behalf of:
Environmental Impact Management Services (Pty) Ltd

Compiled by:
JFW Mostert (M.Sc. Hydrogeology, *Pr.Sci.Nat.*)

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REPORT REVIEW AND SIGN OFF

Report undertaken by:	JFW Mostert
Signature:	
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Reference Number:	HG-R-20-006-V1
Date:	05 March 2020

INDEMNITY AND SPECIALIST DECLARATION

The findings, results, observations, conclusions and recommendations given in this report are based on the author's best scientific and professional knowledge as well as available information. The report is based on assessment techniques, which are limited by information available, time and budgetary constraints relevant to the type and level of investigation undertaken and Gradient Consulting (Pty) Ltd reserve the right to modify aspects of the report including the recommendations if and when new information may become available from ongoing research, monitoring, further work in this field, or pertaining to the investigation.

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This report has been drafted as per the latest requirements for specialist reports as set by the Department of Environmental Affairs and listed in Government Gazette No. 40713, dated 24 March 2017 and Government Gazette No. 40772 dated 07 April 2017 in terms of the National Environmental Management Act, 1998 (Act No. 107 of 1998) (NEMA).

I, JFW Mostert, hereby declare that:

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

JFW Mostert (Hydrogeologist)

M.Sc. Hydrogeology, Pr.Sci.Nat.

Executive summary

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd to conduct a hydrogeological specialist investigation and groundwater impact assessment in support of an Integrated Water use Licence (IWUL) application process to be followed for Anker Coal and Mineral Holdings SA (Pty) Ltd Elandsfontein Colliery. Elandsfontein Colliery is an existing colliery which was approved in terms the Minerals Act (1999) and currently holds two mining rights (MP 314 MR as well as MP63 MR).

The objective of this investigation is to determine the status quo of the regional groundwater system and quantify and qualify potential impacts of existing activities and infrastructure on the regional groundwater regime.

The project extent and greater mine lease area is located on a portion of the remaining extent of portion 8; remaining extent of portion 1; a portion of the remaining extent of portion 6; portion 44; portion 14 and the remaining extent of portion 7 of the Farm Elandsfontein 309 JS, situated approximately 4.0 km south of Kwa-Guqa and about 16.0 km west of Emalahleni, Mpumalanga Province, South Africa

The topography of the greater study area is characterised by moderately undulating plains and pans. The north-eastern perimeter is shaped by a topographical high at 1565 mamsl and forms the watershed between quaternary catchments B20G and B11K. The lowest on-site elevation is situated towards the southwest and is recorded at 1476 mamsl. On-site gradients are relatively gentle to moderate with the average slope calculated at 2.30% and –2.20% respectively.

The resource management of the greater study area falls under the Olifants WMA and quaternary catchment B20G.

Although local surface water drainage on site is inferred to be in a general southwestern direction, the regional drainage occurs in a general north to north-western direction. The Grootspruit drainage transects the project area to the southwestern perimeter.

The calculated mean annual precipitation (MAP) for this rainfall zone is 530.76 mm/a, while the mean annual evaporation accounts to 1689.0 mm/a.

The study area is underlain by the Ecca Group of the Karoo Supergroup and fall within the Madzaringwe Formation, consisting mainly of arenaceous strata. On a regional scale, two geological lineaments (potentially faults zones) exist in close proximity to the greater study area, striking in a general north-south and southwest-northeast orientation respectively.

The site is predominantly underlain by an intergranular and fractured aquifer system (d3) comprising mostly fractured and weathered compact sedimentary/ arenaceous rocks.

Two main hydrostratigraphic units can be inferred in the saturated zone:

i. A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock.

ii. An intermediate/deeper fractured aquifer where groundwater flow will be dictated by transmissive fracture zones that occur in the relatively competent host rock.

The hydraulic conductivity of sandstone formations can range from $9e^{-05}$ – $9e^{-01}$ m/d whereas the hydraulic conductivity of denser shale formations is lower and estimated at $9e^{-09}$ – $9e^{-05}$ m/d. It should also be noted that mined out and back-filled areas may have different hydraulic properties as the inherent values have been altered and modified.

An approximation of recharge for the study area is estimated at ~6.21 % of MAP i.e. ~32.93 mm/a.

Off the boreholes visited during the hydrocensus user survey, the majority is in use (>73.0%)) with the groundwater application mostly for monitoring purposes as well as domestic and livestock purposes. It should be noted that there is various neighbouring boreholes in close proximity (< 1.0 km) to the mining operations.

The unsaturated zone within the study area is in the order of ~2.85 to ~17.34 m with a mean thickness of approximately 7.84 m.

Analysed water level data for the shallow aquifer indicate that the majority of levels correlate very well to the topographical elevation and it can be assumed that the regional groundwater flow direction of the shallow aquifer is dictated by topography. Accordingly, the inferred groundwater flow direction will be in a general southwestern direction towards the lower laying drainage system of the Grootspruit drainage system.

The average groundwater gradient (i) of the shallow, weathered aquifer in the vicinity of the potential high-risk seepage areas i.e. mine discard dump and/or slurry ponds is moderately flat and calculated at approximately 0.004 with gradients increasing towards the southwestern perimeter of the mine lease area.

The expected seepage rate from contamination originating at the mine discard dump is estimated at an average of 0.96 m/a and will be dependent on local groundwater gradients.

The overall ambient groundwater quality of the shallow aquifer is good with the majority of macro and micro determinants below the SANS 241:2015 limits. Isolated sampling localities indicate above limits ammonium (NH_4) concentrations which may suggest nearby anthropogenic activities.

The local groundwater quality is indicative of an impacted groundwater system and suggest coal mine pollution and acid mine drainage (AMD) conditions present. The latter is characterised by a low pH environment increasing the solubility and concentrations of metals i.e. usually aluminum, iron and manganese.

The overall water quality of the upstream surface water samples is poor due to elevated levels of sulphate as well as heavy metals (Fe, Al and Mn) i.e. coal mine pollution indicators. The downstream water quality is unacceptable due to highly elevated levels of sulphate as well as heavy metals (Fe, Al and Mn) causing high salt loads. There is a definite deterioration of water quality evident in a downstream direction and suggest contaminated water ingress from potentially mine decant and interflow zones or seepage from mine discard dumps.

The majority of regional/ neighbouring boreholes suggest either a recently recharged and unimpacted water environment (Calsium-Bi-carbonate dominance), and/or area of dissolution and mixing, whereas current monitoring boreholes on site indicate a static and disordinate environment (Sulphate dominance suggesting impacts from coal mine pollution).

Furthermore, groundwater sampling localities ECBH03, ELNBH03 correlate well to the hydrochemical signature of surface water sampling locality ASW01 and suggest similar water environments and potential origins.

The tailings sludge/ slurry sample analysed record intermediate sulphide content of 0.14% with a high negative NNP value of -45.0. The NPR ratio of zero suggest that the material does not consists of any buffering capacity and is likely to acid generating. The NAG pH is 1.53 with the NAG value 88.0 (at pH 7.0), indicating that the material has a high capacity for acid formation. It should be stated that although the sample does consist of oxidisable sulphides, the content is relatively low and insufficient to sustain long term acid generation.

The coal sample analysed record a high sulphide content of 1.89% with a high negative NNP value of -99.69. The NPR ratio of zero suggest that the material does not have any buffering capacity and is likely to generate acid. The NAG pH is 2.07 with the NAG values 29.80 (at pH 7.0), also indicating a high capacity for acid formation. It should be stated that the sample has high oxidisable sulphides and has the potential to sustain long-term acid generation.

The sandstone sample (non-carbonaceous) analysed record a very low sulphide content of 0.01% with a positive NNP value of 12.29. The high NPR ratio of 30.98 suggest that the material consist of adequate buffering capacity and is likely to generate acid. The NAG pH is 9.69 with a low NAG value of 0.01 (at pH 7.0) which suggest that the material is non-acid forming.

The shale sample (carbonaceous) analysed record an intermediate sulphide content of 0.15% with a high slightly negative NNP value of -1.43. The small NPR ratio of 0.79 suggest that the material does not have adequate buffering capacity and is likely to generate acid. The NAG pH is 3.74 with the NAG values 1.17 (at pH 7.0), shows that the material does have a low capacity for acid formation. It should be stated that the sample has intermediate oxidisable sulphides, however, will not sustain long-term acid generation.

A Toxicity characteristic leaching procedure (TCLP) leach test was performed on composite samples of sulphide containing waste material suggest elevated concentrations of manganese (Mn) as well as sulphate ($S0_4$) for the tailings slurry sample, manganese (Mn) for the coal product sample and barium (Ba), manganese (Mn) as well as zinc (Zn) for the carbonaceous shale sample.

All waste samples analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly.

A **GQM Index = 4** was estimated for the aquifer system and according to this estimate, a "**Medium**" level groundwater protection is required for this aquifer system. According to the DRASTIC index methodology applied, this mining activities and associated infrastructure's risk to groundwater pollution is rated as "**Moderate**", Di = 102.

List of Abbreviations

ABA	**Acid Base Accounting**
ASLP	**Australian Standard Leaching Procedure**
AP	**Acid Potential**
ARD	**Acid Rock Drainage (also referred to as acid mine drainage (AMD))**
ASTM	**American Society for Testing Materials**
AUC	**Average Upper Crust**
Avg	**Average**
BH	**Borehole**
CMB	**Chloride Mass Balance**
b	**Saturated Thickness**
DMR	**Department of Environmental Affairs**
DEM	**Digital Elevation Model**
DRASTIC	**DI Index**
DWS	**Department of Water Affairs and Sanitation (currently Department of Human Settlements, Water and Sanitation)**
EC	**Electrical Conductivity (mS/m)**
EA	**Environmental Authorisation**
EIA	**Environmental Impact Assessment**
E.N.	**Electro Neutrality**
EPA	**United States Environmental Protection Agency**
ha	**Hectares**
GIS	**Geographic Information Systems**
GN	**Government Notice**
GQM	**Groundwater Quality Management**
i	**Hydraulic gradient (dimensionless)**
ICP-OES	**Inductively coupled plasma optical emission spectrometer**
ICP-MS	**Inductively coupled plasma mass spectrometry**
IWULA	**Integrated Water Use License Application**
ISP	**Internal Strategic Perspective**
K	**Hydraulic Conductivity (m/d)**
LC	**Leachable Concentration**
LCT	**Leachable Concentration Threshold**
l/s	**Litre per second**
LOI	**Loss on Ignition**
LoM	**Life of Mine**
m^3/d	**Cubic meters per day**
MAE	**Mean Annual Evaporation OR Mean Absolute Error**
mamsl	**Metres Above Mean Sea Level**
MAP	**Mean Annual Precipitation**
MAR	**Mean Annual Runoff**
mbgl	**Metres Below Ground Level**
mcm	**Million Cubic Metres**
ME	**Mean Error**
meq/L	**Mili-equivalents per litre**
mg/l	**Milligrams per litre**

mm/a	**Millimetre per annum**
MPRDA	**Minerals and Petroleum Resources Development Act (Act 28 of 2002)**
n	**Porosity**
NAG	**Net-Acid Generation**
NAWL	**No Access to Water Level**
NGA	**National Groundwater Archive**
NNP	**Net Neutralisation Potential**
NP	**Neutralisation Potential**
NPR	**Neutralisation Potential Ratio**
NGDB	**National Groundwater Database**
NRMSD	**Normalised Root Mean Square Deviation**
NWA	**National Water Act (Act 36 of 1998)**
REV	**Representative Elementary Value**
RMSE	**Root Mean Square Error**
ROR	**Rate of Rise**
RWD	**Return Water Dam**
S	**Storage coefficient**
Sc	**Specific Storage**
SoW	**Scope of Work**
SANAS	**South African National Accreditation System**
SANS	**South African National Standards**
T	**Transmissivity (m2/d)**
TC	**Total Concentration**
TCLP	**Toxicity characteristic leaching procedure**
TCT	**Total Concentration Threshold**
TDS	**Total Dissolved Solids**
TSF	**Tailings Storage Facility**
UNESCO	**The United Nations Educational, Scientific and Cultural Organisation**
USGS	**United States Geological Survey**
WGS	**World Geodetic System**
WM	**With Mitigation**
WOM	**Without Mitigation**
WUL	**Water Use Licence**
XRD	**X-Ray Diffraction**
XRF	**X-Ray Fluorescence**

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1. INTRODUCTION

1.1. Project background

Gradient Consulting (Pty) Ltd was appointed by Environmental Impact Management Services (Pty) Ltd (hereafter referred to as EIMS) to conduct a hydrogeological specialist investigation and groundwater impact assessment in support of an Integrated Water Use Licence Application (IWULA) to be lodged in terms of Section 40 of the National Water Act, Act 36 of 1998 (NWA) for Anker Coal and Mineral Holdings SA (Pty) Ltd Elandsfontein Colliery. Elandsfontein Colliery is an existing colliery which was approved in terms the Minerals Act (1999) and currently holds two mining rights (MP 314 MR as well as MP63 MR). The applicant plans to consolidate the two mining right areas into a single mining right with associated consolidated EMPR. Furthermore, the applicant proposes to expand the existing mining operations to include additional mineral resource areas within the consolidated mining right boundary. This investigation will focus on the status quo of the regional groundwater system and quantify/ qualify potential impacts of the proposed activities on sensitive environmental receptors.

1.2. Objectives

The objective of this investigation is to:

i. Establish site baseline and background conditions and identify sensitive environmental receptors.
ii. Determine the current status quo of the regional groundwater system including aquifer classification, aquifer unit delineation and vulnerability.
iii. Geochemical assessment and first order assessment on the long-term potential for the occurrence of Acid Mine (Rock) Drainage (AMD).
iv. Waste classification in accordance with Regulation GNR 635 of the National Waste Act (Act 59 of 2008).
v. Development of a numerical groundwater flow model.
vi. Development of a contaminant transport model with of a source term derived from the geochemical assessment.
vii. Hydrogeological impact assessment and risk matrix.
viii. Recommendations on best practise mitigation and management measures to be implemented.
ix. Compilation of an integrated groundwater monitoring network and protocol.

1.3. Terms of reference

The investigation is based on the terms of reference and scope of work (SoW) as detailed in proposal ref.no. HG-P-19-050-V1, submitted in September 2019. This project plan and scope of work (SoW) was compiled based on Government Notice NO. R. 267: Regulations regarding the procedural requirements for water use licence applications as published by the Department of Water Affairs and Sanitation (DWS, 2017) as well as Government Notice NO. R. 982: Environmental Impact Assessment (EIA) Regulations controlling environmental authorization applications (NEMA, 2014). The scope of work is listed below.

1.4. Phase A: Desk study and gap analysis

Phase A will entail the following activities:

i. Information gathering and data acquisition.

ii. Desk study and review of historical groundwater baseline information, existing specialist reports as well as DWS supported groundwater databases i.e. national groundwater archive (NGA).

iii. Fatal flaw and gap analysis.

1.5. Phase B: Hydrogeological baseline assessment - hydrocensus user survey, hydrochemical analysis and aquifer classification

Phase B will entail the following activities:

i. Hydrocensus user survey to evaluate and verify existing surface and groundwater uses, local and neighbouring borehole locations and depths, spring localities and seepage zones, regional water levels, abstraction volumes, groundwater application as well as environmental receptors in the vicinity of the mining footprints.

ii. Sampling of existing boreholes and surface water bodies according to best practise guidelines and analyses of ten (10) water samples to determine the macro and micro inorganic chemistry and hydraulic connections based on hydrochemistry (analyses at SANAS accredited laboratory).

iii. Assess the structural geology and geometry of the aquifer systems with respect to hydraulic interactions and compartmentalisation.

iv. Data interpretation aiding in aquifer classification, delineation and vulnerability ratings. Development of a scientifically defendable hydrogeological baseline.

v. Compilation of geological, hydrogeological and hydrochemical thematic maps summarising the aquifer system(s), indicating aquifer delineation, groundwater piezometric map, depth to groundwater, groundwater flow directions as well as regional geology.

1.6. Phase C: Geochemical assessment, waste classification and source term determination

Phase C will entail the following activities:

i. Review and analysis of existing information.

ii. Laboratory analysis and geochemical assessment of composite waste samples of strategically placed sampling localities (Static leach testing (TCLP), AMD generation, NAG Potential and sulphide speciation (4 samples)).

iii. Processing of geochemical data.

iv. Geochemical interpretation of laboratory results and source term determination.

v. Formulation of a geochemical conceptual model.

vi. Report writing.

1.7. Phase D: Development of a numerical groundwater flow and mass transport model

Phase D will entail the following activities:

i. Development of a conceptual hydrogeological model in conjunction with interpreted geology data and gathered site characterisation information.

ii. Development of a regional numerical groundwater flow model by applying the Finite Element Flow (FEFLOW) modelling software. Model domain to include proposed infrastructure and mine extension footprint as well as associated activities.

iii. Calibration of groundwater flow model using site specific data including hydrocensus geosites as well as existing time-series monitoring data.

iv. Development of a numerical mass transport model utilizing the calibrated groundwater flow model as basis.

v. The calibrated model will be used to simulate management scenario's as follows:

a. Steady state groundwater flow directions, hydraulic gradient and flow velocities.

b. Potential groundwater inflow volumes and mine dewatering rates.

c. Seepage potential from wastewater facilities and mass transport plume migration with time.

d. Mine post-closure decant positions and volumes with time.

e. Water management alternatives and best practice mitigation measures.

1.8. Phase E: Hydrogeological impact assessment and reporting

Phase E will entail the following activities:

i. Compilation of a detailed hydrogeological specialist investigation report with conclusions and recommendations on the following aspects:

a. Fatal flaw and gap analyses.

b. Site baseline characterisation.

c. Field work summary and interpretation.

d. Aquifer classification and vulnerability.

e. Geochemical source term determination.

f. Numerical groundwater flow and mass transport model development, calibration and simulations.

g. Formulation of an impact assessment and risk matrix of proposed activities.

h. Recommendation on best practise mitigation and management measures to be implemented.

ii. Development of an integrated surface water and groundwater monitoring program for implementation.

1.9. Project assumptions and limitations

Data limitations were addressed by following a conservative approach and assumptions include the following:

i. The scale of the investigation was set at 1:50 000 resolutions in terms of topographic and spatial data, a lower resolution of 1:250 000 scale for geological data and a 1: 500 000 scale resolution for hydrogeological information.
ii. The Digital Elevation Model (DEM) data was interpolated with a USGS grid spacing of 25 m intervals.
iii. Rainfall data and other climatic data was sourced from the WR2012 database.
iv. Water management and catchment-based information was sourced from the GRDM and Aquiworx databases.
v. The concept of representative elementary volumes (REV) have been applied i.e. a scale has been assumed so that heterogeneity within a system becomes negligible and thus can then be treated as a homogeneous system. The accuracy and scale of the assessment will result in deviations at point e.g. individual boreholes.
vi. No site characterisation boreholes were drilled as part of this investigation and aquifer parameters as well as hydrostratigraphic units were assumed based on historical investigation and similar studies conducted.
vii. The investigation relied on data collected as a snapshot of field surveys and existing monitoring data. Further trends should be verified by continued monitoring as set out in the monitoring program.
viii. Groundwater divides have been assumed to align with surface water divides and it is assumed that groundwater cannot flow across this type of boundaries.
ix. Where data was absent or insufficient, values were assumed based on literature studies and referenced accordingly[1].

[1] Where model assumptions were made or reference values used, a conservative approach was followed. Data gaps identified should be addressed as part of the model update.

2. METHODOLOGY

The groundwater impact assessment was undertaken by applying the methodologies as summarised below.

2.1. Desk study and review

This task entails the review of available geological and hydrogeological information including DWS supported groundwater databases (NGA/ Aquiworx), existing specialist reports, mine plans as well as climatic and other relevant groundwater data. Data collected was used to delineate various aquifer and hydrostratigraphic units, establish the vulnerability of local aquifers, aquifer classification as well as aquifer susceptibility.

2.2. Hydrocensus user survey

A hydrocensus user survey was undertaken in August 2019 (representing dry-season contribution) in order to confirm the presence of potential sensitive environmental receptors in the vicinity of the project area, determine the surrounding groundwater application and piezometric water levels and collect water samples for analysis. Furthermore, a site visit and terrain walk-over were conducted in order to formulate and define the hydrogeological conceptual model.

2.3. Hydrochemical analysis

Water samples collected were submitted at a SANAS accredited laboratory to determine the macro and micro inorganic chemistry and potential hydraulic connections present. SANS 241:2015 Drinking Water Standards was applied and used a guideline for all water quality analysis. Inorganic chemistry was used to develop hydrochemical diagnostic plots for evaluation of hydrochemical signatures.

2.4. Geochemical assessment and waste classification

The potential risk of mine waste to generate acid i.e. acid rock drainage (ARD) was evaluated by acid base accounting testing. The latter involves a combined measurement of sulphur contents (total sulphur, sulphuric acid, sulphur, and organic sulphur), neutralisation capacity (NP), paste pH and the calculation of acid potential (AP), net neutralisation potential (NNP) and NP/AP ratio (NPR). Furthermore, waste classification of waste was undertaken in terms of the NEMA National Norms and Standards for the Assessment of Waste for Landfill Disposal (DEAT, 2010) [2]. The process includes identifying the chemical substances present in the waste through analysis of the total concentrations (TC) and leachable concentrations (LC) of samples taken.

2.5. Numerical groundwater flow and mass transport model

A numerical groundwater flow and mass transport model was developed based on site characterisation data gathered as well as the defined groundwater conceptual model. The latter will serve as a tool to evaluate various water management options and different scenarios will be applied to quantify and qualify potential groundwater

[2] It should be noted that, although a pollution control barrier system designed in terms of the National Norms and Standards for the Assessment of Waste for Landfill Disposal (GN R635 and the National Norms and Standards for the Disposal of Waste to Landfill (GN R636) is no longer applicable and/or enforceable for mine residue, the Total Concentration (TC) and Leachable Concentration (LC) thresholds as stipulated in GNR635 standards are still applied as part of the waste assessment risk based approach.

impacts.

2.6. Groundwater impact assessment

Identification of preliminary and potential impacts and ratings related to new developments and/or listed activities are defined based on outcomes of the investigation. An impact can be defined as any change in the physical-chemical, biological, cultural and/or socio-economic environmental system that can be attributed to human and/or other related activities. The broad approach to the significance rating methodology is to determine the environmental risk (ER) by considering the consequence (C) of each impact (comprising Nature, Extent, Duration, Magnitude, and Reversibility) and relate this to the probability/likelihood (P) of the impact occurring. This determines the environmental risk. In addition, other factors including cumulative impacts, public concern, and potential for irreplaceable loss of resources, are used to determine a prioritisation factor (PF) which is applied to the ER to determine the overall significance (S). Mitigation measures were recommended in order to render the significance of impacts identified.

3. LEGAL FRAMEWORK AND REGULATORY REQUIREMENTS

The following water management legislation should be adhered to:

3.1. The National Water Act (Act 36 of 1998)

The purpose of the National Water Act, 36 of 1998 ("NWA") as set out in Section 2, is to ensure that the country's water resources are protected, used, developed, conserved, managed and controlled, in a way which inter alia considers the reduction, prevention and degradation of water resources. The NWA states in Section 3 that the National Government is the public trustee of the Nation's water resources. The National Government must ensure that water is protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner for the benefit of all persons and in accordance with its constitutional mandate. Section 22 of the NWA states that a person may only use water without a license if such water use is: permissible under Schedule 1, if that water use constitutes as a continuation of an existing lawful water use, or if that water use is permissible in terms of a general authorization issued under Section 39. Permissible water use furthermore includes water use authorised by a license issued in terms of the NWA or alternatively without a license if the responsible authority dispensed with a license requirement under subsection 3.

3.1.1. Section 21 water use activities

Section 21 of the National Water Act indicates that water use includes the following:

a. taking water from a water resource (section 21(a));

b. storing water (section 21(b));

c. impeding or diverting the flow of water in a water course (section 21(c));

d. engaging in a stream flow reduction activity contemplated in section 3649 (section 21(d));

e. engaging in a controlled activity which has either been declared as such or is identified in section

37(1)50 (section 21(e));

f. discharging waste or water containing waste into a water resource through a pipe, canal, sewer, sea outfall or other conduit (section 21(f));

g. disposing of waste in a manner which may detrimentally impact on a water resource (section 21(g);

h. disposing in any manner of water which contains waste from, or which has heated in, any industrial or power generation process (section 21 (h));

i. altering the bed, banks, course or characteristics of a water course (section 21(i));

j. removing, discharging or disposing of water found underground if it is necessary for the efficient continuation of an activity or for the safety of people (section 21(j)); and

k. using water for recreational purposes (section 21(k)).

3.1.2. GN 704 Regulations on the use of water for mining and related activities aimed at the protection of water resources (1999)

It is important that integrated water management should be conducted in accordance with Government Notice (GN) 704. The following regulations were referenced from the GN 704 document published.

Section 4: Restriction of Locality

"No person in control of a mine or activity may-

i. Locate or place any residue deposit, dam, reservoir, together with any associated structure or any other facility within the 1:100 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, borehole or well, excluding boreholes or wells drilled specifically to monitor the pollution of groundwater, or on waterlogged ground, or on the ground likely to become waterlogged, undermined, unstable or cracked;

ii. Except in relation to a matter contemplated in regulation 10, carry on any underground or opencast mining, prospecting or any other operation or activity under or within the 1:50 year flood-line or within a horizontal distance of 100 metres from any watercourse or estuary, whichever is the greatest;

iii. Place or dispose of any residue or substance which causes or is likely to cause pollution of a water resource, in the workings of any underground or open cast mine excavation, prospecting diggings, pit or any other excavation; or

iv. Use any area or locate any sanitary convenience, fuel depots, reservoir or depots for any substance which causes or is likely to cause pollution of a water resource within the 1:50 year flood-line of any watercourse or estuary."

Section 6: Capacity requirements of clean and dirty water systems

"Every person in control of a mine or activity must-

i. Confine any unpolluted water to a clean water system, away from any dirty area;

ii. Design, construct, maintain and operate any clean water system at the mine or activity so that it is not likely to spill into any dirty water system more than once in 50 years;

iii. Collect the water arising within any dirty area, including water seeping from mining operations, outcrops or any other activity, into a dirty water system;

iv. Design, construct, maintain and operate any dirty water system at the mine or activity so that it is not likely to spill into any clean water system more than once in 50 years; and

v. Design, construct, maintain and operate any dam or tailings dam that forms part of a dirty water system to have a minimum freeboard of 0.8 metres above full supply level, unless otherwise specified in terms of Chapter 12 of the Act.

vi. Design, construct and maintain all water systems in such a manner as to guarantee the serviceability of such conveyances for flows up to and including those arising as a result of the maximum flood with an average period of recurrence of once in 50 years."

Section 7: Protection of water resources

"Every person in control of a mine or activity must take reasonable measures-

i. Prevent water containing waste or any substance which causes or is likely to cause pollution of a water resource from entering any water resource, either by natural flow or by seepage, and must retain or collect such substance or water containing waste for use, re-use, evaporation or for purification and disposal in terms of the Act;

ii. Design, modify, locate, construct and maintain all water systems, including residue deposits, in any area so as to prevent the pollution of any water resource through the operation or use thereof and to restrict the possibility of damage to the riparian or in-stream habitat through erosion or sedimentation, or the disturbance of vegetation, or the alteration of flow characteristics;

iii. Cause effective measures to be taken to minimise the flow of any surface water or floodwater into mine workings, opencast workings, other workings or subterranean caverns, through cracked or fissured formations, subsided ground, sinkholes, outcrop excavations, adits, entrances or any other openings;

iv. Design, modify, construct, maintain and use any dam or any residue deposit or stockpile used for the disposal or storage of mineral tailings, slimes, ash or other hydraulic transported substances, so that the water or waste therein, or falling therein, will not result in the failure thereof or impair the stability thereof;

v. Prevent the erosion or leaching of materials from any residue deposit or stockpile from any area and contain material or substances so eroded or leached in such area by providing suitable barrier dams, evaporation dams or any other effective measures to prevent this material or substance from entering and polluting any water resources;

vi. ensure that water used in any process at a mine or activity is recycled as far as practicable, and any facility, sump, pumping installation, catchment dam or other impoundment used for recycling water, is of adequate design and capacity to prevent the spillage, seepage or release of water containing waste at any time;

vii. At all times keep any water system free from any matter or obstruction which may affect the efficiency thereof; and

viii. Cause all domestic waste, including wash-water, which cannot be disposed of in a municipal sewage system, to be disposed of in terms of an authorisation under the Act.

3.2. Mineral and Petroleum Resources Development Act (Act 28 of 2002)

The establishment, reclamation, expansion or decommissioning of residue stockpiles or residue deposits must be authorised in terms of the Mineral and Petroleum Resources Development Act (MPRDA) (Act 28 of 2002). Section 42 of the MPRDA states that:

i. Residue stockpiles and residue deposits must be managed in the prescribed manner on any site demarcated for that purpose in the environmental management plan or environmental management programme in question.

ii. No person may temporarily or permanently deposit any residue stockpile or residue deposit on any site other than on a site contemplated in subsection.

3.3. National Environmental Management: Waste Act (Act 59 of 2008)

Furthermore, the establishment, reclamation, expansion or decommissioning of residue stockpiles or residue deposits must also be authorised through a waste management licence issued in terms of the National Environmental Management Waste Act 59 of 2008.

The classification and definitions herein considered the following documents[3]:

i. Government Notice 635, National Environmental Management: Waste Act 59 of 2008: National Norms and Standards for the Assessment of Waste for Landfill Disposal (hereafter referred to as GNR 635).

ii. Government Notice 636, National Environmental Management: Waste Act 59 of 2008: National Norms and Standards for Disposal of Waste to Landfill (hereafter referred to as GNR 636).

It should be noted that Government Notice GN 990 published in September 2018 serve to amend the regulations regarding the planning and management of residue stockpiles and residue deposits (2015). The main aim is to allow for the pollution control measures required for residue stockpiles and residue deposits, to be determined on a case by case basis, based on a risk analysis conducted by a competent person. Accordingly, a risk analysis must be conducted to determine the pollution control measures suitable for a specific residue stockpile or residue deposit as part of an application for a waste management licence.

[3] It should be noted that, although a pollution control barrier system designed in terms of the National Norms and Standards for the Assessment of Waste for Landfill Disposal (GN R635 and the National Norms and Standards for the Disposal of Waste to Landfill (GN R636) is no longer applicable and/or enforceable, the Total Concentration (TC) and Leachable Concentration (LC) thresholds as stipulated in GNR635 standards are still applied as part of the waste assessment because guidelines and limits are based on Environmental Protection Agency (EPA) of the Australian State of Victoria and still bears reference.

4. STUDY AREA AND LISTED ACTIVITIES

4.1. Regional setting and site locality

The project extent and greater mine lease area is located on a portion of the remaining extent of portion 8; remaining extent of portion 1; a portion of the remaining extent of portion 6; portion 44; portion 14 and the remaining extent of portion 7 of the Farm Elandsfontein 309 JS, situated approximately 4.0 km south of Kwa-Guqa and about 16.0 km west of Emalahleni, Mpumalanga Province, South Africa. The site is accessible from the N4 national route and N104 to the north as well as route R547 to the east. General site coordinates are listed in Table 4-1 with the site locality and layout depicted in Figure 4-2.

Table 4-1 General site coordinates (Coordinate System: Geographic, Datum: WGS84).

Latitude	-25.904
Longitude	29.092

4.2. Mining infrastructure and schedule

Elandsfontein Colliery holds two mining right areas i.e. MP 314 MR (593 ha) as well as MP63 MR (237 ha). The roll over strip mining method is utilised to extract coal from the shallower No.2 coal seam. The existing opencast operations has an approximate extend of 257 ha while the applicant wishes to authorise an additional 69.47 ha. Deeper coal is extracted by underground bord and pillar mining using decline shafts to access No. 1 coal seam. The historical underground footprint covers an approximate area of 182 ha, while the applicant wishes to authorise an additional 379 ha. Associated infrastructure consists of a discard dump, coal ROM stockpiles, overburden stockpiles, pollution control dams (PCD) and slurry dam. Refer to Figure 4-2 for a summary of existing/ proposed mining zones and infrastructure map.

Figure 4-1 **Aerial extent and greater study area.**

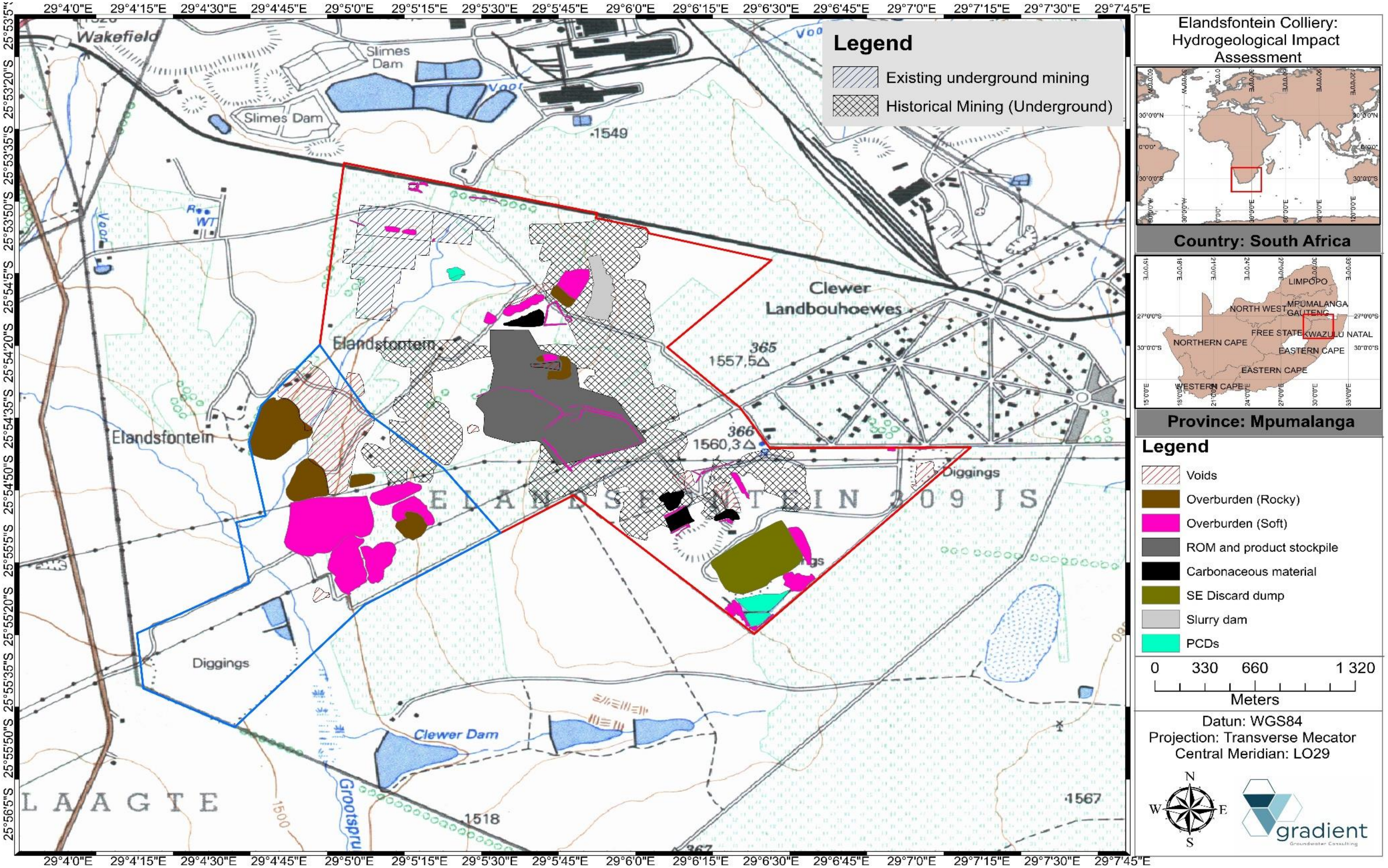


Figure 4-2 **Mine infrastructure (1:50 000 topographical mapsheet 2529CC).**

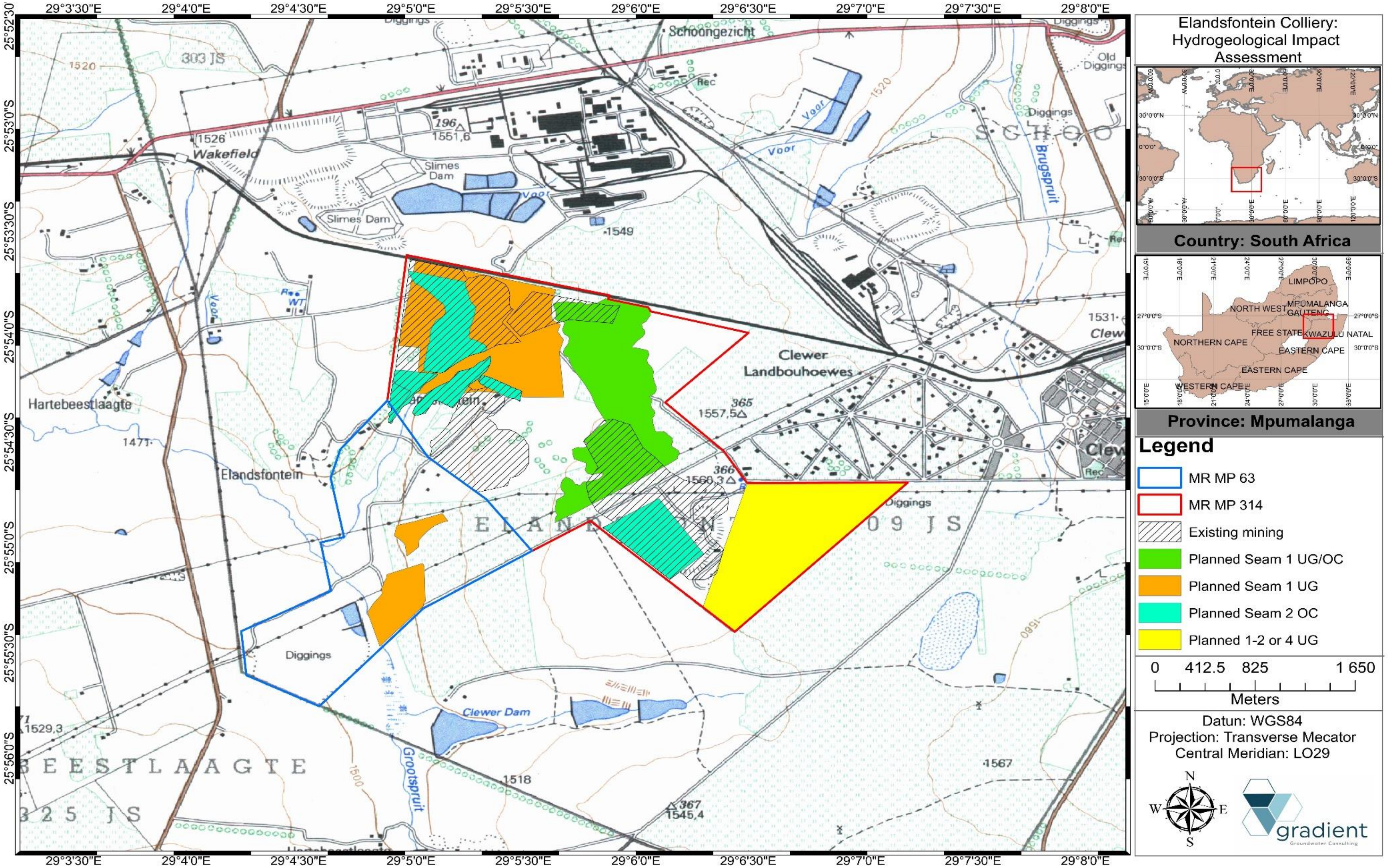


Figure 4-3 **Mining schedule.**

5. PHYSIOGRAPHY

5.1. Topography

The topography of the greater study area is characterised by moderately undulating plains and pans. The north-eastern perimeter is shaped by a topographical high at 1565 meters above mean sea level (mamsl) and forms the watershed between quaternary catchments B20G and B11K. To the south and southeast, the landscape gradually flattens out towards the lower laying drainage system with the lowest on-site elevation recorded as 1476 mamsl.

On-site gradients are relatively gentle to moderate with the average slope calculated at 2.30% and –2.20% respectively with an elevation loss of ~30.0 m over a lateral distance of ~3.50 km. Figure 5-1 depicts a northsouth-eastwest topographical cross-section of the greater study area while Figure 5-2 shows the regional topographical contours and setting.

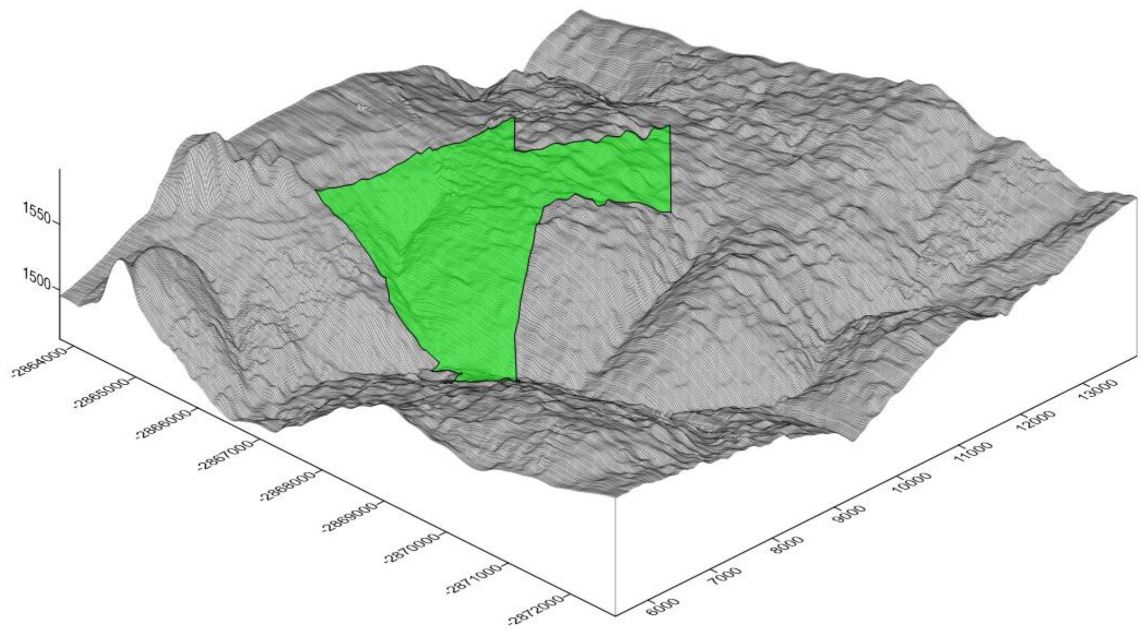


Figure 5-1 Topographical cross-sections of the greater study area.

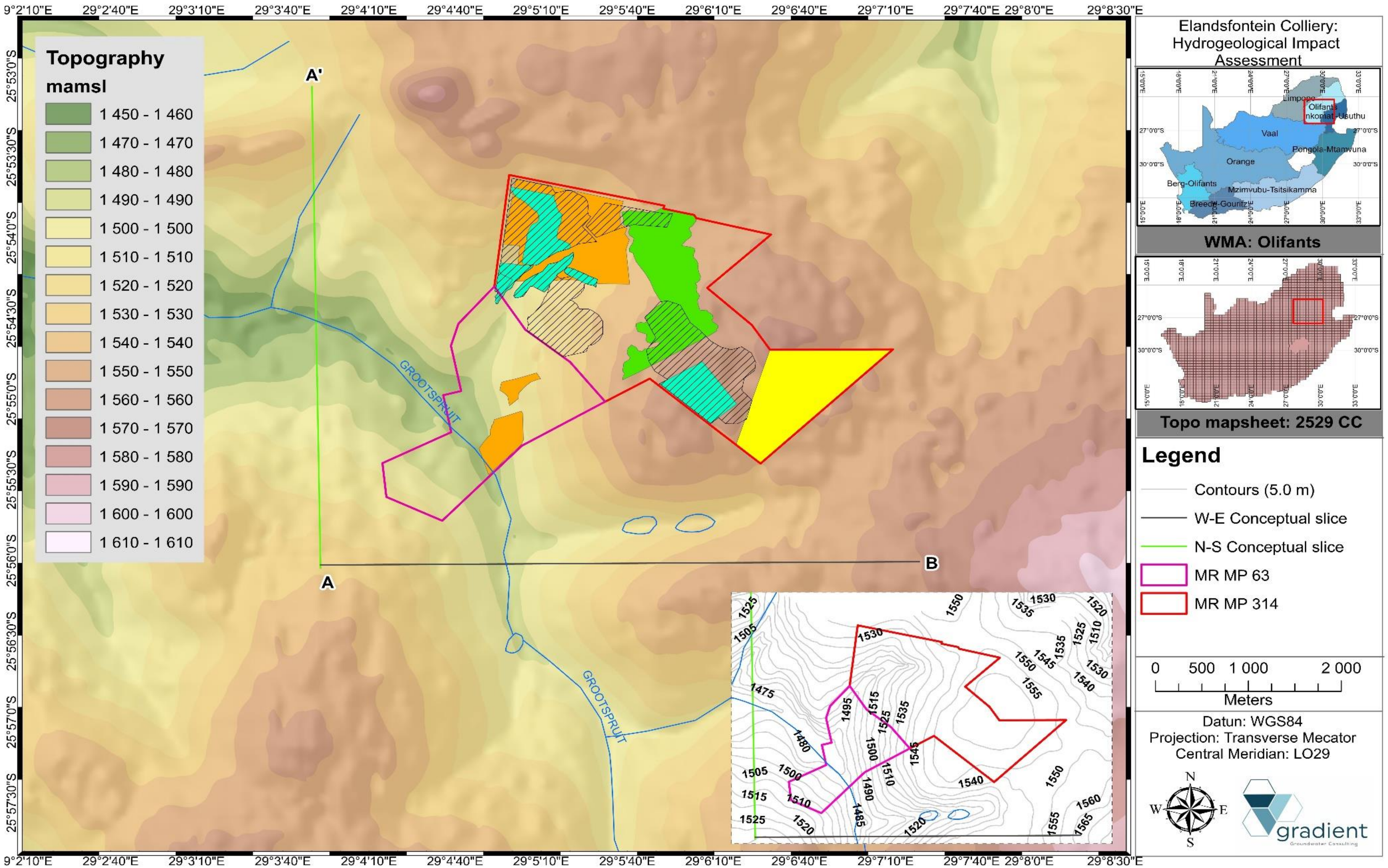


Figure 5-2 **Regional topography (Figure 11-2).**

5.2. Drainage and catchment

The project area is situated in primary catchment (B) of the Elands, Wilge, Steelpoort and Olifants River drainage systems. The resource management falls under the Olifants Water Management Area (WMA) (54 550 km^2) which spans portions of the Limpopo, Mpumalanga as well as Gauteng. The study area is situated within quaternary catchment B20G (nett surface area of 519.4 km^2), falls within hydrological zone J and has an estimated mean annual runoff (MAR) of 44.1 mcm (million cubic metres) (WR 2012).

Although local surface water drainage on site is inferred to be in a general southwestern direction, the regional drainage occurs in a general north to north-western direction. The Grootspruit, transecting the project area to the southwest, convergences with the Saalboomspruit approximately 5.0 km to the northwest of the mine lease area from where it flows in a general northern direction before joining the Kromdraaispruit and Wilge Rivier ~ 20.0 km to the north. Major surface water features within this quaternary catchment include the Clewer dam < 1.0 km up-gradient of the mine lease boundary.

Refer to Figure 5-3 for a spatial layout of the project area in relation the water management area, quaternary catchments as well as regional drainage patterns. Table 5-1 provides a summary of relevant climatological and hydrogeological information for quaternary catchment B20G.

Table 5-1 Quaternary catchment information: CB20G.

Attribute	Catchment information
Water Management Area (WMA)	Olifants
Primary catchment	B
Secondary catchment	B2
Tertiary catchment	B20
Quaternary catchment	B20G
Major rivers	Elands,Wilge,Steelpoort and Olifants
Hydro-zone	J
Rainfall zone	B2C
Area (km^2)	522.0
Mean annual rainfall (mm)	669.0
Mean annual evaporation (mm)	1700.0
Mean annual runoff (mm)	44.1
Baseflow	10.8
Population	34279.0
Total groundwater use (l/s)	5.2
Present Eco Status Category	Category E/F
Recharge	7.0
Average water level (mbgl)	13.4
Soil type	SaClLm
Groundwater General Authorization	0 m^3/ha/a

Note: Catchment based information sourced from Aquiworx 2014

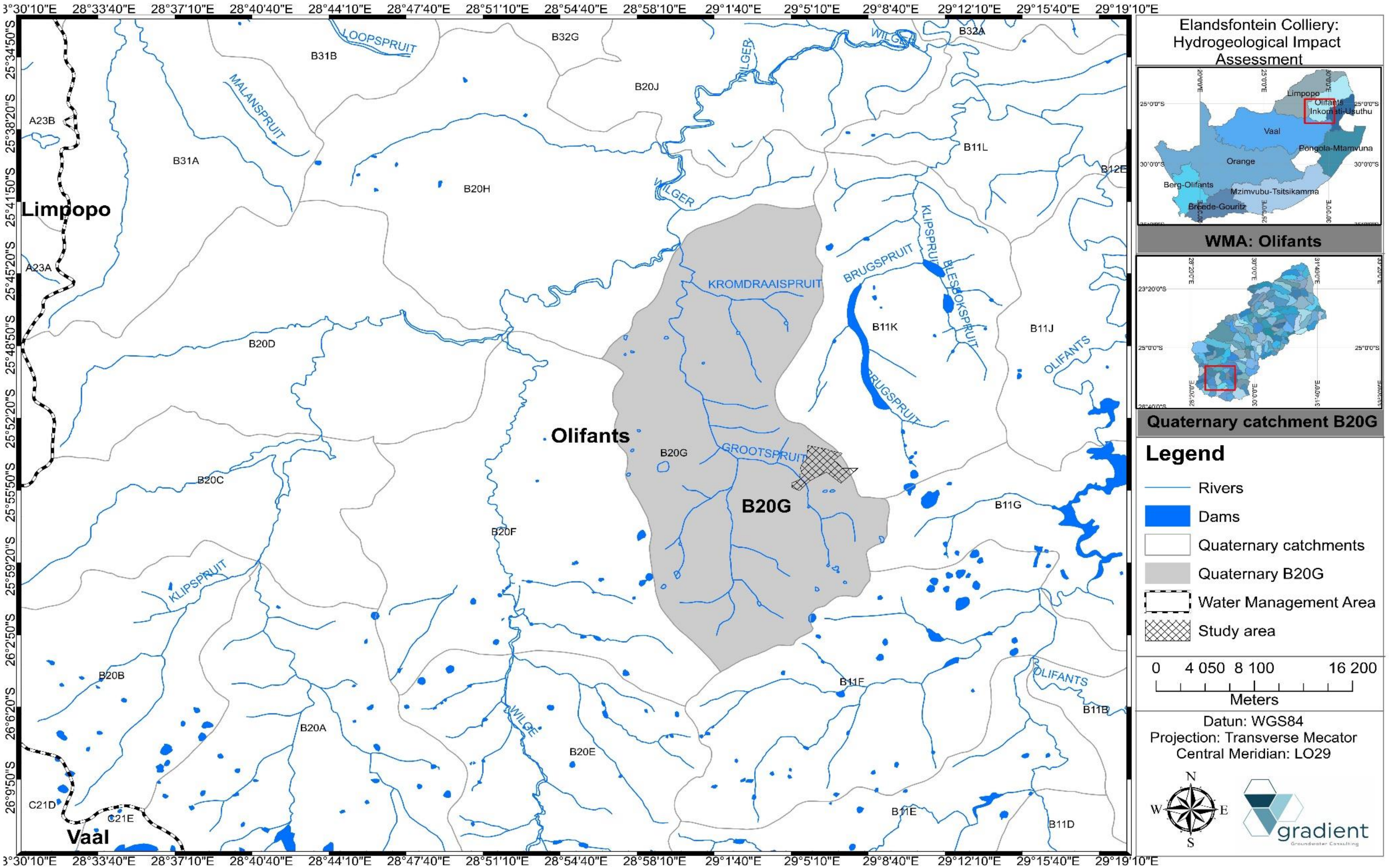


Figure 5-3 **Quaternary catchments and water management area.**

5.3. Climate

The study area's weather pattern reflects a typical summer rainfall region, with > 85.0% of precipitation occurring as high-intensity thunderstorms from October to March. Patched rainfall and evaporation data were sourced from the WR2012 database (Rainfall zone B2C) and span a period of some 90 years (1920 – 2009). The calculated mean annual precipitation (MAP) for this rainfall zone is 530.76 mm/a, with the 5th percentile of the data set (roughly equivalent to a 1:20 year drought period) calculated at 342.74 mm/a and the 95th percentile (representing a ~1:20 flood period) 717.84 mm/a. The highest MAP for the 90 years of rainfall data was recorded as of 940.85 mm (1995) while the lowest MAP of 291.38 mm was recorded during 1965. This quaternary catchment is categorised under evaporation zone 4A which have a mean annual evaporation (s-pan) of 1689.0 mm/a, more than double the annual precipitation for the greater study area. Figure 5-4 depicts a bar chart of the yearly rainfall distributions with Figure 5-5 indicating monthly rainfall patterns. Figure 5-6 provides a comparison of monthly precipitation and evaporation volumes. A summary of rainfall data used as part of this statistical analysis is summarised in Appendix A: Rainfall data.

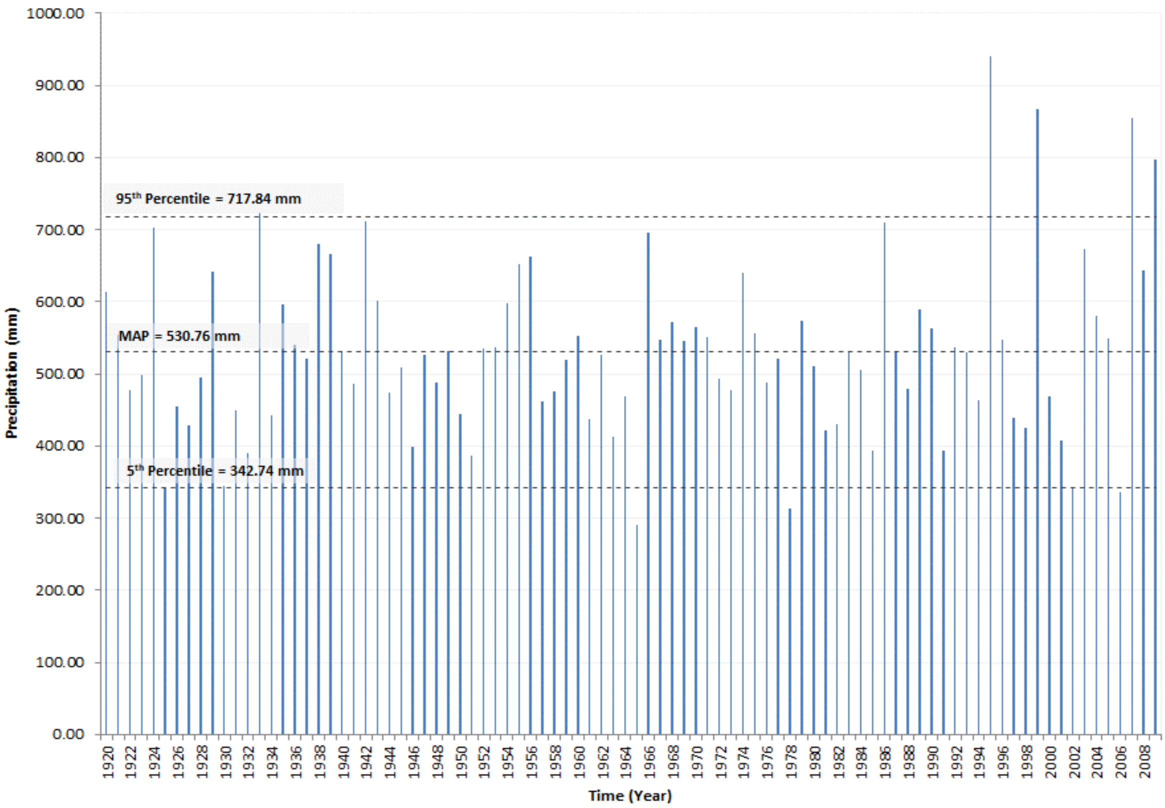


Figure 5-4 Bar chart indicating yearly rainfall distribution for rainfall zone B2C (WR2012).

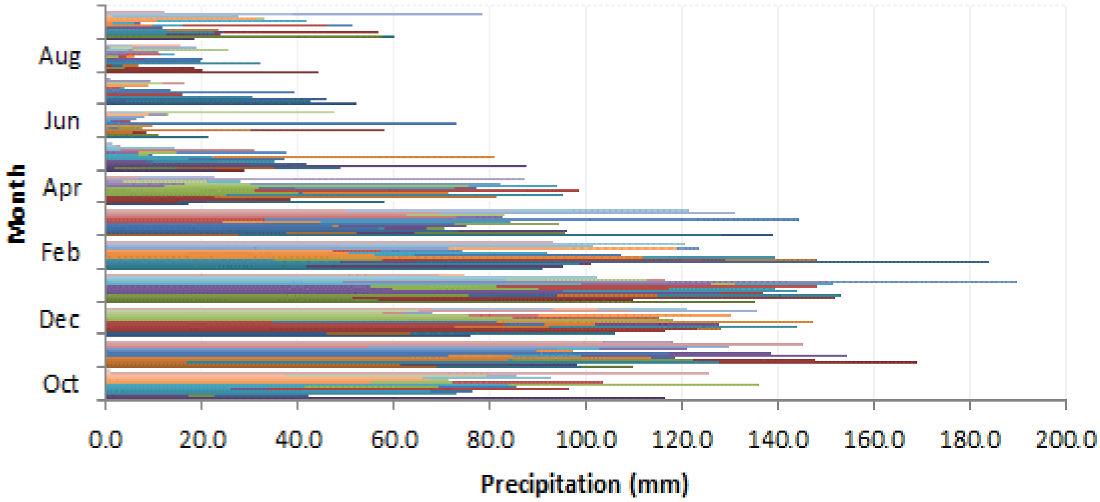


Figure 5-5 **Bar chart indicating monthly rainfall distribution for rainfall zone B2C (WR2012).**

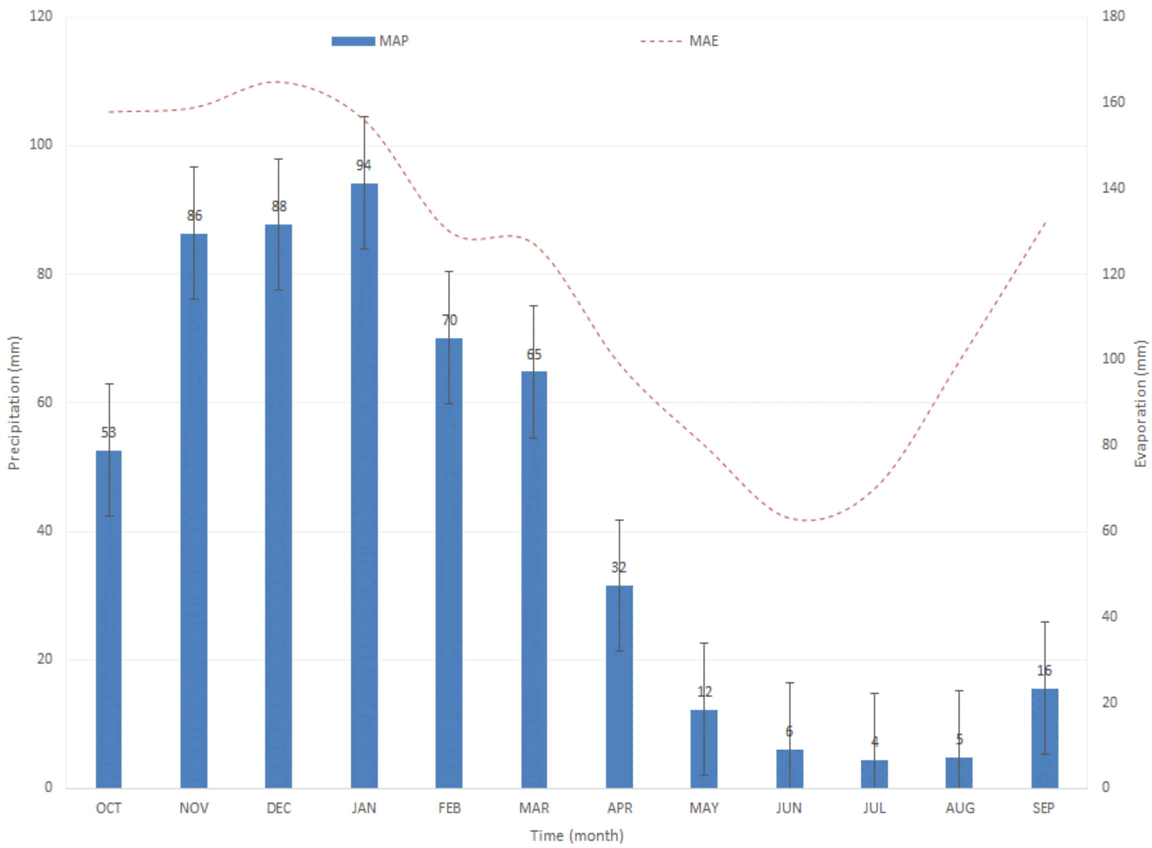


Figure 5-6 **Bar chart and curve comparing monthly rainfall and evaporation distribution (WR2012).**

5.4. Geological setting

5.4.1. Regional geology

The greater study area falls within the Ecca Group of the Karoo Supergroup, which consists of a sequence of units, mostly of nonmarine origin, deposited between the Late Carboniferous and Early Jurassic (Schlüter and Thomas, 2008). The Permian Ecca Group follows conformably after the Dwyka Group in certain sections, however in some localities overlies unconformably over older basement rocks. The Ecca Group underlies the Beaufort Group in all known outcrops and exposures and comprises a total of 16 formations consisting largely of shales and sandstones (Figure 5-7).

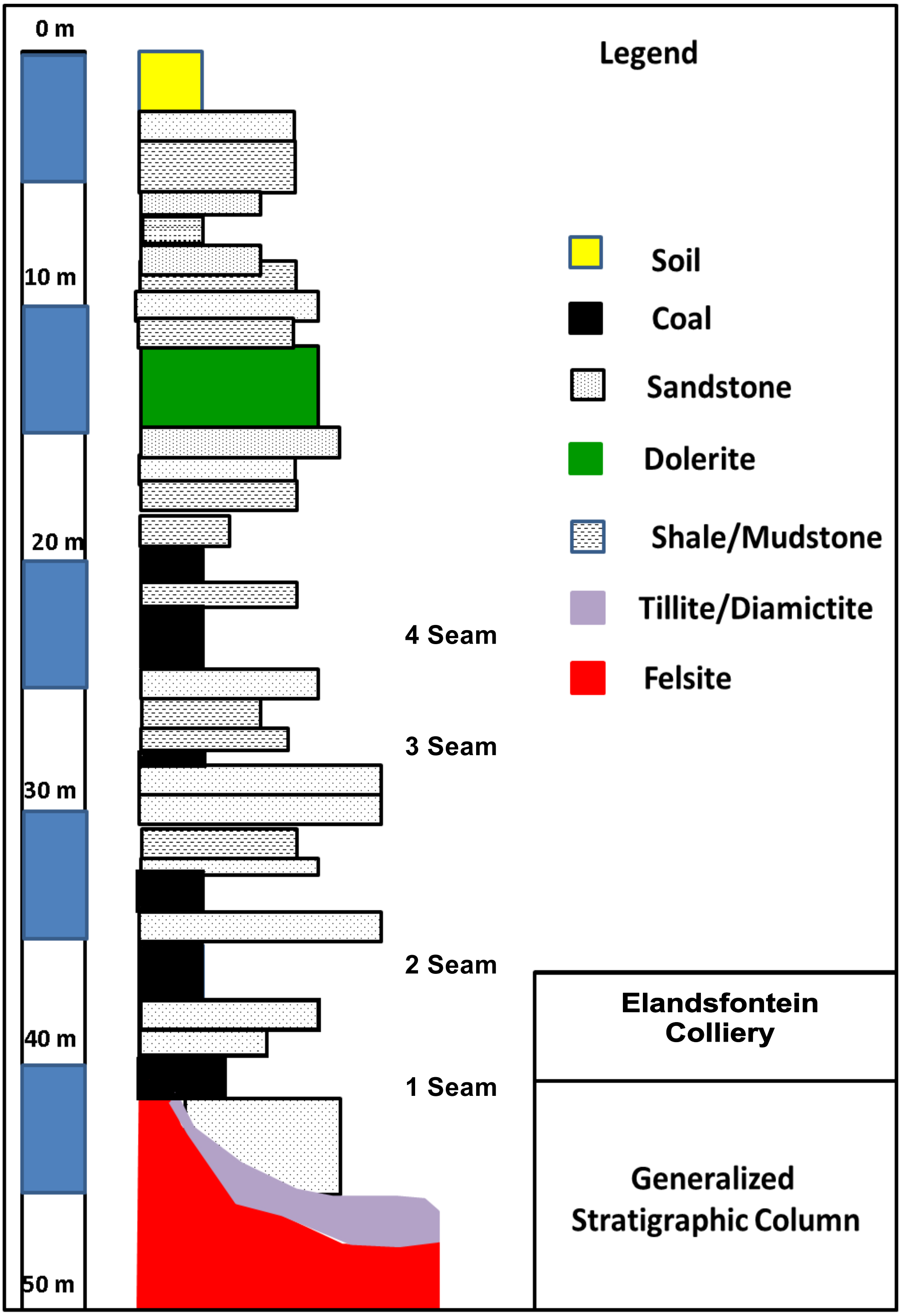
5.4.2. Local geology

According to the 1:250 000 geological mapsheet (2528, Pretoria) the study area falls within the Madzaringwe formation with surficial geology consisting mainly of shale, shaly sandstone, grit, sandstone, conglomerate as well as interlaminated coal layers and entail predominantly arenaceous formations. Refer to Table 5-2 for a simplified stratigraphic column of the study area.

5.4.3. Structural geology

On a regional scale, two geological lineaments (potentially faults zones) exist in close proximity to the greater study area, striking in a general north-south and southwest-northeast orientation respectively. Faults zones may have an impact on the local hydrogeological regime as it can serve as potential preferred pathways for groundwater flow and contaminant transport.

Table 5-2 Simplified stratigraphic column of the greater study area (Georock, 2020).



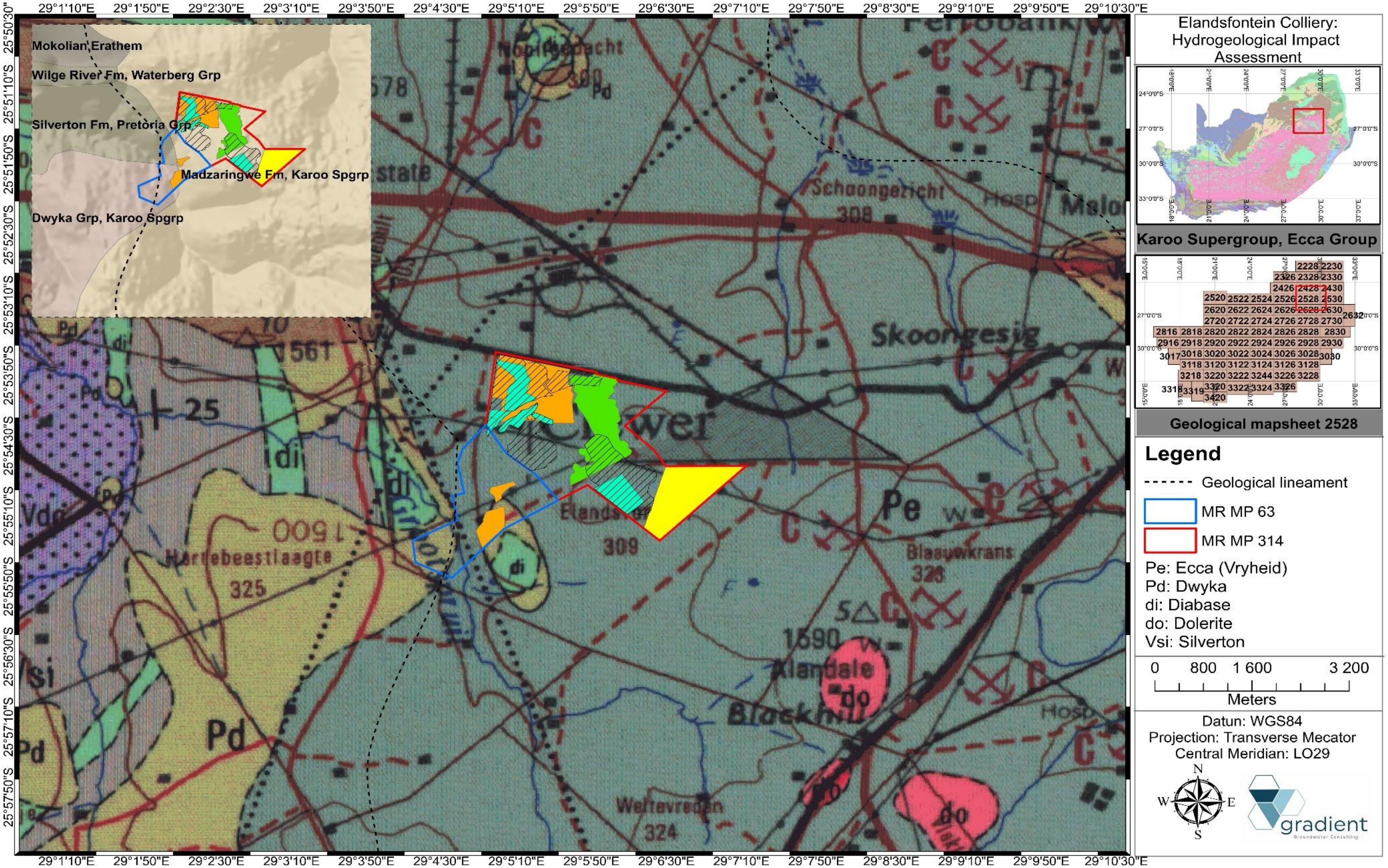


Figure 5-7 **Regional geology and stratigraphy (Geological mapsheets 2630).**

6. HYDROGEOLOGICAL BASELINE ASSESSMENT

6.1. Regional hydrogeology

The Department have characterised South African aquifers based on host-rock formations in which it occurs together with its capacity to transmit water to boreholes drilled into relative formations. The water bearing properties of respective formations can be classified into four aquifer classes defined as:

a. **Class A:** Intergranular o Aquifers associated either with loose and unconsolidated formations such as sands and gravels or with rock that has weathered to only partially consolidated material.
b. **Class B:** Fractured o Aquifers associated with hard and compact rock formations in which fractures, fissures and/or joints occur that are capable of both storing and transmitting water in useful quantities.
c. **Class C:** Karst o Aquifers associated with carbonate rocks such as limestone and dolomite in which groundwater is predominantly stored in and transmitted through cavities that can develop in these rocks.
d. **Class D:** Intergranular and fractured o Aquifers that represent a combination of Class A and B aquifer types. This is a common characteristic of South African aquifers. Substantial quantities of water are stored in the intergranular voids of weathered rock but can only be tapped via fractures penetrated by boreholes drilled into it. Each of these classes is further subdivided into groups relating to the capacity of an aquifer to transmit water to boreholes, typically measured in l/s. The groups therefore represent various ranges of borehole yields.

According to the DWS Hydrogeological map (DWS Hydrogeological map series 2526 Johannesburg) the site is predominantly underlain by an intergranular and fractured aquifer system (d3) comprising mostly fractured and weathered compact sedimentary/ arenaceous rocks (Figure 6-1). The Ecca Group consists mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices. Water is stored mainly in decomposed/partly decomposed rock and water bearing fractures are principally restricted to a shallow zone below the static groundwater level. Sustainable borehole yields are limited to < 0.5 l/s, while higher yielding boreholes (> 3.0 l/s) may occur along structural features i.e. fault and fracture zones (Barnard, 2000). Water levels are variable and controlled by topography, ranging from 10.0 mbgl (in low laying areas) to > 40.0 mbgl in higher elevated areas (Olifants ISP DWS, 2004). The maximum aquifer depth fluctuates between 30.0 – 50.0 mbgl. depicted in Figure 6-2.

6.2. Local hydrostratigraphic units

For the purposes of this investigation, two main hydrostratigraphic units can be inferred in the saturated zone[4]:

i. A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock. Ecca sediments are weathered to depths between 5.0 – 15.0 mbgl (Digby Wells, 2018). Groundwater flow patterns usually follow the topography, discharging as natural springs and/or baseflow at topographic low-laying areas. Usually this aquifer can be classified as a secondary porosity aquifer and is generally unconfined with phreatic water levels. Due to higher effective porosity (*n*) this aquifer is most susceptible to impacts from contaminant sources.

ii. An intermediate/deeper fractured aquifer where groundwater flow will be dictated by transmissive fracture zones that occur in the relatively competent host rock. Fractured sandstones and shales sequences are considered as hard-rock aquifers holding water in storage in both pore spaces and fractures. Groundwater yields, although more heterogeneous, can be expected to be higher than the weathered zone aquifer. This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position.

[4] it should be noted that no site characterisation boreholes have been drilled to confirm this assumption and this is based on historical hydrogeological investigation in this area and/or similar environments.

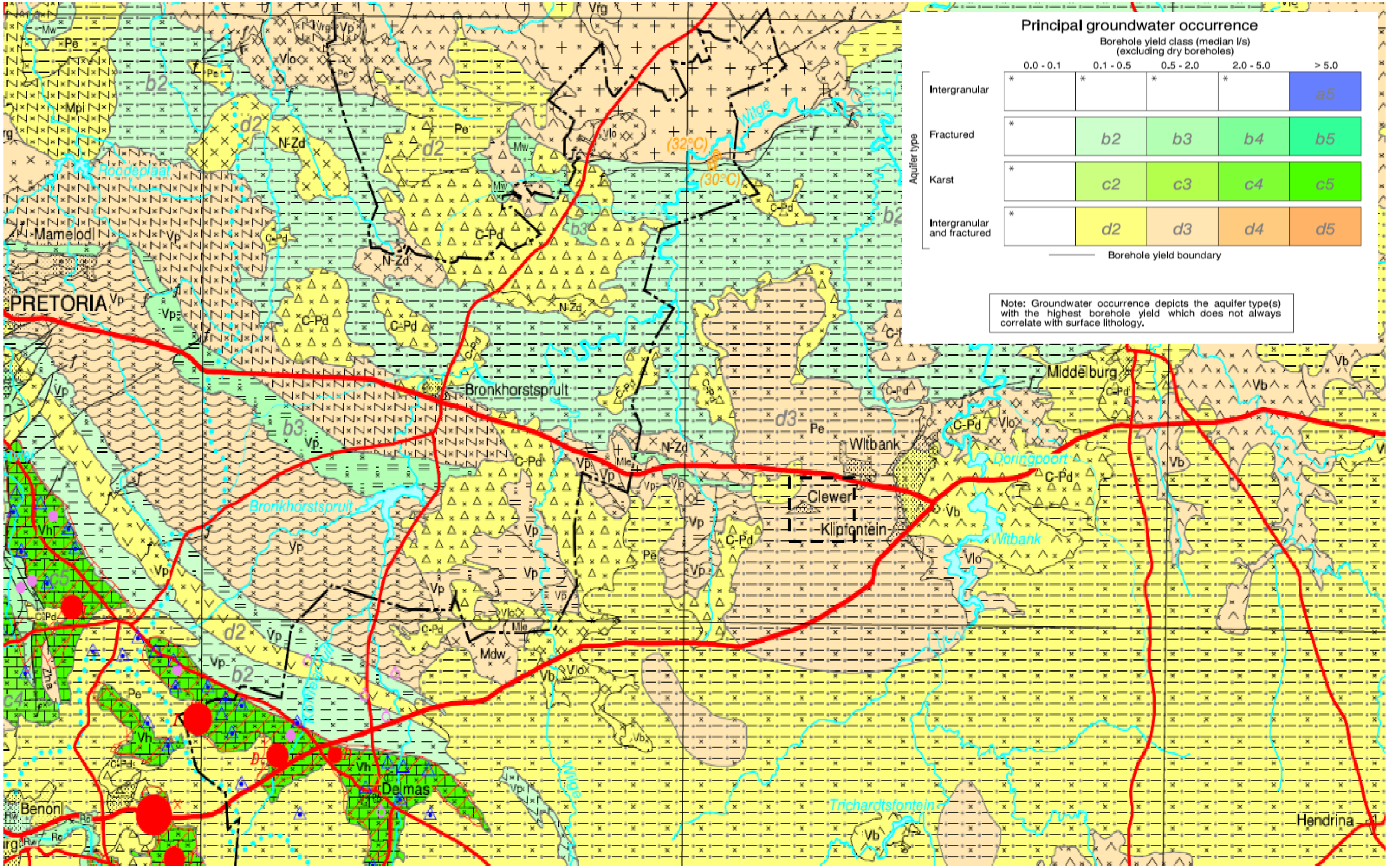


Figure 6-1 **Hydrogeological map illustrating the typical groundwater occurrence for the study region.**

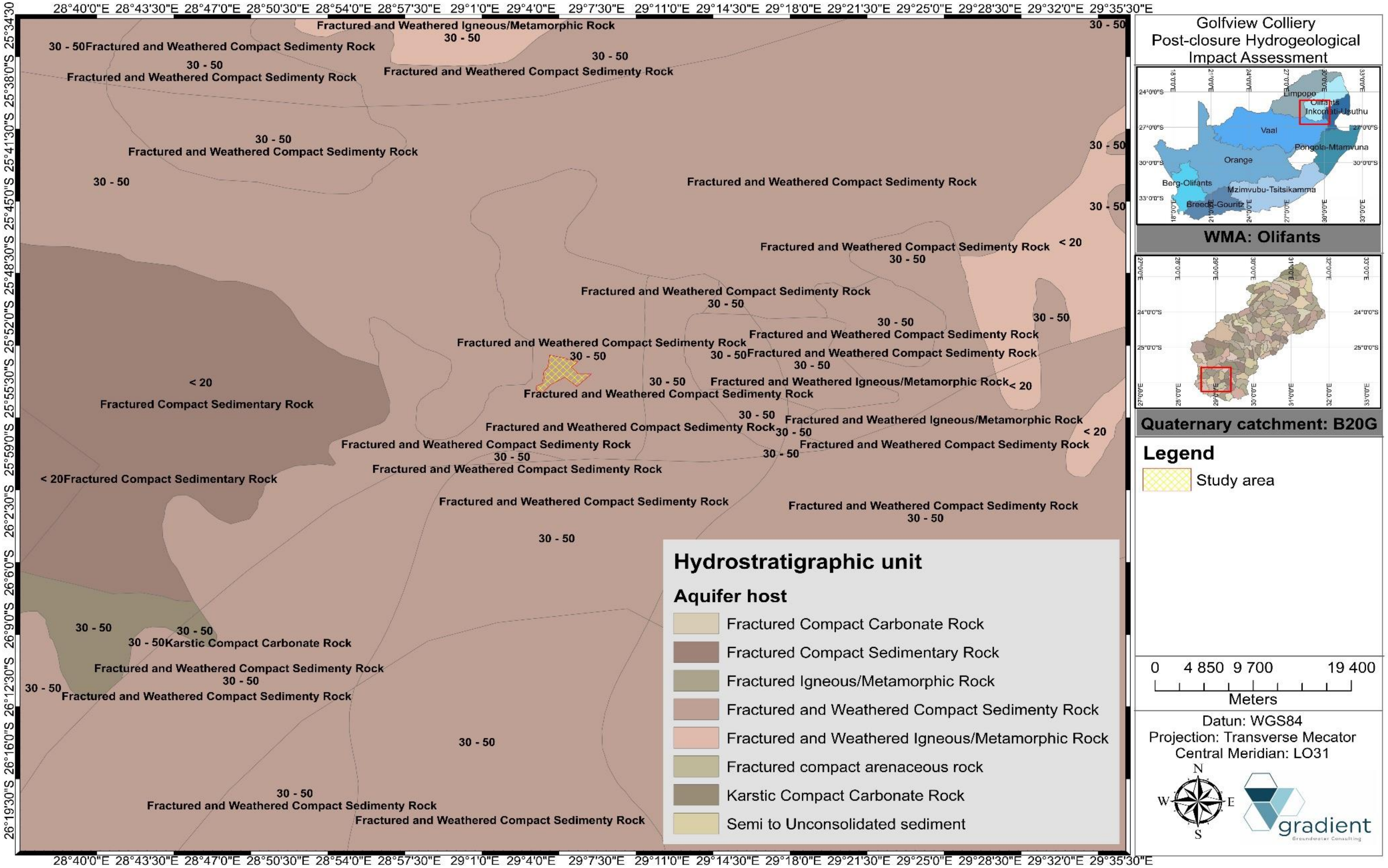


Figure 6-2 **Hydrostratigrpahical units.**

6.3. Hydraulic parameters

To follow is a brief overview of aquifer hydraulic parameters based on published literature for similar hydrogeological conditions as well as historical reports.

6.3.1. Hydraulic conductivity and Transmissivity

Hydraulic conductivity is the constant of proportionality in Darcy's Law which states that the rate of flow through a porous medium is proportional to the loss of head, and inversely proportional to the length of the flow path as indicated in the following equation:

Equation 6-1 Hydraulic Conductivity (Darcy's Law).

$$\boldsymbol{K} = \frac{\boldsymbol{Q}}{\boldsymbol{A}\left(\frac{dh}{dl}\right)}$$

where:

K = Hydraulic Conductivity (m/d).

Q = Flow of water per unit of time (m^3/d).

dh/dl = Hydraulic gradient.

A = is the cross-sectional area, at a right angle to the flow direction, through which the flow occurs (m^2)

The hydraulic conductivity of sandstone formations can range from $9e^{-05}$ – $9e^{-01}$ m/d whereas the hydraulic conductivity of denser shale formations is lower and estimated at $9e^{-09}$ – $9e^{-05}$ m/d. The conductivity of the weathered aquifer, including brittle coal seams, may be orders of magnitude higher and is estimated at $5e^{-02}$ m/d. It should also be noted that mined out and back-filled areas may have different hydraulic properties as the inherent values have been altered and modified (Freeze and Cherry, 1979).

Transmissivity can be expressed as the product of the average hydraulic conductivity (K) and thickness (b) of the saturated portion of an aquifer and expressed by:

Equation 6-2 Transmissivity.

$$\boldsymbol{T} = \boldsymbol{Kb}$$

where:

T = Transmissivity (m^2/d).

K = Hydraulic Conductivity (m/d).

b = Saturated aquifer thickness.

The average transmissivity for the shallow, weathered aquifer is estimated at 1.0 m^2/d.

6.3.2. Storativity

Storativity refers to the volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness. Typical storativity values for dense sedimentary formations is in the order of 10^{-5} – 10^{-3} while storativity values of the shallow, weathered aquifer can be slightly higher at 10^{-2} (Freeze and Cherry, 1979).

6.3.3. Porosity

Porosity is an intrinsic value of seepage velocity and hence contamination migration. The porosity of sandstone formations ranges between 0.05 – 0.30, while porosity of shale formations varies from 0 – 0.10. Porosity of the weathered aquifer and unconsolidated formations can be as high as 0.25 – 0.40 depending on the nature and state of weathering as well as sorting (Freeze and Cherry, 1979).

6.3.4. Recharge

An approximation of recharge for the study area is estimated at ~6.21 % of MAP i.e. ~32.93 mm/a as summarised in Table 6-1. Groundwater recharge was calculated using the RECHARGE Program1 (van Tonder and Xu, 2000), which includes using qualified guesses as guided by various schematic maps. The following methods/sources were used to estimate the recharge: (i) Chloride Mass Balance (CMB) method (ii) Geology (iii) Vegter Groundwater Recharge Map (Figure 6-3) (iv) Harvest Potential Map; (v) Baseflow as a minimum recharge value (Figure 6-4) (vi) Literature and (vi) Qualified opinion. It should be noted that due to the modified mining environment, recharge values may differ at certain zones i.e. backfilled areas, discard dumps etc. Using the simplified CMB method as proposed by Bean (2003), the following equation applies to calculating recharge.

Equation 6-3 Chloride Mass Balance formula.

$$R = \frac{Cl_{p+D}}{Cl_g}$$

where:

R = Recharge (mm/a)

Cl_p = Representative mean chloride concentration in rainwater including contributions from dry deposition

Cl_g = Chloride concentration in groundwater resulting from diffuse recharge

Table 6-1 Recharge estimation (after van Tonder and Xu, 2000).

Recharge method/ Reference	Recharge (mm/a)	Recharge (% of MAP)	Weighted Average (High = 5; Low = 1)
Chloride	28.89	5.44	3.00
Geology	28.25	5.32	3.00
Vegter	32.00	6.03	4.00
Harvest Potential	25.00	4.71	4.00
Baseflow	37.50	7.07	3.00
Literature	40.00	7.54	5.00
Qualified Opinion	37.15	7.00	3.00
Weighted average	**32.93**	**6.21**	**25.00**
Notes: Recharge per annum were calculated using a MAP of 531 mm/a.			

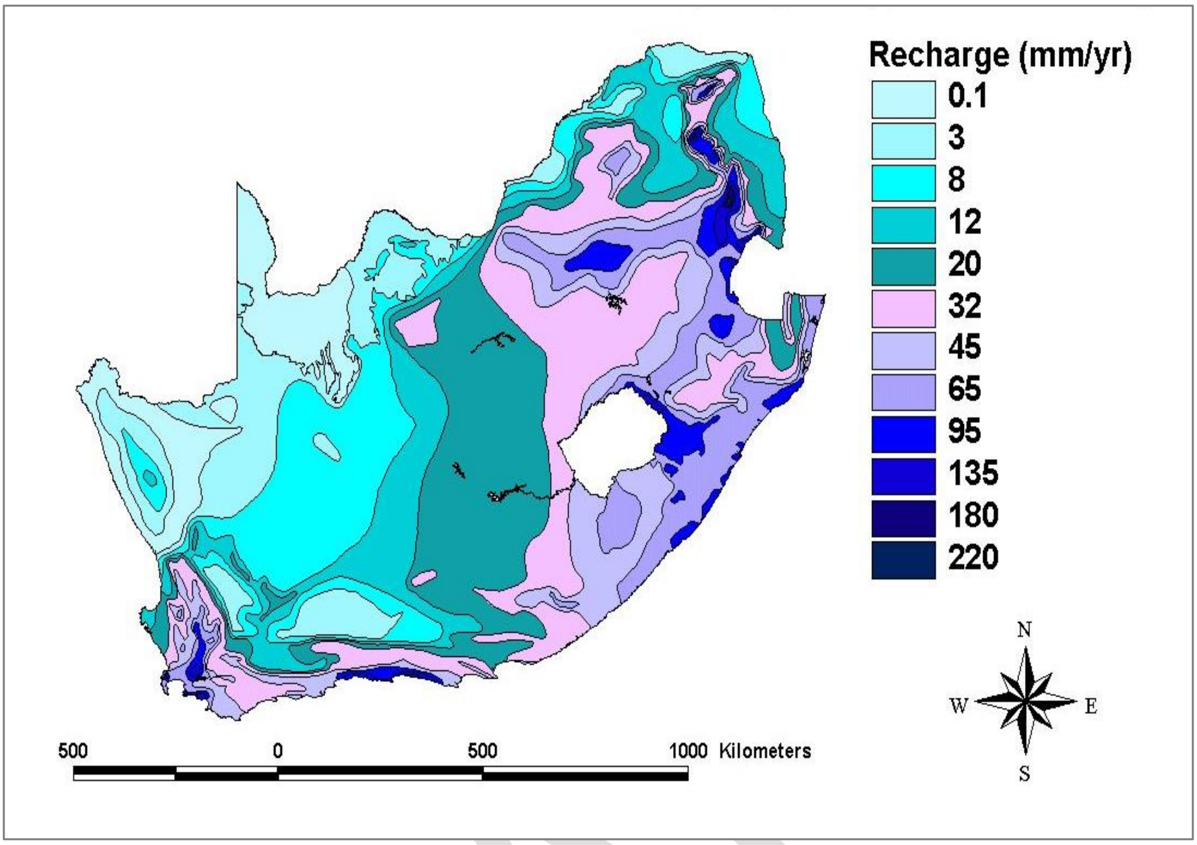


Figure 6-3 **Groundwater recharge distribution in South Africa (After Vegter, 1995).**

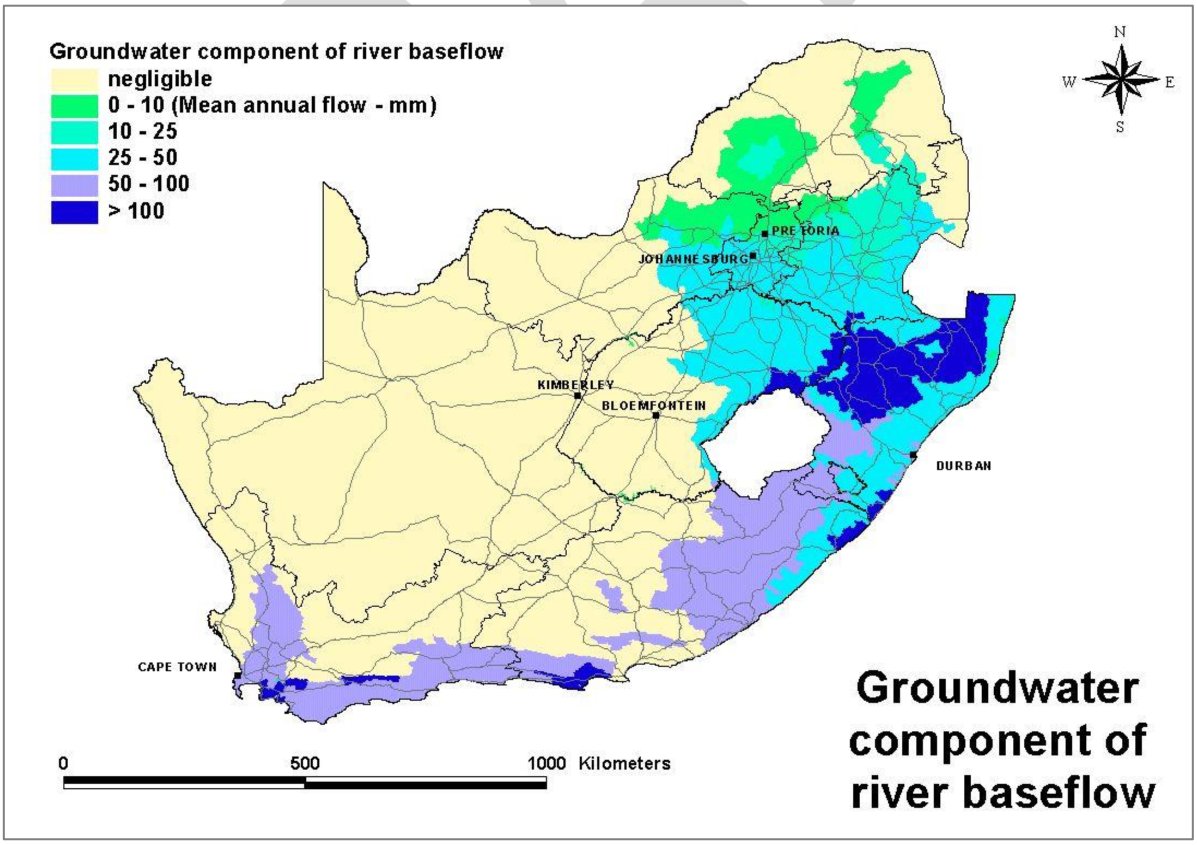


Figure 6-4 **Groundwater component of river baseflow in South Africa (DWS, 2013).**

6.4. Site investigation

A hydrocensus user survey within the greater study area was conducted during August 2019[5] where relevant hydrogeological baseline information was gathered. The aim of the hydrocensus survey is to determine the ambient and background groundwater conditions and applications prior to the proposed activities and to identify potential sensitive environmental receptors i.e. groundwater users in the direct vicinity of the operations. Geosites visited include 21 boreholes as well as two (2) surface water features i.e. drainages. Relevant hydrocensus information is summarised in Table 6-2 with a spatial distribution map shown in Figure 6-5.

6.4.1. Groundwater status

Of the boreholes recorded, the majority are in use (>73.0%) with only two boreholes are not currently utilised Refer to Figure 6-7.

6.4.2. Groundwater application

According to the Olifants Internal Strategic Perspective (ISP) (2004), the greater study area is charatcerised by agricultural activities, mostly stock farming, but with maize and other arable crops grown in flat areas. Most boreholes recorded are being applied for monitoring purposes (> 70.0 %) while groundwater application recorded for domestic and livestock purposes is ~17.0% and domestic and household purposes accounts for ~11.0% as summarised in Figure 6-8.

6.4.3. Borehole equipment

Most boreholes visited are not equipped (>70.0 %) while the remaining boreholes are equipped with submersible pumps (~28.0%) as indicated in Figure 6-9.

[5] It should be noted that relevant site information gathered will be representative of dry season contribution.

Table 6-2 Hydrocensus user survey: relevant geosite information.

Site ID	Latitude	Longitude	Water level (mbgl)	Water level status	Site type	Site status	Equipment	Water application	Owner	Contact details	Comments
ASW 01	-25.90871	29.06532	0.00		River	Not in use		Not in use		Witbank Anker Mine	
AHBH01	-25.91653	29.06203	4.85	Static	Borehole	Domestic	Submersible	Water supply	0724114242	Witbank Anker Mine	Pump 1x per week for 20 min
AHBH02	-25.91809	29.04529	10.29	Static	Borehole	Domestic & Livestock	Submersible	Water supply	0728984173	Witbank Anker Mine	Pump 4X per week for 1Hour
AHBH03	-25.92835	29.07116	8.18	Static	Borehole	Domestic	Submersible	Water supply	0715370381	Witbank Anker Mine	Pump 1x evey 2 weeks for 1,5 Hours
ELNBH1	-25.91337	29.10857	36.31	Static	Borehole	Monitoring	Not Equipped	Monitoring		Witbank Anker Mine	
ECBH05	-25.90390	29.09791	39.07	Static	Borehole	Monitoring	Not Equipped	Monitoring		Witbank Anker Mine	
ELNBH 07 S	-25.90810	29.09977	13.98	Static	Borehole	Monitoring	Not Equipped	Monitoring		Witbank Anker Mine	
ELNBH 06 D	-25.90823	29.09978	0.00		Borehole	Not in use	Not equipped	Not in use		Witbank Anker Mine	Ants closed borehole
ECBH 02	-25.90317	29.09656	7.56	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
ECBH 03	-25.90300	29.09633	7.57	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
ECBH 04	-25.90200	29.09721	9.55	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
ELNBH 02	-25.91422	29.10172	49.69	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	Not allot of water to take sample
GW 02	-25.91337	29.09551	23.19	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
ELNBH 03	-25.91994	29.08637	17.34	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
ASW 02	-25.91884	29.07801	0.00		River	Not in use		Not in use		Witbank Anker Mine	
BH 173	-25.92416	29.07895	4.02	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
BH 172	-25.92389	29.07795	5.78	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
FFBH 11	-25.98498	29.08882	6.81	Static	Borehole	Monitoring	Not equipped	Monitoring		Witbank Anker Mine	
AHBH04	-25.91113	29.11185	7.18	Static	Borehole	Not in use	Not equipped	Not in use	0826263161	Witbank Anker Mine	
AHBH05	-25.90756	29.11130	38.68	Recovering	Borehole	Domestic & Livestock	Submersible	Water supply	0727833920	Witbank Anker Mine	Timer pump 1every hour foe 5min
AHBH06	-25.90661	29.11516	19.89	Recovering	Borehole	Domestic & Irrigation	Submersible	Water supply	0836607410	Witbank Anker Mine	Pump 1x pd for 9h
AHBH07	-25.90243	29.11997	7.54	Static	Borehole	Not in use	Not equipped	Not in use	0790532976	Witbank Anker Mine	
AHBH08	-25.90627	29.12654	4.28	Static	Borehole	Not in use	Submersible	Not in use	0790782209	Witbank Anker Mine	

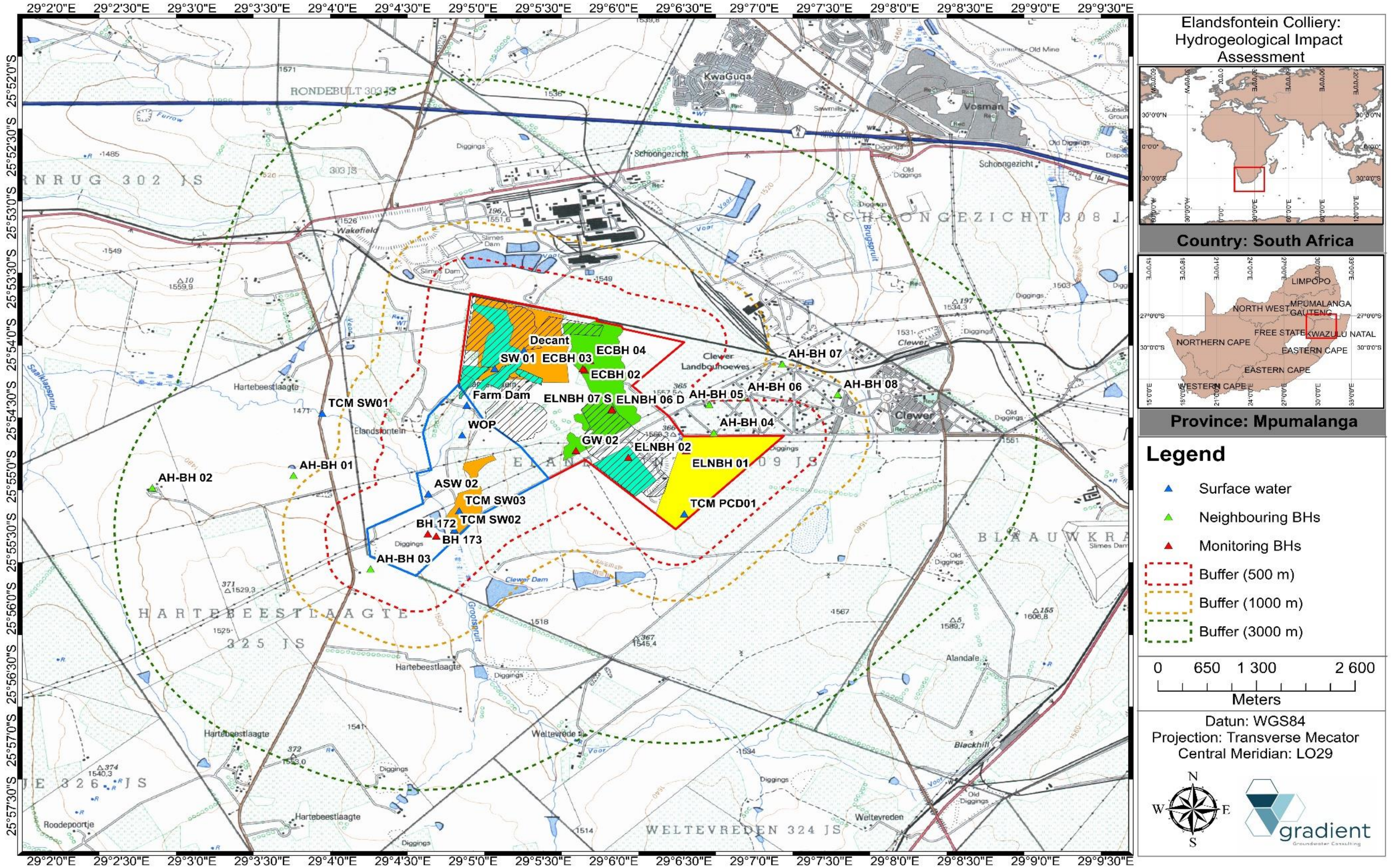


Figure 6-5 **Spatial distribution of hydrocensus user survey geosites.**

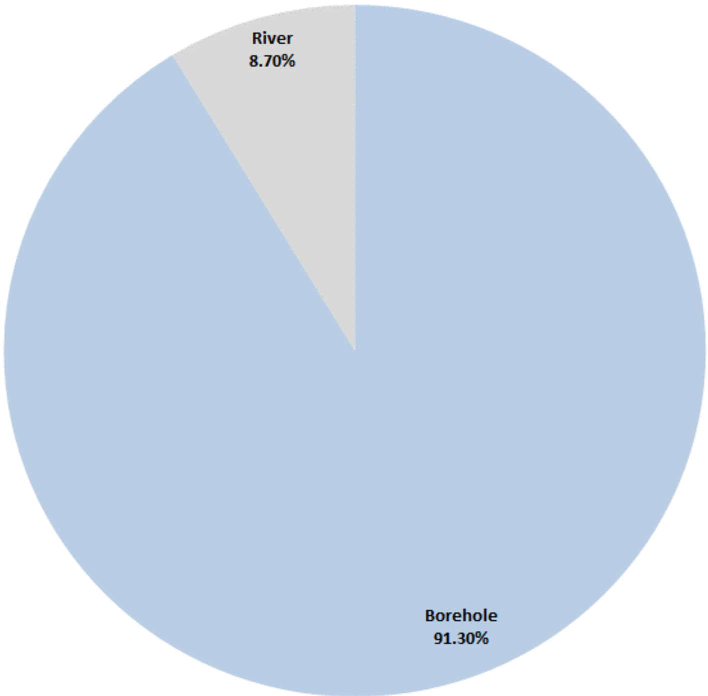


Figure 6-6 Hydrocensus user survey: Geosite recorded.

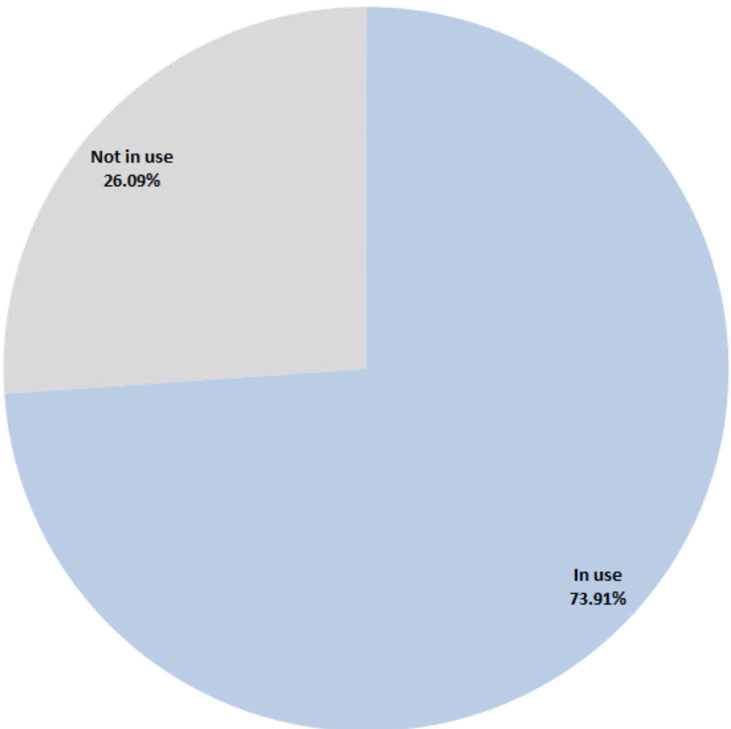


Figure 6-7 Hydrocensus user survey: Groundwater status.

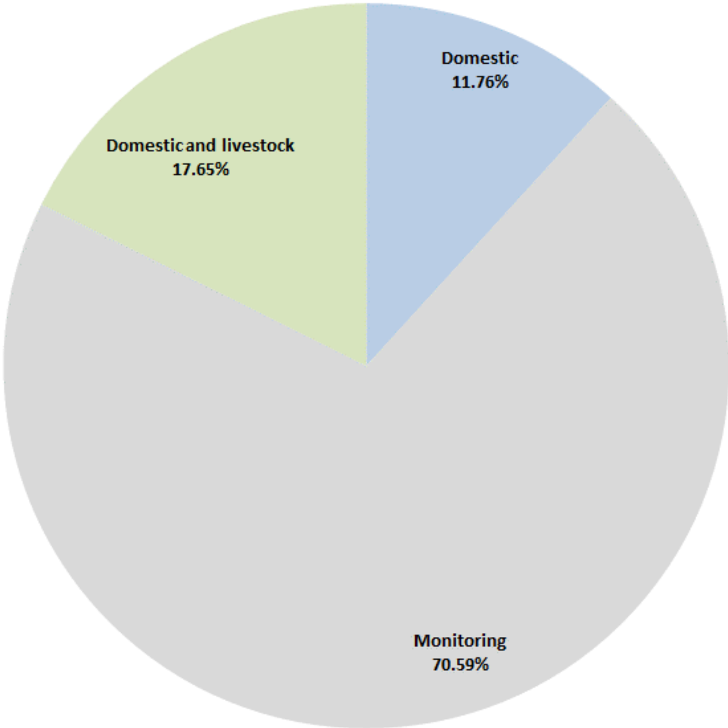


Figure 6-8 Hydrocensus user survey: Groundwater application.

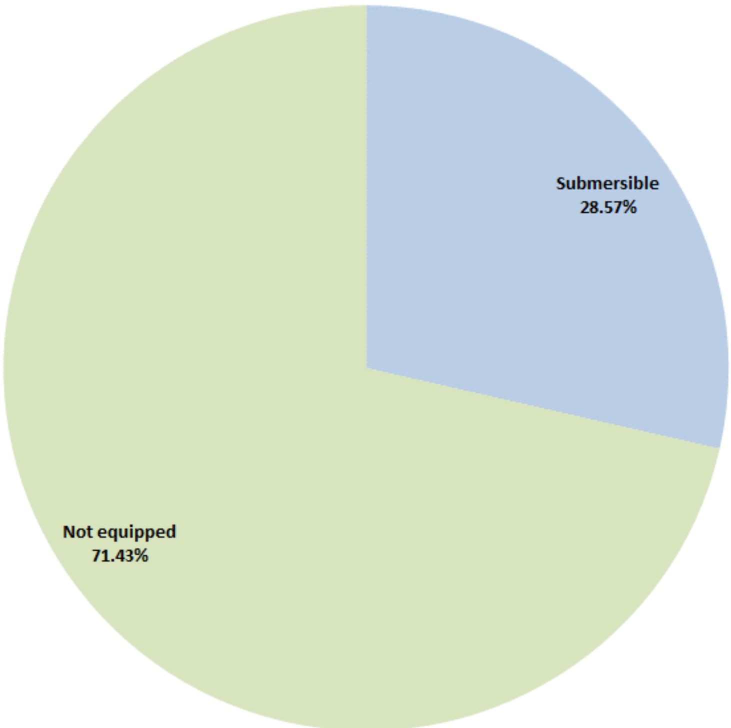


Figure 6-9 Hydrocensus user survey: Equipment type.

7. GROUNDWATER FLOW EVALUATION

The following sub-sections outline the site-specific hydrogeology of the study area.

7.1. Unsaturated zone

The thickness of the unsaturated or vadose zone was determined by subtracting the undisturbed static water level elevation from corresponding surface topography. The latter will govern the infiltration rate, as well as effective recharge of rainfall to the aquifer. Furthermore, the nature of the formation(s) forming the unsaturated zone will significantly influence the mass transport of surface contamination to the underlying aquifer(s). The unsaturated zone[6] within the study area is in the order of ~2.85 to ~17.34 m with a mean thickness of approximately 7.84 m.

7.2. Depth to groundwater

A distribution of borehole water levels recorded as part of the hydrocensus user survey as well as boreholes forming part of the existing groundwater monitoring network were considered and used to interpolate local groundwater elevation and hydraulic head contours. The groundwater levels available from the hydrocensus survey and monitoring boreholes in and around the mining areas are summarized in Table 7-1 and depicted in Figure 7-1.The minimum water level was recorded at on-site borehole GW05 (2.85 mbgl), while the deepest water level measured was at borehole locality ELNBH02, 49.69 mbgl[7].

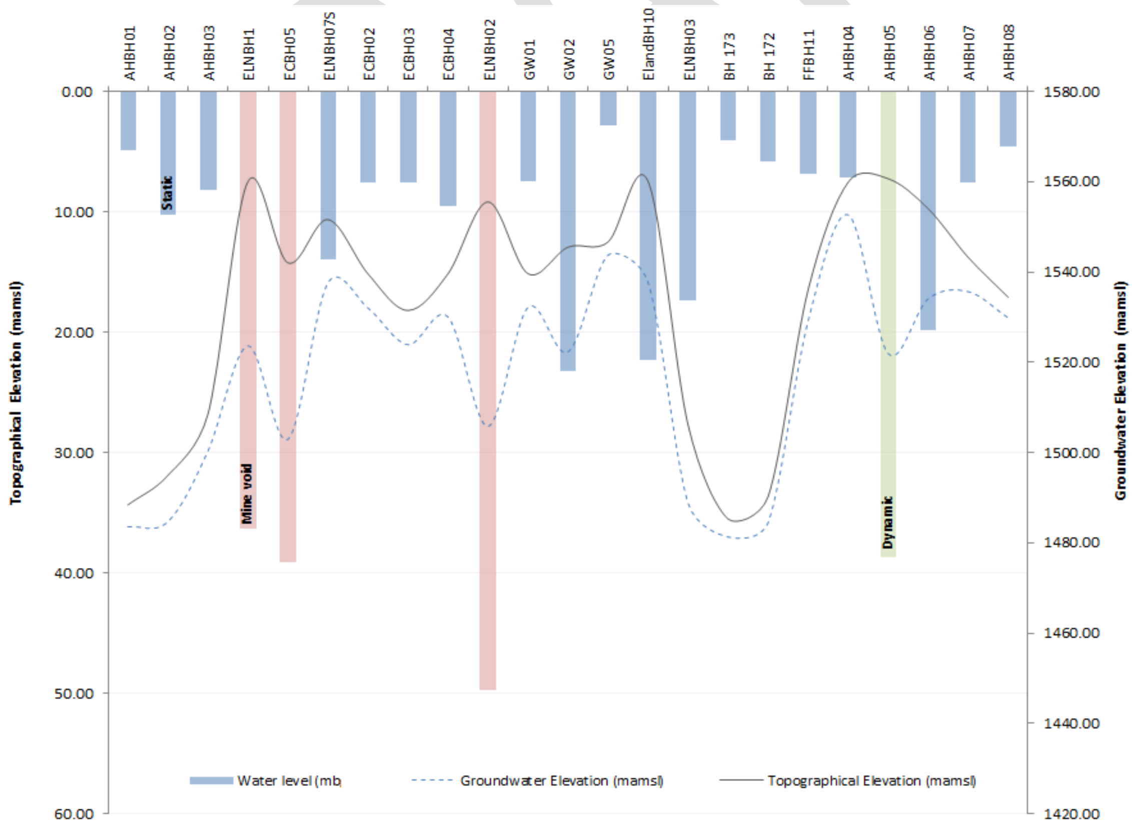


Figure 7-1 Topographical elevation vs. groundwater elevation correlation graph.

[6] This is based on all static groundwater levels measured at surveyed boreholes.

[7] It should be noted that static water levels in excess of ~35.0 mbgl measured within the mining footprints are assumed to enter historical mine voids. Hydrochemistry analysis also confirm this assumption.

Table 7-1 Regional water level summary[8].

Site ID	Topographical Elevation (mamsl)	Water level (mbgl)	Groundwater Elevation (mamsl)	Water level status
AHBH01	1488.41	4.85	1483.56	Static
AHBH02	1494.94	10.29	1484.65	Static
AHBH03	1508.46	8.18	1500.28	Static
ELNBH1	1559.92	36.31	1523.61	Shaft
ECBH05	1541.99	39.07	1502.92	Shaft
ELNBH07S	1551.57	13.98	1537.59	Static
ECBH02	1539.57	7.56	1532.01	Static
ECBH03	1531.45	7.57	1523.88	Static
ECBH04	1539.57	9.55	1530.02	Static
ELNBH02	1555.47	49.69	1505.78	Dynamic
GW01	1539.58	7.43	1532.15	Static
GW02	1545.46	23.19	1522.27	Dynamic
GW05	1546.62	2.85	1543.77	Static
ElandBH10	1559.99	22.33	1537.66	Static
ELNBH03	1506.10	17.34	1488.76	Static
BH 173	1485.29	4.02	1481.27	Static
BH 172	1490.29	5.78	1484.51	Static
FFBH11	1536.04	6.81	1529.23	Static
AHBH04	1559.84	7.18	1552.66	Static
AHBH05	1560.58	38.68	1521.90	Dynamic
AHBH06	1553.95	19.89	1534.06	Dynamic
AHBH07	1543.18	7.54	1535.64	Static
AHBH08	1534.39	4.58	1529.81	Static
Harmonic mean	**1533.20**	**4.98**	**1517.87**	
Minimum	**1485.29**	**2.85**	**1481.27**	
Maximum	**1560.58**	**49.69**	**1552.66**	
Standard deviation	**24.45**	**13.12**	**21.29**	
Correlation		**0.84**		

[8] Correlation factor calculated by accounting for all water levels measured on-site (static, dynamic and mine void water levels).

7.3. Groundwater flow direction and hydraulic gradients

Analysed data indicate that the regional groundwater elevation correlates moderately to the topographical elevation (R^2 ~ 0.84) suggesting a dynamic environment. However, water level data for the shallow aquifer indicate that the majority of levels correlate very well to the topographical elevation ($R^2 > 0.93$) (Figure 7-1). Accordingly, it can be assumed that the regional groundwater flow direction of the shallow aquifer is dictated by topography. Accordingly, the inferred groundwater flow direction of the shallow aquifer will be in a general southwestern direction towards the lower laying drainage system of the Grootspruit transecting the project area from where it will discharge as baseflow. On-site water levels of the underground mine void do not correlate well to topography and is a function of the coal seam floor contours historically mined.

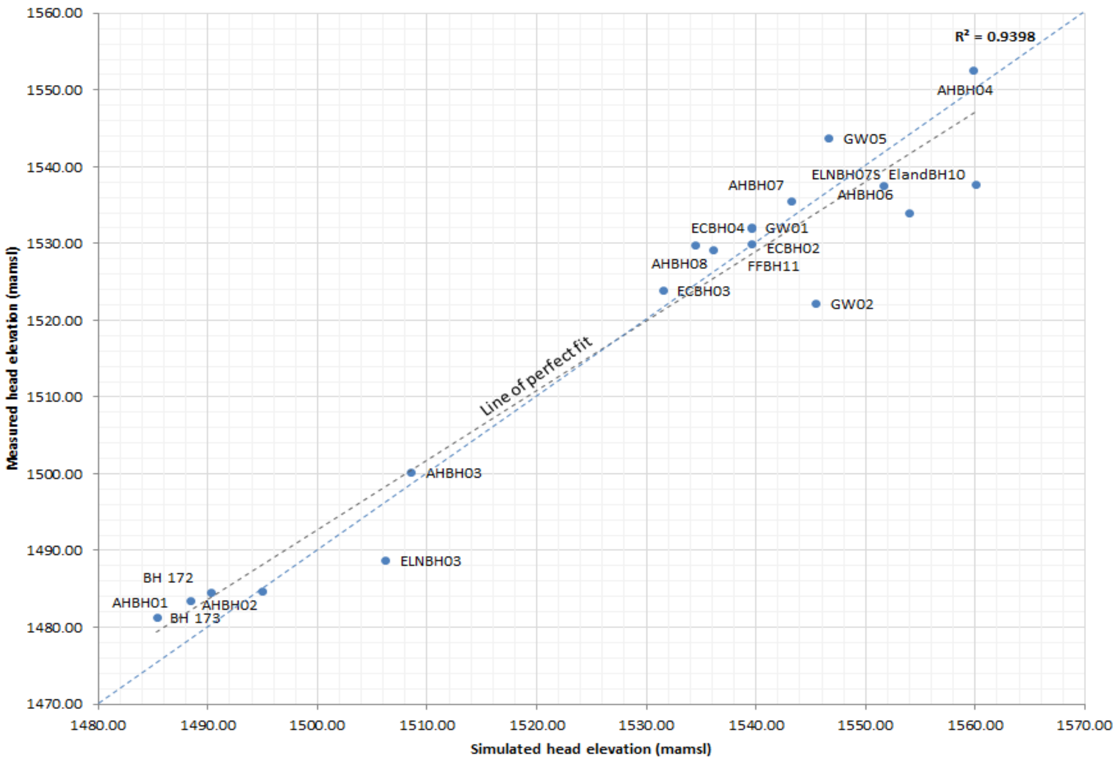


Figure 7-2 **Correlation between topography and groundwater elevation in the shallow aquifer (static WL).**

Groundwater flow path lines are lines perpendicular to groundwater contours, flow generally occurs faster where contours are closer together and gradients are thus steeper as depicted in Figure 7-3.The groundwater or hydraulic gradient is the change in the hydraulic head over a certain distance, mathematically it is the difference in hydraulic head over a distance along the flow path between two points. The latter provides an indication of the direction of groundwater flow. The following equation can be applied:

Equation 7-1 **Hydraulic gradient.**

$$i = \frac{dh}{dl}$$

where:

i = Hydraulic gradient (dimensionless).

dh = Is the head loss between two observation wells.

dL = Horizontal distance between two observation points.

The average groundwater gradient (i) of the shallow, weathered aquifer in the vicinity of the potential high-risk seepage areas i.e. mine discard dump and/or slurry ponds is moderately flat and calculated at approximately 0.004, with a maximum of 0.013 towards the west and southwest while a gentler gradient of -0.003 exists to the north as summarised in Table 7-2.

Table 7-2 Inferred groundwater gradient and seepage direction.

Inferred seepage direction	Hydraulic gradient (i)
South	0.013
East	-0.005
West	0.011
North	-0.003
Minimum	**-0.005**
Maximum	**0.013**
Standard deviation	**0.008**
Geometric Mean	**0.004**

7.4. Darcy flux and groundwater flow velocity

The Darcy flux (or velocity) is a function of the hydraulic conductivity (K) and the hydraulic gradient as suggested by Equation 7-2 whereas the seepage velocity can be defined as the Darcy flux divided by the effective porosity[9] (Equation 7-3). This is also referred to as the average linear velocity and can be calculated by applying the following equations (Fetter 1994).

Equation 7-2 Darcy flux.

$$v = Ki$$

Equation 7-3 Seepage velocity.

$$v = \frac{Ki}{ø}$$

where:

v = flow velocity (m/d).

K = hydraulic conductivity (m/d).

i = hydraulic gradient (dimensionless).

ø = effective porosity.

[9] It should be noted that effective porosity percentages have been assumed and in situ tests have not been conducted to confirm these ratios.

The expected seepage rate from contamination originating at the discard dump is estimated at an average of 0.48 m/a, with a maximum distance of 2.37 m/a in a southern to southwestern direction as summarized in Table 7-3[10].

Table 7-3 Darcy flux and seepage rates.

Shallow, weathered aquifer	Hydraulic gradient (i)	Hydraulic conductivity (K)	Darcy flux (m/d)	Effective porosity	Seepage velocity (m/d)	Seepage velocity (m/a)
South	0.013	0.050	0.001	0.100	0.007	2.373
East	0.005	0.050	0.000	0.100	0.002	0.890
West	0.011	0.050	0.001	0.100	0.005	1.986
North	0.003	0.050	0.000	0.100	0.001	0.476
Minimum	**0.003**	**0.050**	**0.000**	**0.100**	**0.001**	**0.476**
Maximum	**0.013**	**0.050**	**0.001**	**0.100**	**0.007**	**2.373**
Standard deviation	**0.004**	**0.000**	**0.000**	**0.000**	**0.002**	**0.774**
Harmonic Mean	**0.005**	**0.050**	**0.000**	**0.100**	**0.003**	**0.964**

[10] This estimate does however not take into account all known or suspected zones in the aquifer like preferential flow paths formed by faults and fracture zones or igneous contact zones like the intrusive dykes that have higher transmissivities than the general aquifer matrix. Such structures may cause flow velocities to increase several meters or even tens of meters per year under steady state conditions. Under stressed conditions such as at groundwater abstraction areas the seepage velocities could increase another order of magnitude.

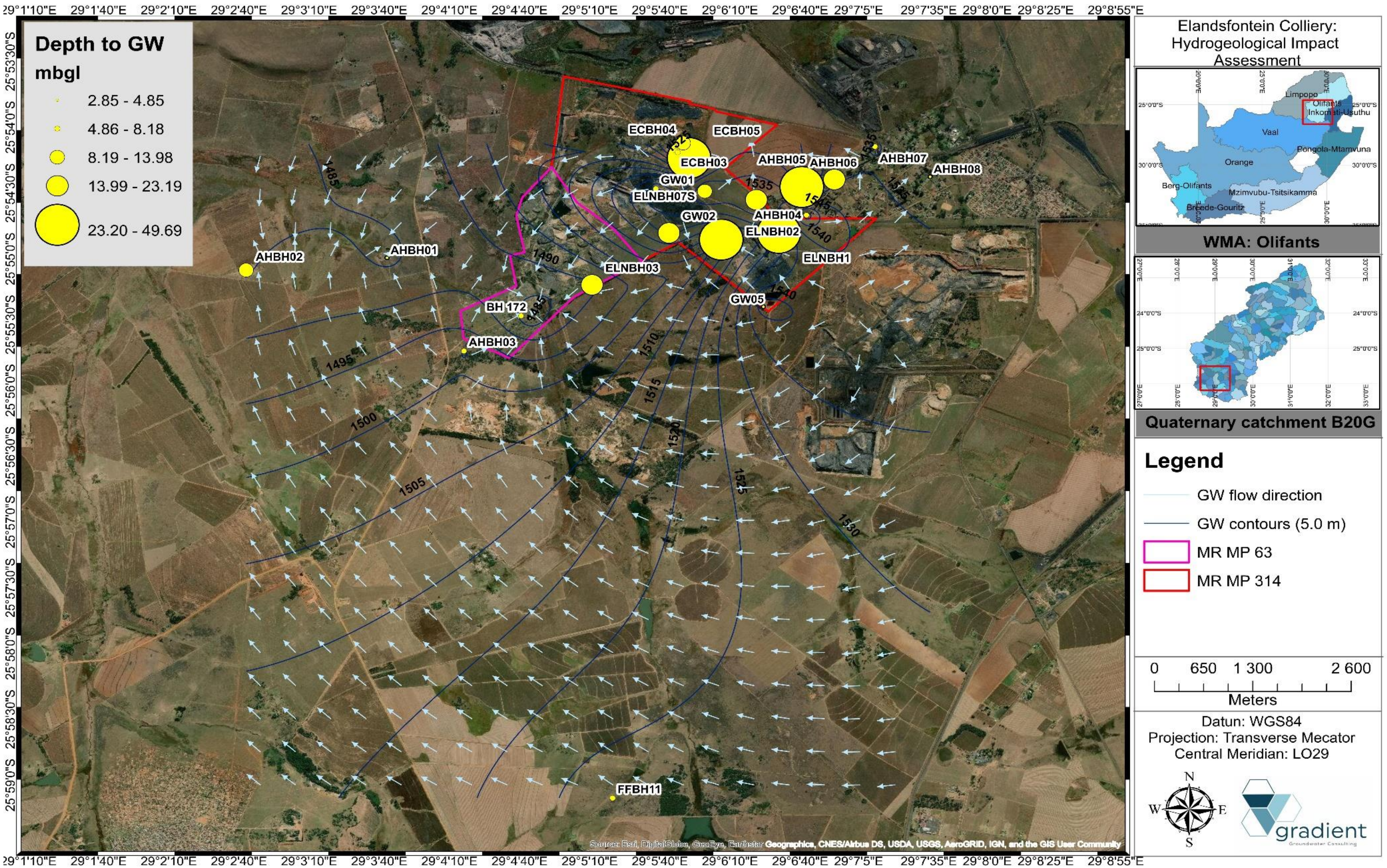


Figure 7-3 **Regional groundwater flow direction and depth to groundwater.**

8. HYDROCHEMISTRY

8.1. Water quality analysis

The South African National Standards (SANS 241: 2015) have been applied to assess the water quality within the project area. The standards specify a maximum limit based on associated risks for constituents (Refer to Table 8-1). Water samples were submitted for analysis at a SANAS accredited laboratory for inorganic analysis. Parameters exceeding the stipulated SANS 241:2015 thresholds are highlighted in red (acute health), elemental concentrations above this range are classed as unsuitable for domestic consumption without treatment whereas yellow highlighted cells indicate parameters above aesthetic limits. These standards were selected for use as the current and future water uses in the area are primarily domestic application and/or livestock watering. Refer to Appendix B for laboratory analysis certificates.

Table 8-1 SANS 241:2015 risks associated with constituents occurring in water.

Risk	Effect
Aesthetic	Determinant that taints water with respect to taste, odour and colour and that does not pose an unacceptable health risk if present at concentration values exceeding the numerical limits specified.
Operational	Determinant that is essential for assessing the efficient operation of treatment systems and risks to infrastructure.
Acute Health – 1	Routinely quantifiable determinant that poses an immediate health risk if consumed with water at concentration values exceeding the numerical limits specified.
Acute Health – 2	Determinant that is presently not easily quantifiable and lacks information pertaining to viability and human infectivity which, however, does pose immediate unacceptable health risks if consumed with water at concentration values exceeding the numerical limits specified.
Chronic Health	Determinant that poses an unacceptable health risk if ingested over an extended period if present at concentration values exceeding the numerical limits specified.

Table 8-2 SANS 241:2015 physical aesthetic, operational and chemical parameters.

Parameter	Risk	Unit	Standard limits [a]
Physical and aesthetic determinants			
Electrical conductivity (EC)	Aesthetic	mS/m	≤170
Total Dissolved Solids (TDS)	Aesthetic	mg/l	≤1200
Turbidity [b]	Operational	NTU	≤1
	Aesthetic	NTU	≤5
pH [c]	Operational	pH units	≥5 to ≤9,7
Chemical determinants – macro			
Nitrate as N[d]	Acute health	mg/l	≤11
Sulphate as SO_4^{-2}	Acute health	mg/l	≤500
	Aesthetic	mg/l	≤250
Fluoride as F	Chronic health	mg/l	≤1.5
Ammonia as N	Aesthetic	mg/l	≤1.5
Chloride as Cl^-	Aesthetic	mg/l	≤300
Sodium as Na	Aesthetic	mg/l	≤200
Zinc as Zn	Aesthetic	mg/l	≤5
Chemical determinants – micro			
Antimony as Sb	Chronic health	mg/l	≤0.02
Arsenic as As	Chronic health	mg/l	≤0.010
Cadmium as Cd	Chronic health	mg/l	≤0.003
Total chromium as Cr	Chronic health	mg/l	≤0.050
Copper as Cu	Chronic health	mg/l	≤2.0
Iron as Fe	Chronic health	mg/l	≤2.0

Parameter	Risk	Unit	Standard limits [a]
	Aesthetic	mg/l	≤0.30
Lead as Pb	Chronic health	mg/l	≤0.010
Manganese as Mn	Chronic health	mg/l	≤0.50
	Aesthetic	mg/l	≤0.10
Mercury as Hg	Chronic health	mg/l	≤0.006
Nickel as Ni	Chronic health	mg/l	≤0.07
Selenium as Se	Chronic health	mg/l	≤0.010
Uranium as U	Chronic health	mg/l	≤0.015
Vanadium as V	Chronic health	mg/l	≤0.2
Aluminium as Al	Operational	mg/l	≤0.3

a The health-related standards are based on the consumption of 2 L of water per day by a person of a mass of 60 kg over a period of 70 years.

b Values in excess of those given in column 4 may negatively impact disinfection.

c Low pH values can result in structural problems in the distribution system.

d This is equivalent to nitrate at 50 mg/l NO_3^-.

8.2. Data validation

The laboratory precision was validated by employing the plausibility of the chemical analysis, electro neutrality (E.N.) which is determined according to Equation 8-1, below. An error of less than 5% is an indication that the analysis results are of suitable precision for further evaluation. All samples analysed indicate a good plausibility and data can be considered as accurate and correct (Table 8-3).

Equation 8-1 Electro-neutrality.

$$E.N. = \frac{\sum cations \left[\frac{meq}{L}\right] + \sum anions \left[\frac{meq}{L}\right]}{\sum cations \left[\frac{meq}{L}\right] - \sum anions \left[\frac{meq}{L}\right]} .100\% < 5.0\%$$

Table 8-3 Laboratory precision and data validity.

Sample Localities	Σ Major cations (meq/l)	Σ Major anions (meq/l)	Electro-Neutrality [E.N.] %
ASW 01	32.70	32.96	-0.40%
AHBH 01	1.23	1.28	-2.02%
AHBH 02	4.71	4.79	-0.85%
AHBH 03	2.07	2.17	-2.52%
AHBH 04	2.00	2.00	0.09%
AHBH 05	0.84	0.84	-0.11%
AHBH 06	0.49	0.50	-0.96%
AHBH 07	0.84	0.86	-0.89%
ELN BH 01	1.03	1.09	-2.87%
ELN BH 03	28.68	29.05	-0.64%
ELN BH 07	0.46	0.48	-2.11%
ECBH 02	4.97	5.15	-1.75%
ECBH 03	30.38	32.47	-3.31%
ECBH 04	7.99	8.12	-0.80%
ECBH 05	1.52	1.61	-2.97%
BH172	16.09	15.97	0.36%
BH173	1.29	1.23	2.23%
ASW 02	7.40	7.46	-0.40%
FFBH 11	11.01	11.06	-0.20%

Note: E.N. < 5.0% generally reflect an accurate laboratory analysis.

In order to assess future impacts of the proposed mining expansion activities on the groundwater regime, it is necessary to develop a baseline for groundwater prior to onset. The following section serves to characterise ambient groundwater conditions and develop a relevant baseline for future reference. Table 8-4, Table 8-5 as well as Table 8-6 below classify water quality according to pH, Total Dissolved Solids (TDS) as well as total hardness.

Table 8-4 Hydrochemical classification according to pH-values.

pH Values used to indicate alkalinity or acidity of water	
pH: > 8.5	Alkaline/Basic
pH: 6.0- 8.5	Neutral
pH: < 6	Acidic

Table 8-5 Hydrochemical classification according to salinity.

TDS Concentrations to indicate the salinity of water	
TDS < 450 mg/l	Non-saline
TDS 450 - 1 000 mg/l	Saline
TDS 1 000 - 2 400 mg/l	Very saline
TDS 2 400 - 3 400 mg/l	Extremely saline

Table 8-6 Hydrochemical classification according to hardness.

Hardness concentrations to indicate softness or hardness of water	
Hardness < 50 mg/l	Soft
Hardness 50 – 100 mg/l	Moderately soft
Hardness 100 – 150 mg/l	Slightly hard
Hardness 150 – 200 mg/l	Moderately hard
Hardness 200 – 300 mg/l	Hard
Hardness 300 – 600 mg/l	Very hard
Hardness > 600mg/l	Extremely hard

8.3. Groundwater quality

The overall ambient groundwater quality of the shallow aquifer is good with the majority of macro and micro determinants below the SANS 241:2015 limits. Isolated sampling localities indicate above limits ammonium (NH4) concentrations which may suggest nearby anthropogenic activities.

The local groundwater quality is indicative of an impacted groundwater system and suggest coal mine pollution and acid mine drainage (AMD) conditions present. The latter is characterised by a low pH environment increasing the solubility and concentrations of metals i.e. usually aluminum, iron and manganese. Leaching from mined out faces as well as other waste facilities i.e. discard dumps containing carbonaceous material and sulphides will allow for oxidation and hydration resulting in the generation of acidity (H^+), sulphates (SO_4^{2-}) and ferric (Fe^{3+}) and ferrous (Fe^{2+}) iron species and the movement of other conservative contaminants with groundwater in a downgradient direction from the source.

8.4. Surface water quality

The overall water quality of the upstream surface water samples is poor due to elevated levels of sulphate as well as heavy metals (Fe, Al and Mn) i.e. coal mine pollution indicators. The downstream water quality is unacceptable due to highly elevated levels of sulphate as well as heavy metals (Fe, Al and Mn) causing high salt loads. There is a definite deterioration of water quality evident in a downstream direction and suggest contaminated water ingress from potentially mine decant and interflow zones. Figure 8-1 depicts a bar-chart of major anion and cation composition while Figure 8-2 indicate a spatial distribution map of major anion and cation composition per sample. To follow is a brief description of the water quality for each sample analysed as summarised in Table 8-7.

8.4.1. Surface water sampling locality ASW01

Water quality can be described as neutral, very saline and extremely hard:

- pH of 7.16.
- TDS of 2150.86 mg/l.
- Total Hardness ($CaCO_3$/l) of 1500.02 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- EC of 239.0 mS/m.
- TDS of 2150.86 mg/l.
- SO_4 of 1529.17 mg/l.
- Al of 6.60 mg/l.
- Mn of 8.14 mg/l.

8.4.2. Surface water sampling locality ASW02

Water quality can be described as neutral, saline and very hard:

- pH of 7.09.
- TDS of 487.86 mg/l.
- Total Hardness ($CaCO_3$/l) of 327.74 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- SO_4 of 349.0 mg/l.
- Al of 1.52 mg/l.
- Fe of 0.80 mg/l.
- Mn of 4.52 mg/l.

8.4.3. Groundwater sampling locality ABHB01

Water quality can be described as neutral, non-saline and soft:

- pH of 7.09.
- TDS of 487.86 mg/l.
- Total Hardness ($CaCO_3$/l) of 327.74 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.4.4. Groundwater sampling locality ABHB02

Water quality can be described as neutral, non-saline and slightly hard:

- pH of 7.44.
- TDS of 248.46 mg/l.
- Total Hardness ($CaCO_3$/l) of 119.43 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- F of 1.91 mg/l.

8.4.5. Groundwater sampling locality ABHB03

Water quality can be described as acidic, non-saline and moderately soft:

- pH of 5.71.

- TDS of 108.69 mg/l.
- Total Hardness ($CaCO_3$/l) of 73.95 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.4.6. Groundwater sampling locality ABHB04

Water quality can be described as acidic, non-saline and soft:

- pH of 5.68.
- TDS of 137.83 mg/l.
- Total Hardness ($CaCO_3$/l) of 48.79 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.4.7. Groundwater sampling locality ABHB05

Water quality can be described as acidic, non-saline and soft:

- pH of 5.45.
- TDS of 58.86 mg/l.
- Total Hardness ($CaCO_3$/l) of 24.83 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.4.8. Groundwater sampling locality ABHB06

Water quality can be described as acidic, non-saline and soft:

- pH of 5.90.
- TDS of 34.62 mg/l.
- Total Hardness ($CaCO_3$/l) of 14.66 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.4.9. Groundwater sampling locality AHBH07

Water quality can be described as neutral, non-saline and soft:

- pH of 6.49.
- TDS of 48.94 mg/l.
- Total Hardness (CaCO3/l) of 17.94 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- Mn of 0.14 mg/l.

8.4.10. Groundwater sampling locality ELNBH01

Water quality can be described as acidic, non-saline and soft:

- pH of 2.90.
- TDS of 59.73 mg/l.
- Total Hardness (CaCO3/l) of 36.99 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- pH of 2.90.

8.4.11. Groundwater sampling locality ELNBH03

Water quality can be described as acidic, very saline and extremely hard:

- pH of 5.17.
- TDS of 1832.71 mg/l.
- Total Hardness (CaCO3/l) of 899.00 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- EC of 254.00 mS/m.
- TDS of 1832.71 mg/l.
- SO_4 of 1306.71 mg/l.
- F of 32.18 mg/l.
- Al of 31.20 mg/l.
- Fe of 8.11 mg/l.
- Mn of 105.00 mg/l.

8.4.12. Groundwater sampling locality ELNBH07

Water quality can be described as neutral, non-saline and soft:

- pH of 6.50.
- TDS of 33.96 mg/l.
- Total Hardness ($CaCO_3$/l) of 17.56 mg/l.

None of the chemical variable concentrations exceeded SANS 241-1: 2015.

8.4.13. Groundwater sampling locality ECBH02

Water quality can be described as neutral, non-saline and moderately hard:

- pH of 5.98.
- TDS of 333.37 mg/l.
- Total Hardness (CaCO3/l) of 174.80 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- NH_4 of 44.40 mg/l.

8.4.14. Groundwater sampling locality ECBH03

Water quality can be described as acidic, very saline and extremely hard:

- pH of 4.83.
- TDS of 2091.54 mg/l.
- Total Hardness (CaCO3/l) of 1469.39 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- pH 4.83.
- EC of 218.00 mS/m.
- TDS of 2091.54 mg/l.
- SO_4 of 1461.00 mg/l.
- Fe of 1.54 mg/l.
- Mn of 0.37 mg/l.

8.4.15. Groundwater sampling locality ECBH04

Water quality can be described as neutral, non-saline and very hard:

- pH of 5.06.
- TDS of 524.92 mg/l.
- Total Hardness (CaCO3/l) of 359.12 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- SO_4 of 371.74 mg/l.
- Al of 1.07 mg/l.
- Fe of 1.16 mg/l.
- Mn of 2.02 mg/l.

8.4.16. Groundwater sampling locality ECBH05

Water quality can be described as acidic, non-saline and moderately soft:

- pH of 3.07
- TDS of 105.62 mg/l.
- Total Hardness (CaCO3/l) of 70.39 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- pH of 3.07

8.4.17. Groundwater sampling locality BH172

Water quality can be described as neutral, very saline and very hard:

- pH of 6.39.
- TDS of 1023.88 mg/l.
- Total Hardness (CaCO3/l) of 529.39 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- SO_4 of 733.86 mg/l.
- F of 12.31 mg/l.
- Al of 20.10 mg/l.
- Fe of 43.40 mg/l.
- Mn of 13.00 mg/l.

8.4.18. Groundwater sampling locality BH173

Water quality can be described as acidic, non-saline and soft:

- pH of 3.25.
- TDS of 76.49 mg/l.
- Total Hardness (CaCO3/l) of 48.54 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- pH of 3.25.
- F of 2.91 mg/l.

8.4.19. Groundwater sampling locality FFBH11

Water quality can be described as alkaline, saline and moderately hard:

- pH of 8.75.
- TDS of 741.57 mg/l.
- Total Hardness (CaCO3/l) of 152.19 mg/l.

The following chemical variable concentrations exceeded SANS 241-1: 2015:

- SO_4 of 362.00 mg/l.
- Mn of 0.15 mg/l.

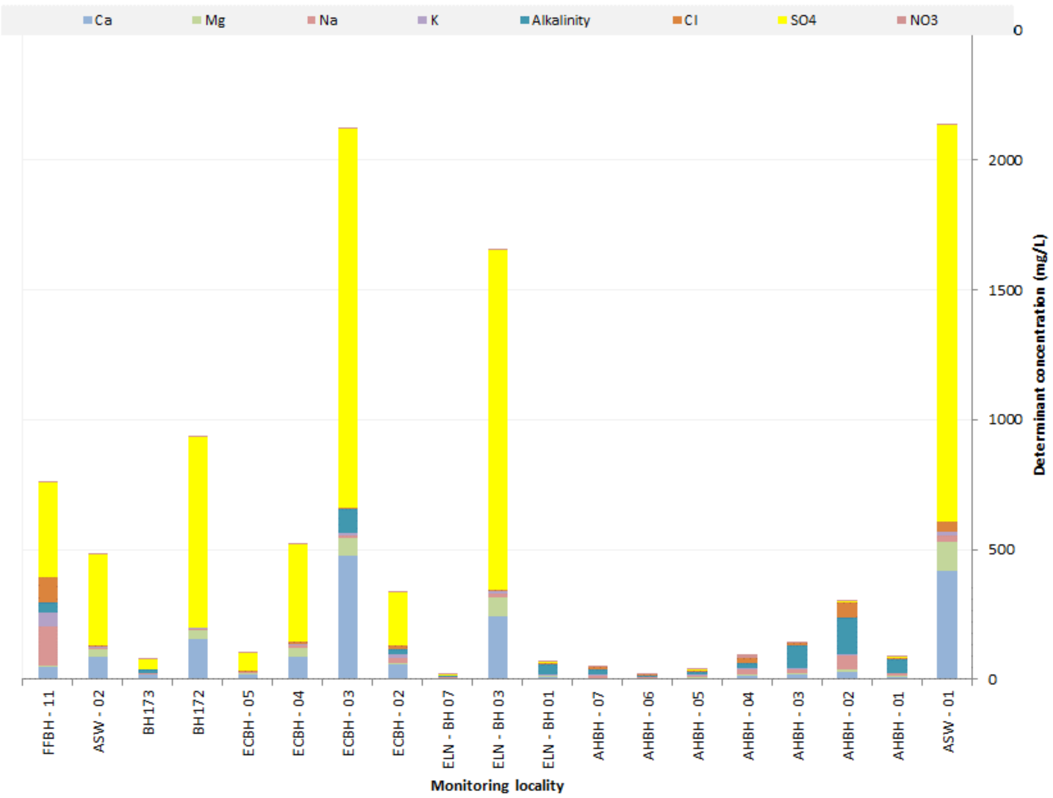


Figure 8-1 Hydrochemistry: Composite bar-chart indicating sample major anion cation composition (mg/l).

Table 8-7 Hydrochemistry: Hydroccensus user survey geosite water quality evaluation (SANS 241:2015).

Determinant	Unit	Risk	SANS 241:2015 limits	ASW 01	ASW 02	AHBH 01	AHBH 02	AHBH 03	AHBH 04	AHBH 05	AHBH 06	AHBH 07	ELN BH01	ELN BH03	ELN BH07	ECBH 02	ECBH 03	ECBH 04	ECBH 05	BH172	BH173	FFBH 11
General parameters																						
pH	-	Operational	≥5.0 ≤ 9.5	7.16	7.09	7.57	7.44	5.71	5.68	5.45	5.90	6.49	2.90	5.17	6.50	5.98	4.83	5.06	3.07	6.39	3.25	8.75
EC	mS/m	Aesthetic	≤170.0	239.00	91.40	12.76	47.80	21.40	22.10	10.90	6.46	10.40	12.10	254.00	5.56	52.20	218.00	80.00	18.00	169.00	14.70	119.00
TDS		Aesthetic	≤ 1 200.0	2150.86	487.86	63.01	248.46	108.69	137.83	58.86	34.62	48.94	59.73	1832.71	33.96	333.37	2091.54	524.92	105.62	1023.88	76.49	741.57
Total Alkalinity	CaCO3/l	-	-	0.00	0.00	55.60	141.00	91.80	18.00	7.60	5.80	20.60	38.00	0.00	3.20	19.80	90.20	2.60	2.80	0.00	11.20	38.20
Total Hardness	mg/l	-	-	1500.02	327.74	36.71	119.43	73.95	48.79	24.83	14.66	17.94	36.99	899.00	17.56	174.80	1469.39	359.12	70.39	529.39	48.54	152.19
Anions																						
Cl	mg/l	Aesthetic	≤300.0	38.65	5.42	3.60	59.90	6.90	20.94	8.09	3.09	10.63	2.97	4.49	2.24	14.13	5.83	8.85	1.10	1.16	1.55	96.30
SO_4	mg/l	Acute health	≤250.0	1529.17	349.00	2.49	7.63	2.78	1.85	2.43	0.68	1.16	5.95	1306.71	3.05	205.00	1461.00	371.74	68.10	733.86	38.90	362.00
F	mg/l	Acute health	≤1.50	<0.09	0.58	0.21	1.91	1.03	0.09	<0.09	0.10	<0.09	0.18	32.18	0.11	1.47	0.52	0.51	0.09	12.31	2.91	<0.09
NO_3< N	mg/l	Acute health	≤11.0	<0.35	<0.35	<0.35	<0.35	0.40	13.91	5.65	3.80	1.59	1.51	<0.35	3.93	<0.35	0.46	0.66	1.44	<0.35	<0.35	<0.35
PO_4	mg/l	-	-	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.05	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Cations and metals																						
NH_4	mg/l	Aesthetic	≤1.50	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	<0.45	3.05	<0.45	4.44	0.82	<0.45	<0.45	0.63	<0.45	0.62
Na	mg/l	Aesthetic	≤200.0	28.00	8.13	10.41	51.60	10.60	19.92	3.83	2.92	9.93	3.17	17.07	1.58	20.04	11.30	8.92	1.50	6.06	5.30	150.00
K	mg/l	-	-	12.10	3.21	1.08	2.52	4.63	5.81	6.61	2.49	1.76	5.52	9.74	1.36	10.50	9.96	5.07	1.34	4.18	2.45	54.10
Ca	mg/l	-	-	416.26	89.15	7.13	28.70	20.10	12.40	5.77	3.71	3.59	8.73	243.78	5.12	56.10	475.00	86.10	20.90	153.54	16.76	46.60
Mg	mg/l	-	-	111.86	25.53	4.59	11.60	5.77	4.33	2.53	1.31	2.18	3.69	70.49	1.16	8.43	68.80	35.00	4.42	35.45	1.63	8.70
Al	mg/l	Operational	0.3	6.60	1.52	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	31.20	0.01	0.02	<0.01	1.07	0.05	20.10	0.14	<0.01
Fe	mg/l	Aesthetic	0.3	0.09	0.80	0.13	<0.01	0.03	<0.01	<0.01	<0.01	<0.01	0.02	105.00	<0.01	<0.01	1.54	1.16	<0.01	43.40	0.06	<0.01
Mn	mg/l	Aesthetic	0.1	8.14	4.52	<0.01	<0.01	<0.01	0.09	0.01	0.01	0.14	<0.01	8.11	0.02	0.07	0.37	2.02	0.06	13.00	0.09	0.15

Note: "- " indicate that no limits have been provided by the SANS 2015:241 guidelines.
"< " indicate that results analysed are below the detection limits.
Shaded cells exceed SANS 241:2015 drinking water guidelines.

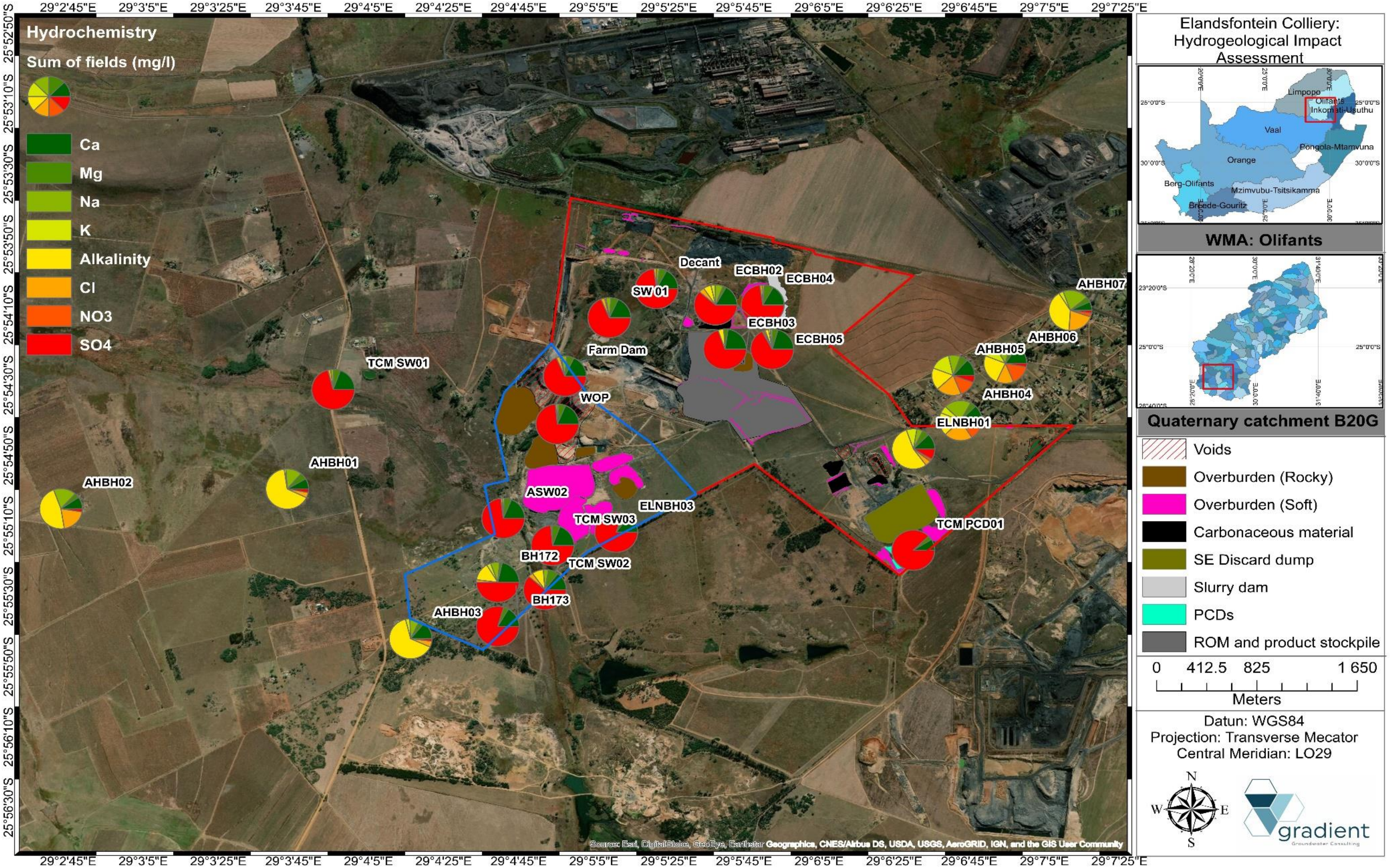


Figure 8-2 **Hydrochemical analysis spatial distribution (mg/l).**

8.5. Hydrochemical signature

The hydrochemical signature of the samples analysed were evaluated by means of diagnostic plots. The latter aid to get an understanding of various environments and sources from where groundwater and surface water originates. Three types of diagnostic plots were used to characterise analysed water samples based on hydrochemistry.

8.5.1. Piper diagrams

A piper diagram is a diagnostic representation of major anions and cations as separate ternary plots (Figure 8-3). Different water types derived from different environments plot in diagnostic areas. The upper half of the diamond normally contains water of static and disordinate regimes, while the middle area generally indicates an area of dissolution and mixing. The lower triangle of this diamond shape indicates an area of dynamic and coordinated regimes. Figure 8-4 depicts a piper diagram developed from the hydrocensus water quality analysis results. The majority of regional/ neighbouring boreholes suggest either a recently recharged and unimpacted water environment (Calsium-Bi-carbonate dominance), and/or area of dissolution and mixing, whereas current monitoring boreholes on site indicate a static and disordinate environment (Sulphate dominance suggesting impacts from coal mine pollution). Sampling locality FFBH11 indicate a Sodium-Chloride dominance suggesting brine waters.

8.5.2. Stiff diagrams

A Stiff diagram, or Stiff pattern, is a graphical representation of chemical analyses and major anions and cations, first developed by H.A. Stiff in 1951. STIFF diagrams plot the equivalent concentrations of major anions and cations on a horizontal scale on opposite sides of a vertical axis. The plot point of each parameter is linked to the adjacent point creating a polygon around the vertical axis. Water with similar major ion ratios will show similar geometries.

Figure 8-5 depicts Stiff diagrams compiled from the hydrocensus user survey sampling analysis. Groundwater sampling localities ECBH03, ELNBH03 correlate well to the hydrochemical signature of surface water sampling locality ASW01 and suggest similar water environments and potential origins.

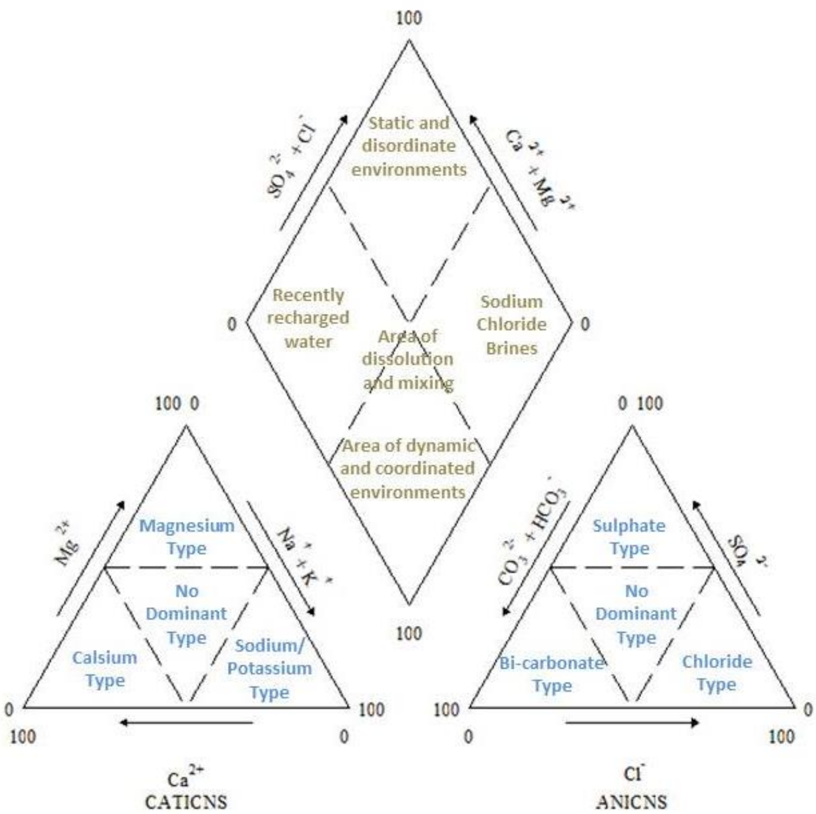


Figure 8-3 **Piper diagram indicating classification for anion and cation facies in terms of ion percentages.**

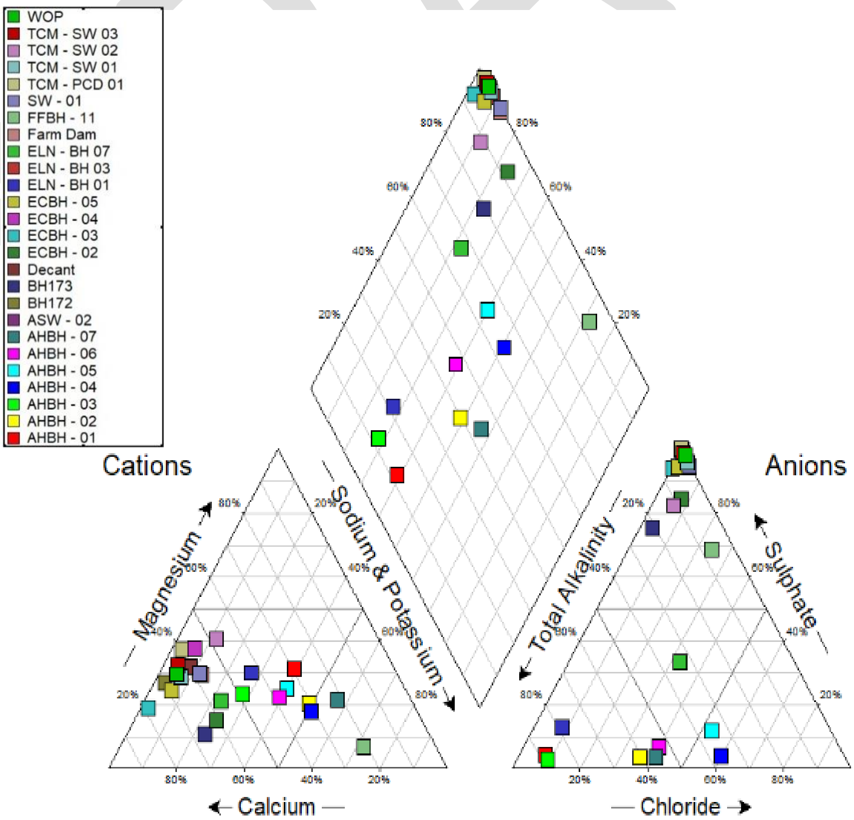


Figure 8-4 **Piper diagram indicating major anions and cations of hydrocnesus water samples.**

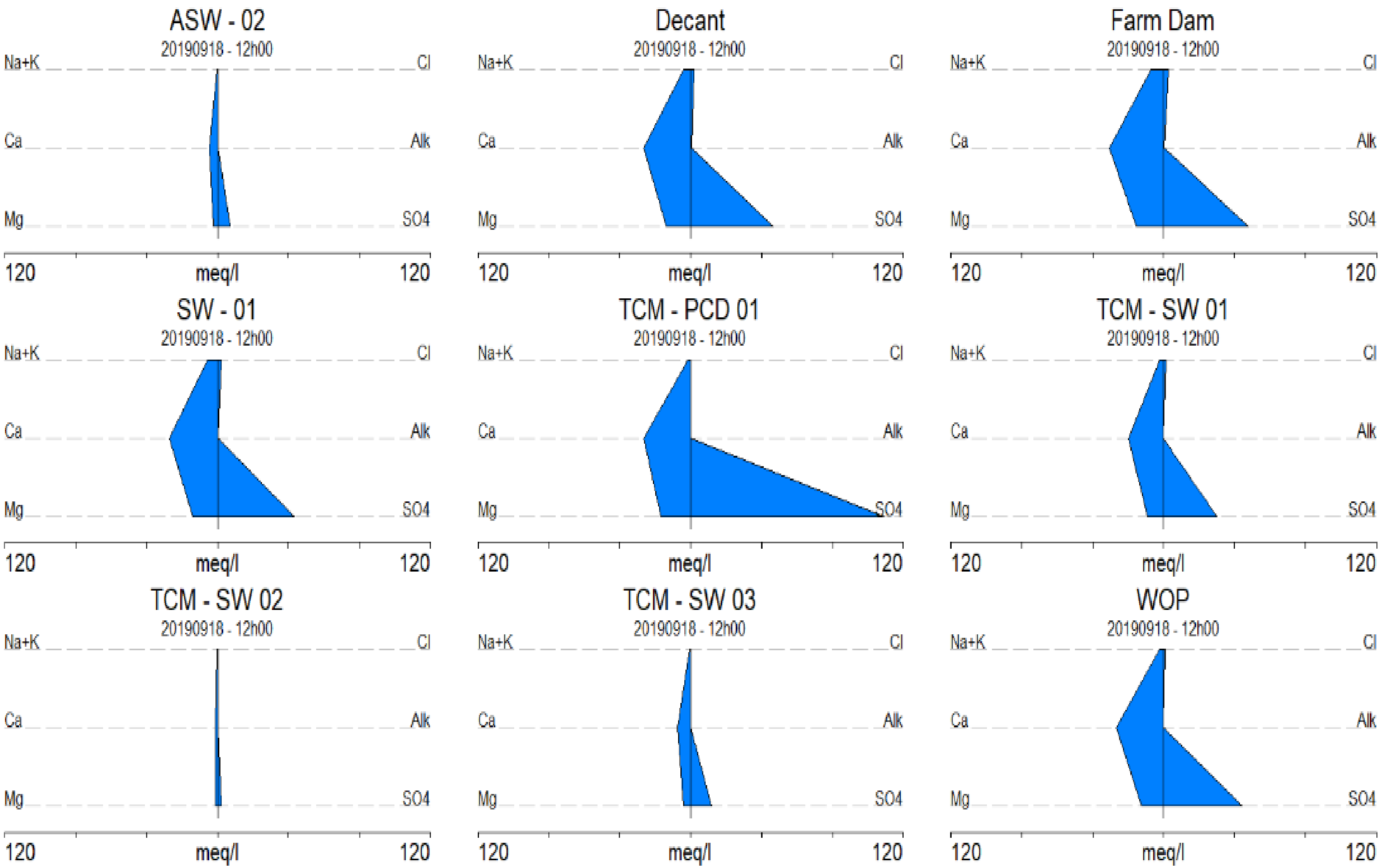


Figure 8-5 **Stiff diagrams representing hydrocenus sampling localities analysed.**

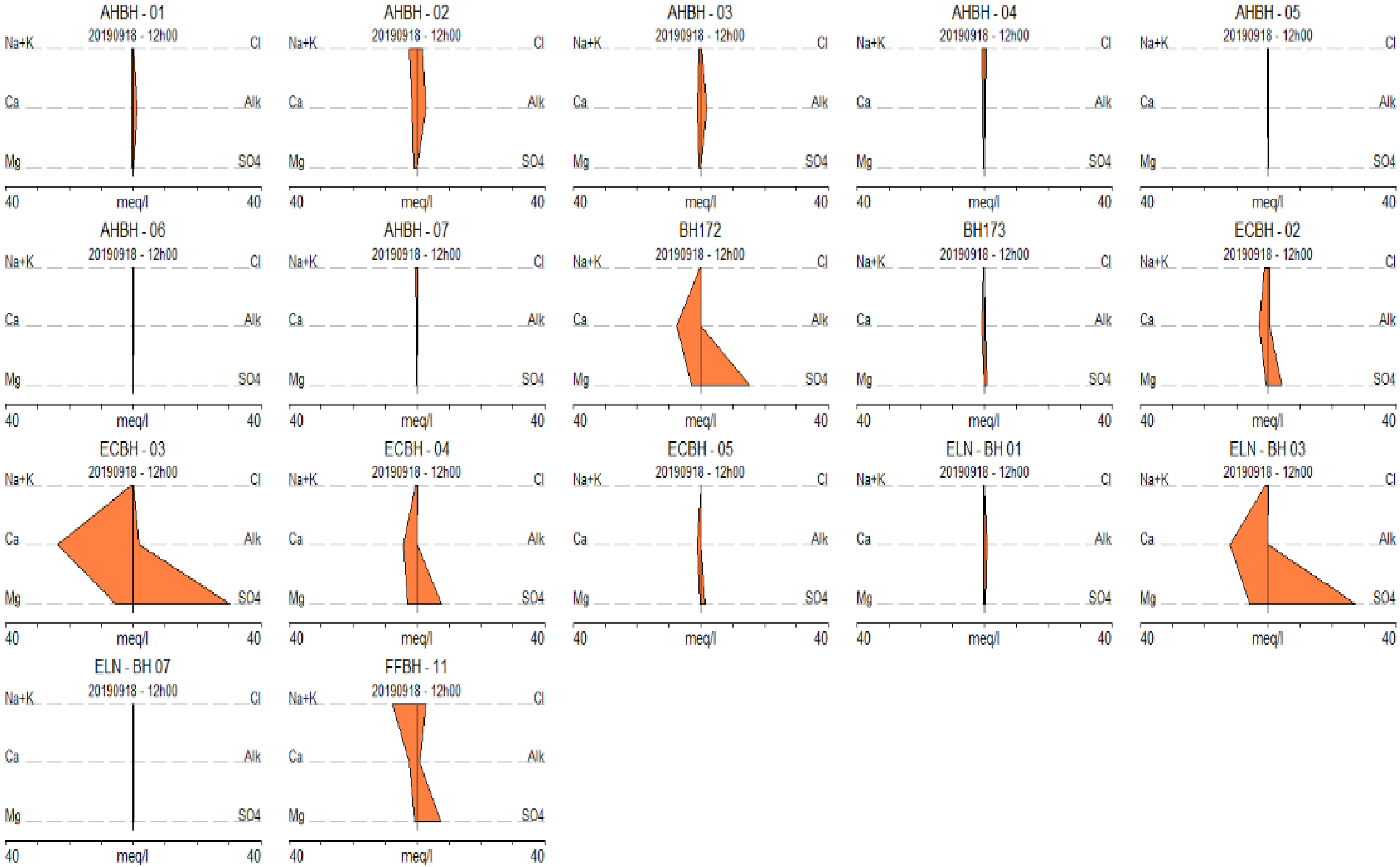


Figure 8-6 **Stiff diagrams representing hydrocenus sampling localities analysed.**

8.6. Expanded Durov diagram

The expanded Durov diagram is used to show hydrochemical processes occurring within different hydrogeological systems. Different fields of the diagram could be summarized as follows:

Field 01: Water (mostly fresh, clean and recently recharged) with HCO_3^- and CO_3 as dominant anion and Ca as dominant cation.

Field 02: Water (mostly fresh, clean, and relatively young) that also has an Mg signature, often found in dolomitic terrain.

Field 03: Often associated with Na ion exchange between groundwater and aquifer material (sometimes in Na-enriched granites or other felsic rocks) or because of contamination effects from a source rich in Na.

Field 04: Often associated with mining related SO_4 contamination.

Field 05: Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4 and NaCl mixing/contamination or old stagnant NaCl dominated water that has mixed with clean water.

Field 06: Groundwater from field 5 that has been contact with a source rich in Na or old stagnant NaCl dominated water that resides in Na rich host rock/material.

Field 07: Water rarely plots in this field that indicates NO_3 or Cl enrichment or dissolution.

Field 08: Groundwater that is usually a mix of different type, for example water from 2 that has undergone Cl mixing/contamination or old stagnant NaCl-dominated water that has mixed with water richer in Mg.

Field 09: Seawater or very old stagnant water that has reached the end of the geohydrological cycle (deserts, salty pans etc.), or water that has moved a long time and/or distance through the aquifer and has undergone significant ion exchange.

The majority of regional/ neighbouring groundwater samples can be classified as Field 02 i.e. mostly fresh, clean and relatively young with HCO_3^- and CO_3 dominance evident, whereas most of the on-site monitoring boreholes can be classified as Field 04 which can often be associated with mining related SO_4 contamination.

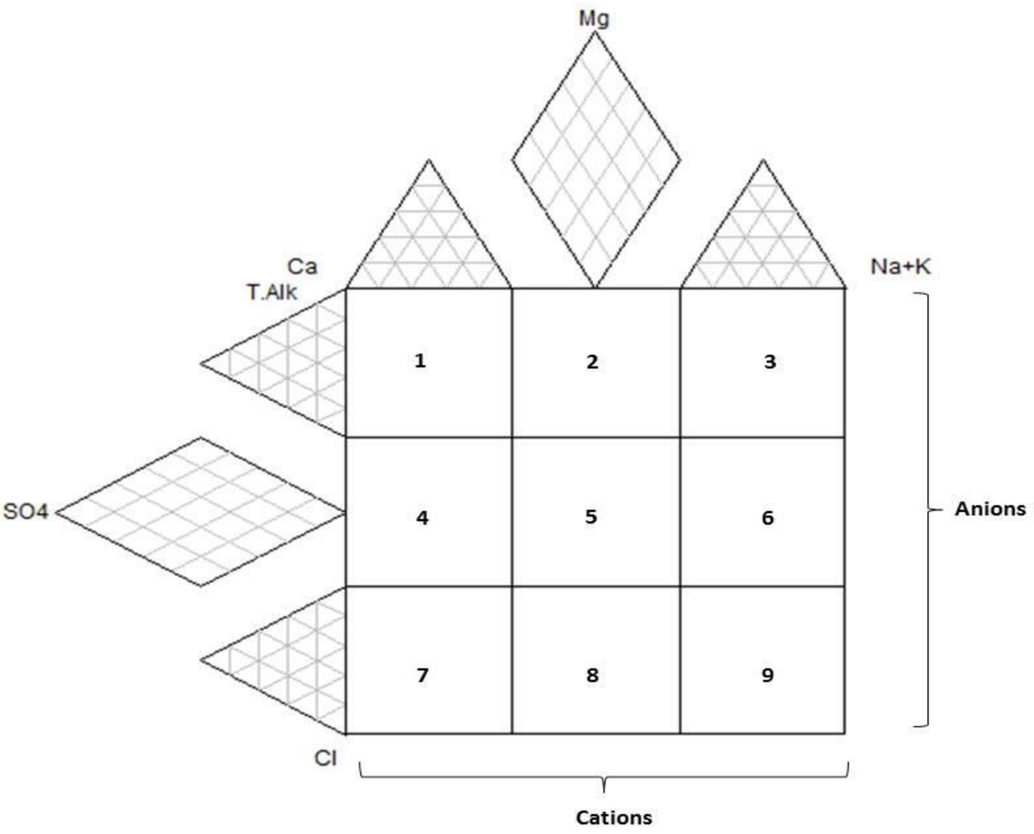


Figure 8-7 **Extended Durov diagram indicating major anions and cations.**

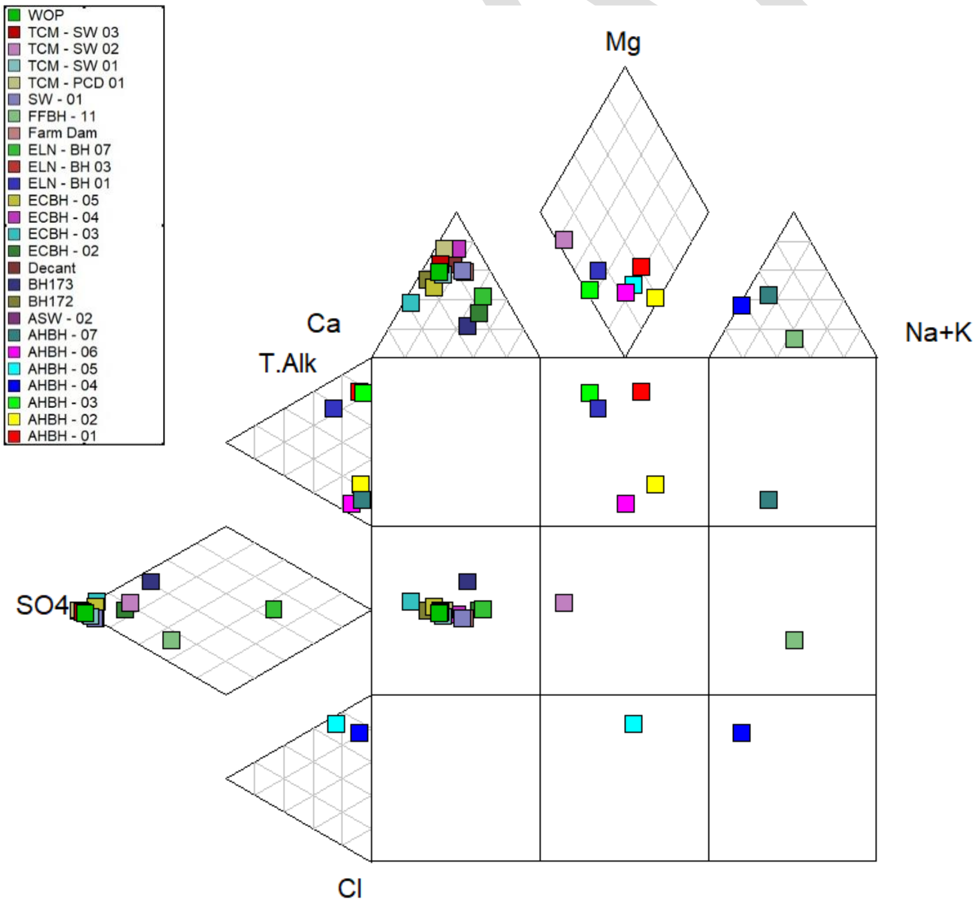


Figure 8-8 **Extended Durov diagram of surface water monitoring points.**

9. GEOCHEMISTRY

The primary objective of this geochemical assessment is to determine the chemical nature and character of the lithologies mined, evaluate its risk potential towards the receiving environment as well as indicate the long-term potential for Acid Rock Drainage (ARD) occurring. Geochemical characterisation in the form of Acid Base Accounting (ABA), Net-Acid Generation (NAG), Sulphur speciation as well as static leach tests was performed on gathered samples. Geochemical test methodologies applied are summarised in Table 9-12. Refer to Appendix F for laboratory results and certificates.

Table 9-1 Geochemical analysis test methodologies.

Test procedure	Objectives	Methodology
X-Ray diffraction (XRD)	Minor to dominant minerals present in rocks.	PANalytical Aeris diffractometer
X-Ray fluorescence (XRF)	Major oxides and trace elements present in rocks.	ASTM D4326-13
Acid-base accounting (ABA) test	Determine the balance between the acid production and acid consumption properties of a mine waste material.	ASTM D3987
Sulphur Speciation	To determine the sulphide content of samples analysed.	ASTM E1915-11.
Nett Acid Generation (NAG Tests)	To indicate the net potential for ARD after oxidation with hydrogen peroxide.	ASTM E1915-13.
Distilled water leach: Australian Standard Leaching, ICP-OES/MS	To determine chemicals of concern that may potentially leach from sample.	Based on ASTM D3987-12 with additional ICP-OES/MS and IC analysis.

9.1. Sampling

A total of four samples were collected for geochemical testing and analysis comprising various lithological units as well as coal stockpiles and discard material. Refer to Table 9-2 for a description of samples analysed as discussed below.

i. Sample ASS01 (Composite): Tailings sludge – sample collected at the existing slurry dam on site.

ii. Sample ASS13 (Composite): Coal product – representative of coal product and potential stockpile areas.

iii. Sample ASS15 (Composite): Sandstone, non-carbonaceous– representative of hanging wall, overburden and potential backfill material.

iv. Sample ASS16 (Composite)): Shale carbonaceous – representative of hanging wall, overburden and potential backfill material.

Table 9-2 Description of geochemical samples analysed.

Sample ID	Sample type	*	Test procedure	Description	Photo
ASS01	Composite		XRF, XRD, ABA, NAG, Sulphur speciation, Distilled water leach (DW 1:4/ TCLP)	Tailings sludge	
ASS13	Composite		XRF, XRD, ABA, NAG, Sulphur speciation, Distilled water leach (DW 1:4/ TCLP)	Coal	
ASS15	Composite		XRF, XRD, ABA, NAG, Sulphur speciation, Distilled water leach (TCLP)	Sandstone	
ASS16	Composite		XRF, XRD, ABA, NAG, Sulphur speciation, Distilled water leach (DW 1:4/TCLP)	Carbonaceous shale	

9.2. Minerology and total element analysis

The mineralogy and total element analysis of the samples was determined through X-Ray diffraction (XRD)[11]and X-Ray fluorescence (XRF) as discussed below.

9.2.1. XRD Analysis

The results from the XRD analyses of the minerals for the composite samples are presented in Table 9-3 and Table 9-4 . The following is noted:

i. The major mineral in the tailings sludge sample analysed (ASS01) is organic carbon (C) as well as kaolinite ($Al_2Si_2O_5(OH)_4$). Quartz ($Si0_2$) and gypsum ($CaSO_2$) is also present while trace amounts of microcline ($KAlSi_3O_8$) and muscovite ($KAl_2(AlSi_3O_{10})(OH,F)_2$ is observed.

ii. The coal product (ASS13) consist of relatively equal amounts of kaolinite ($Al_2Si_2O_5(OH)_4$) and organic carbon (C) Quartz ($Si0_2$) and pyrite (FeS_2) is also present with minor amounts of calcite, dolomite and muscovite observed.

iii. It should be noted that the presence of the sulphide mineral pyrite is observed in relatively small amounts in only the coal product, which may potentially form a main driver of acid rock drainage.

[11] It should be noted that the amorphous phases (carbonaceous minerals), if present, are not taken into account in the quantification. The results therefore reflect the proportion of minerals in the non-carbonaceous phases. The proportion of carbonaceous minerals can be derived from the loss on ignition (LOI) percentages included in the XRF results.

iv. As expected, the major mineral observed within the sandstone sample (ASS15) analysed is Quartz (SiO_2), followed by kaolinite ($Al_2Si_2O_5(OH)_4$) and microcline ($KAlSi_3O_8$). Trace amounts of dolomite and muscovite is also noted.

v. The carbonaceous shale sample (ASS16) analysed indicate that the major minerals present is kaolinite ($Al_2Si_2O_5(OH)_4$) and organic carbon. Microcline and quartz are also noted while trace amounts of dolomite, and muscovite is observed.

vi. It should be noted that the dolomite present in relatively small amounts in the sandstone as well as shale samples may contribute to the buffer capacity of the hanging wall/ overburden formations.

Table 9-3 Description of major minerals identified.

Mineral	*	Formula	Mineral type (Group)	Sub-group
Calcite		$CaCO_3$	Anhydrous Carbonates	Calcite group
Organic Carbon		C	Carbon	
Dolomite		$CaMgCO_3$	Anhydrous Carbonates	Dolomite group
Gypsum		Ca(sulphate).H_2O	Hydrated Sulphates	Gypsum
Microcline		$KAl_2Si_3O_8$	Tectosilicate	K-Feldspar subgroup
Kaolinite		$Al_2Si_2O_5(OH)_4$	Phyllosilicate	Clay mineral group
Muscovite		$KAl_2(AlSi_3O_{10})(OH,F)_2$	Phyllosilicate	Mica group
Quartz		SiO_2	Tectosilicate	Tectosilicate
Pyrite		FeS	Sulfides	Pyrite Group

Table 9-4 XRD Analyses of the composite samples.

Mineral	Chemical composition	Sample (weight %)			
		ASS01	ASS13	ASS15	ASS16
Calcite	$CaCO_3$	0.00	2.07	0.00	0.00
Dolomite	$CaMgCO_3$	0.00	0.46	0.15	0.19
Gypsum	$CaSO_4$	6.10	0.00	0.00	0.00
Kaolinite	$Al_2Si2O_5(OH)_4$	31.69	33.19	34.08	57.13
Microcline	$KAlSi_3O_8$	0.53	0.00	9.39	3.31
Muscovite	$KAl_2(AlSi_3O_{10})(OH,F)_2$	1.21	1.60	1.65	1.03
Quartz	SiO_2	8.27	16.10	54.74	5.67
Organic Carbon	C	52.20	38.99	0.00	32.66
Pyrite	FeS_2	0.00	7.59	0.00	0.00

9.2.2. XRF Analysis

The element specific concentrations were obtained from the XRF analyses as summarised in Table 9-5. Also referenced in Table 9-5 are the Alloway Crustal Abundance (ACU) concentrations of the particular elements. The latter provides an indication of the average abundance of an element in the earth's crust (Alloway *et al*, 1995). By calculating the ratio of the trace element concentrations to the average composition of the earth's crust (Crustal Abundances) an indication can be obtained whether the concentration of a particular element is raised above the average for the earth or enriched above the average due to some process. The comparison to the average Crustal Abundance is geochemically accepted as a means of highlighting elements, which may possibly be enriched in the various lithologies[12]. The following is noted:

vii. Silicon, expressed as silica (SiO_2), is dominant in terms of the major elements in all the samples,

[12] Although enrichment does not necessarily indicate that the element is likely to be an environmental risk, it does, however, indicate where attention should be focussed when assessing metal mobility/solubility.

followed by aluminium (III) oxide (Al_2O_3). Iron (III) oxide (Fe_2O_3) is also dominant in the tailings sludge and coal samples whereas potassium oxide (K_2O) and titanium (II) oxide (TiO_2) is dominant in the sandstone and carbonaceous shale samples respectively.

viii. The majority of samples analysed is slightly lower than the published ACU values with slightly elevated concentration for the following elements: aluminium (III) oxide (Al_2O_3) as well as phosphorus pentoxide (P_2O_5).

Table 9-5 XRF analysis and Major Element Concentrations

Element (%)	Major element concentration (wt %) [s]				**AUC
	ASS01	ASS13	ASS15	ASS16	
Fe_2O_3	6.49353	**16.98403**	1.57476	0.4919	11.2
SiO_2	52.09781	47.16675	**77.74978**	57.86764	66.6
Al_2O_3	**28.31056**	**21.45632**	**16.99827**	**37.40786**	15.4
K_2O	1.02563	0.47236	2.42148	1.55633	2.8
P_2O_5	**0.49971**	**0.42908**	0.05626	**0.31796**	0.15
Mn_3O_4	0.15679	0.06306	0.03672	<0.008	
CaO	**5.36366**	**5.7997**	<0.009	0.28384	3.59
MgO	0.57678	0.53627	0.13301	0.131	2.48
TiO_2	**1.85551**	**1.27456**	**0.78493**	**1.68793**	0.64
Na_2O	<0.010	<0.010	<0.010	<0.010	3.27
V_2O_5	0.03423	0.02084	0.01383	0.03662	
BaO	0.11846	0.06271	0.08026	0.08404	
Cr_2O_3	0.05435	0.02121	0.01855	0.03211	
SrO	0.11567	0.09781	0.02013	0.05185	
ZrO_2	0.08516	0.05972	0.06871	0.12737	
MnO	**0.14582**	0.04542	0.03415	<0.007	0.1
SO_3	3.8927	6.16458	0.11763	0.07656	
CuO	<0.010	<0.010	<0.010	<0.010	
PbO	0.01128	0.00655	0.01279	0.01186	
ZnO	0.02496	0.00823	0.01937	0.04404	
NiO	0.01947	0.00603	0.00982	0.00645	
Total XRF	**100.88**	**100.68**	**100.15**	**100.22**	

****AUC = Average Upper Crust (Rudnick and Gao, 2003)**
Shaded cells exceed AUC values.

9.3. Acid rock drainage

Acid rock drainage (ARD) (or acid mine drainage, AMD) is considered the most significant environmental issue related to mine waste management. As ARD has the potential to impact significantly on surface and groundwater quality, it is necessary to quantify the potential that waste material may have to generate ARD as part of the geochemical characterisation process.

Acid rock drainage is produced through the natural oxidation of sulfidic minerals by air and water, accelerated by bacterial action (*thiobacillus*); thus, exposed sulphide-bearing tailings/discard (and waste rock) are prone to ARD generation. Pyrite and pyrrhotite are the main ARD generating sulphide minerals and are found in many deposits associated with coal. The resulting acid leaches other heavy and toxic metals into the ARD (Weisener et al., 2003). Coal mining is associated with ARD and mining activities usually expose pyrite to oxidising agents such as oxygen and ferric iron (Fe^{3+}). During the oxidation process of sulphide ores, the sulphidic component (S^{2-}) in pyrite is oxidised to sulphate (SO_4^{2-}); acidity (H^+) is generated and ferrous iron (Fe^{2+}) ions are released.

The following reaction steps show the general accepted sequence of pyrite oxidation (Stumm and Morgan, 1996):

Acidity (H^+), ferrous iron (Fe^{2+}) and sulphate (SO_4) are released into the water when the mineral pyrite (FeS_2) is exposed to water and oxygen:

Reaction 1

$$FeS_2(s) + 3.5O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+$$

The highly soluble Fe^{2+} species oxidise to relatively insoluble ferric iron (Fe^{3+}) in the presence of oxygen – the reaction is slow but is increased by microbial activity:

Reaction 2.

$$Fe^{2+} + 0.25O_2 + H^+ \rightarrow Fe^{3+} + 0.5H_2O$$

Fe^{3+} is then hydrolysed by water (at pH >3) to form the insoluble precipitate ferrihydrite $Fe(OH)_3(s)$ (also known as yellow-boy) and more acidity:

Reaction 3.

$$Fe^{3+} + 3H_2O \rightarrow FeOH_3(s) + 3H^+$$

In addition to reacting directly with oxygen, pyrite may also be oxidised by dissolved Fe^{3+} to produce additional Fe^{2+} and acidity:

Reaction 4.

$$FeS_2(s) + 14Fe^{3+} \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+$$

Reaction 4 uses up all available Fe^{3+} and the reaction may cease unless more Fe^{3+} is made available (Appelo and Postma, 1999). Reaction 2, the reoxidation of Fe^{2+}, can sustain the pyrite oxidation cycle (Nordstrom and Alpers, 1999). The rate determining step is the oxidation of Fe^{2+} to Fe^{3+} (reaction 2), usually catalysed by autotrophic bacteria.

The overall reaction as given by Nordstrom and Alpers (1999) is:

Reaction 5.

$$FeS_2(s) + 3.75O_2 + 3.5H_2O \rightarrow Fe(OH)_2(s) + 2SO_4^{2-} + 4H^+$$

Leaching from carbonaceous material and sulphides will allow for oxidation and hydration resulting in the generation of acidity (H^+), sulphates (SO_4^{2-}) and ferric (Fe^{3+}) and ferrous (Fe^{2+}) iron species and the movement of other conservative contaminants with groundwater in a downgradient direction from the source. The resulting acidity will mobilise reactive metal contaminants which will create a pollution plume and can migrate in a downgradient direction polluting aquifers and surfacing at seepage points, contaminating surface waters along the way. Within wetland systems, oxidation of Fe^{2+} to Fe^{3+} will result in the precipitation of ferric hydroxide (FeOH), typically as a gel, which can coat the reactive surfaces of the plants and sediment, thereby greatly reducing the ability of the wetland to remove pollutants by adsorption. In addition, the high salt load is often toxic to aquatic life. Figure 9-1 provides a schematic summary of the different fields for mine drainage as plotted on a sulphate vs pH diagram.

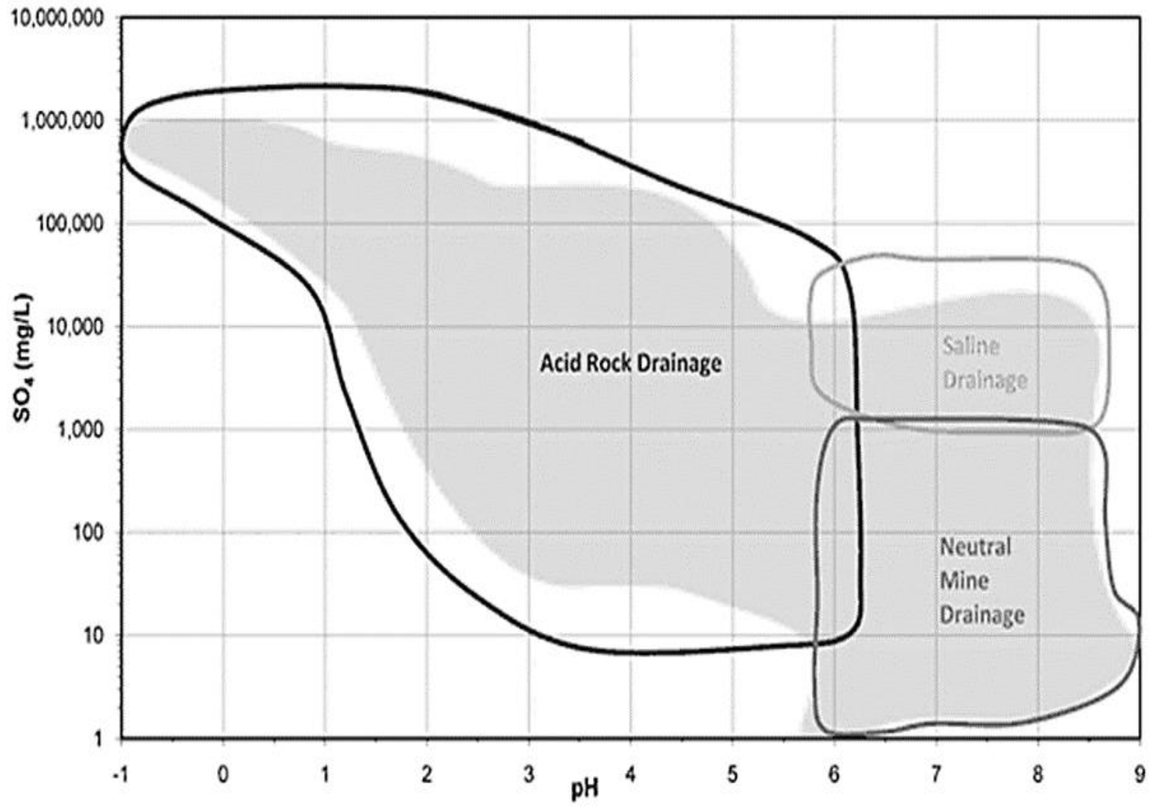


Figure 9-1 **Diagram showing mine drainage as a function of pH and sulfate (Plumlee et al., 1999).**

Figure 9-2 indicates a site conceptual geochemical model summarising the dynamics of ARD within the greater hydrogeological regime.

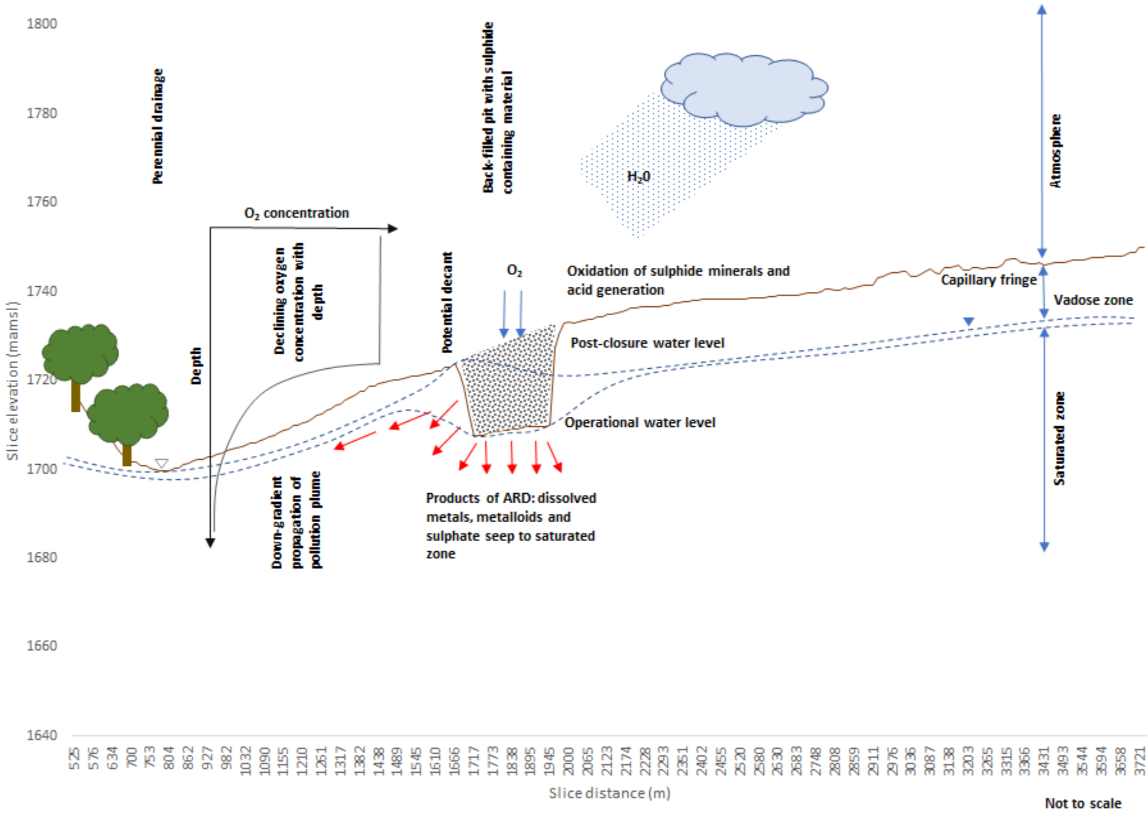


Figure 9-2 Conceptual geochemical model.

9.3.1. Acid Base Accounting

Acid-base accounting (ABA) is a static test where the net potential of the rock to produce acidic drainage is determined. The percentage sulphur (%S), the Acid Potential (AP), the Neutralization Potential (NP) as well as the Net Neutralization Potential (NNP) of the rock material are determined in this test and can be used as an important first order assessment of the potential leachate that could be expected from the rock material. To follow is a brief description of the different ABA components:

- If pyrite is the only sulphide in the rock, the AP (acid potential) is determined by multiplying the percentage sulphur (%S) with a factor of 31.25. The unit of AP is kg $CaCO_3$/t rock and indicates the theoretical amount of calcite neutralized by the acid produced.
- The NP (Neutralization Potential) is determined by treating a sample with a known excess of standardized hydrochloric or sulfuric acid (the sample and acid are heated to ensure reaction completion). The paste is then back titrated with standardized sodium hydroxide in order to determine the amount of unconsumed acid. NP is also expressed as kg $CaCO_3$/t rock as to represent the amount of calcite theoretically available to neutralize the acidic drainage.
- NNP is determined by subtracting AP from NP.

For the material to be classified in terms of their acid-rock drainage potential, the ABA results can be screened in terms of its NNP, %S and NP:AP ratio as follows:

- A rock with NNP < 0 kg $CaCO_3$/t will theoretically have a net potential for acidic drainage. A rock with NNP > 0 kg $CaCO_3$/t rock will have a net potential for the neutralization of acidic drainage. Because of the uncertainty related to the exposure of the carbonate minerals or the pyrite for reaction, the interpretation of whether a rock will be net acid generating or neutralizing is more complex. Research has shown that a range from -20 kg $CaCO_3$/t to 20 kg $CaCO_3$/t exists that is defined as a “grey” area in determining the net acid generation or neutralization potential of a rock. Material with an NNP above this range is classified as R*ock Type IV - No Potential for Acid Generation,* and material with an NNP below this range as *Rock Type I - Likely Acid Generating*. Table 9-6 summarises the deduced acid generating potential based on the net neutralising potential (NNP).

Further screening criteria could be used that attempts to classify the rock in terms of its net potential for acid production or neutralization.

- Table 9-7 summarises the criteria against which the acid forming potential is measured based on the neutralisation potential ratio (NPR) as proposed by Price (1997).
- Soregaroli and Lawrence (1998) further states that samples with less than 0.3% sulphide sulphur are regarded as having insufficient oxidisable sulphides to sustain long term acid generation. According to Li (2006) material with an S% of below 0.1% has no potential for acid generation. Therefore, material with a %S of above 0.3%, is classified as Rock Type I - Likely Acid Generating, 0.2-0.3% is classified as Rock Type II, 0.1-0.2% is classified as Rock Type III, and below 0.1% is classified as Rock Type IV - No Potential for Acid Generation (Table 9-8).

Table 9-6 Net Neutralising Potential (NPP) guideline.

Net neutralising potential (NNP) NNP = NP-AP	Acid generating potential
< -20.0	Likely to be acid generating.
> 20.0	Not likely to be acid generating.
Between -20.0 and 20.0	Uncertain range.

Table 9-7 Neutralisation Potential Ratio (NPR) guidelines (Price, 1997).

Potential for acid generation	NP: AP screening criteria	Comments
Rock Type I. Likely Acid Generating.	< 1:1	Likely AMD generating.
Rock Type II. Possibly Acid Generating.	1:1 – 2:1	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides.
Rock Type III. Low Potential for Acid Generation.	2:1 – 4:1	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficient reactive NP
Rock Type IV. No Potential for Acid Generation. >4:1 No further AMD testing required unless materials are to be used	> 4.1	No further AMD testing required unless materials are to be used as a source of alkalinity.

Table 9-8 Rock classification according to S% (Afetr Li, 2006).

Classification	Acid forming potential	Criteria
Type I	Likely acid generating	Total S (%) > 0.3%
Type II	Potential acid forming	Total S (%) 0.2 - 0.3%
Type III	Intermediate	Total S (%) 0.1 - 0.2%
Type IV	No potential for acid generation	Total S (%) <0.1 %

9.3.2. Net-acid Generation (NAG)

The Net-acid Generating (NAG) test provides a direct assessment of the potential for a material to produce acid after a period of exposure (to a strong oxidant) and weathering. The test can be used to refine the results of the ABA predictions. In the NAG-test hydrogen peroxide (H_2O_2) is used to oxidize sulphide minerals in order to predict the acid generation potential of the sample. The following relates to the methodology:

- In general, the static NAG test involves the addition of 25 ml of 15% H_2O_2 to 0.25 g of sample in a 250 ml wide mouth conical flask or equivalent. The sample is covered with a watch glass and placed in a fume hood or well-ventilated area.
- Once "boiling" or effervescing ceases, the solution can cool to room temperature and the final pH (NAG pH) is determined.
- A quantitative estimation of the amount of net acidity remaining (the NAG capacity) in the sample is determined by titrating it with sodium hydroxide (NaOH) to pH 4.5 (and/or pH 7.0) to obtain the NAG Value. In order to determine the acid generation potential of a sample, the screening method of Miller et al. (1997) is used. Refer to Table 9-9 below:

Table 9-9 NAG test screening method (edited from Miller et al., 1997).

Rock Type	NAG pH	NAG Value (H_2SO_4 kg/t)	NNP ($CaCO_3$ kg/t)
Rock Type Ia. High Capacity Acid Forming.	< 4.5	> 10	Negative
Rock Type Ib. Lower Capacity Acid Forming.	< 4.5	≤ 10	-
Uncertain, possibly Ib.	< 4.5	> 10	Positive
Uncertain.	≥ 4.5	0	Negative (Reassess minerology) *
Rock Type IV. Non-acid Forming.	≥ 4.5	0	Positive

Notes: *If low acid forming sulphides is dominant then Rock type IV.

9.3.3. ABA, NAG test and Sulphur speciation results

The ABA analysis, NAG tests as well as sulphur speciation results are summarised in Table 9-10 and Table 9-11. Figure 9-3 provide a comparison of sulphide percentage vs NPR while Figure 9-4 indicate NP:AP ratios of respective samples. Figure 9-5 summarises NAG pH vs NAG value per sample. Refer to Table 9-12 for a summary of AMD potential per sample evaluated. To follow is a brief summary of the potential risk of relevant samples analysed to cause ARD.

ASS01 (Tailings sludge)

The tailings sludge/ slurry sample analysed record intermediate sulphide content of 0.14% with a high negative NNP value of -45.0. The NPR ratio of zero suggest that the material does not consists of any buffering capacity and is likely to acid generating. The NAG pH is 1.53 with the NAG value 88.0 (at pH 7.0), indicating that the material has a high capacity for acid formation. It should be stated that although the sample does consist of oxidisable sulphides, the content is relatively low and insufficient to sustain long term acid generation.

ASS13 (Coal product)

The coal sample analysed record a high sulphide content of 1.89% with a high negative NNP value of -99.69. The NPR ratio of zero suggest that the material does not have any buffering capacity and is likely to generate acid. The NAG pH is 2.07 with the NAG values 29.80 (at pH 7.0), also indicating a high capacity for acid formation. It should be stated that the sample has high oxidisable sulphides and has the potential to sustain long-term acid generation.

ASS15 (Sandstone non-carbonaceous)

The sandstone sample (non-carbonaceous) analysed record a very low sulphide content of 0.01% with a positive NNP value of 12.29. The high NPR ratio of 30.98 suggest that the material consist of adequate buffering capacity and is likely to generate acid. The NAG pH is 9.69 with a low NAG value of 0.01 (at pH 7.0) which suggest that the material is non-acid forming.

ASS16 (Shale carbonaceous)

The shale sample (carbonaceous) analysed record an intermediate sulphide content of 0.15% with a high slightly negative NNP value of -1.43. The small NPR ratio of 0.79 suggest that the material does not have adequate buffering capacity and is likely to generate acid. The NAG pH is 3.74 with the NAG values 1.17 (at pH 7.0), shows that the material does have a low capacity for acid formation. It should be stated that the sample has intermediate oxidisable sulphides, however, will not sustain long-term acid generation.

Table 9-10 ABA test results summary table.

Sample ID	Lithology	Paste pH	Total Sulphur (%)	Sulphide (%)	AP CaCO3 (kg/t)	NP CaCO3 (kg/t)	NNP CaCO3 (kg/t)	NPR (NP/AP)
ASS01		4.90	1.44	0.14	45.00	0.00	-45.00	0.00
ASS13		3.29	3.19	1.89	99.69	0.00	-99.69	0.00
ASS15		8.30	0.013	0.01	0.41	12.70	12.29	30.98
ASS16		6.79	0.22	0.15	6.94	5.51	-1.43	0.79

Table 9-11 NAG test results summary table.

Sample ID	Lithology	NAG pH	NAG at pH 4.5 (kg H_2SO_4/t)	NAG at pH 7.0 (kg H_2SO_4/t)
ASS01		1.53	88.00	108.00
ASS13		2.07	29.80	45.80
ASS15		9.67	<0.01	<0.01
ASS16		3.74	1.17	5.96

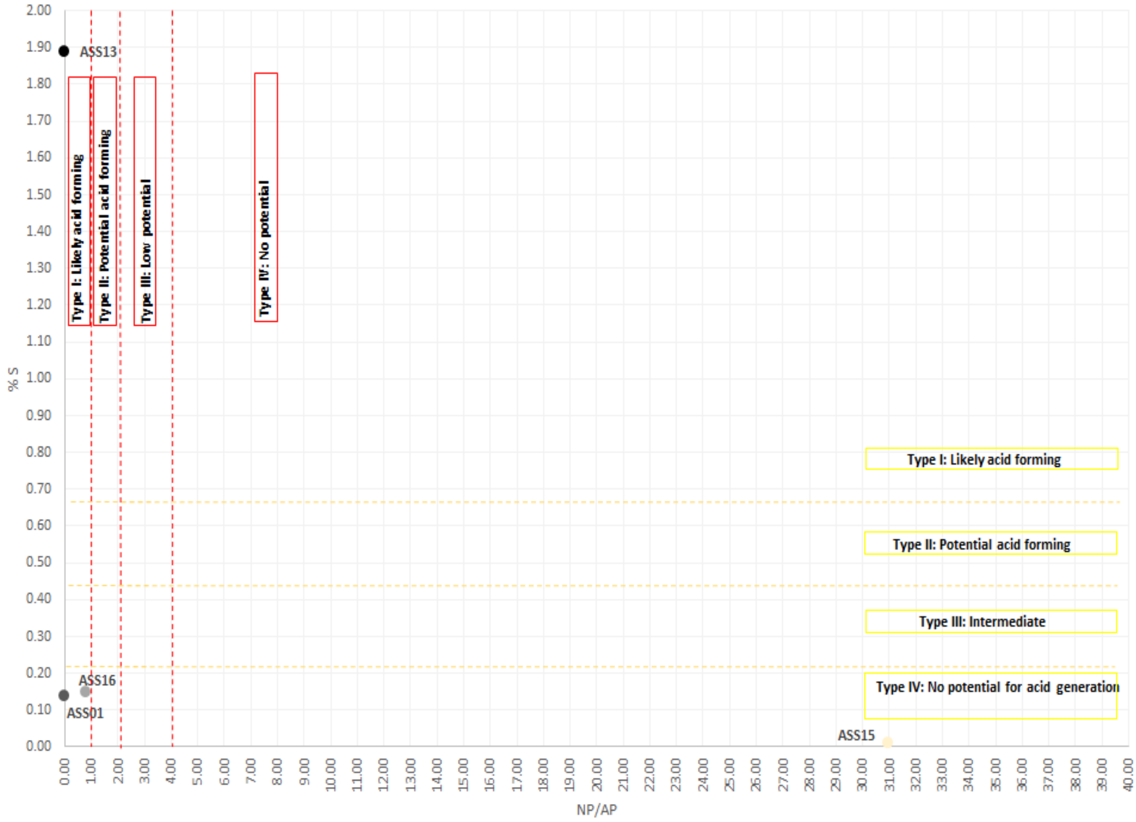


Figure 9-3 Classification of samples in terms of %S (samples below 3%) and NP/AP.

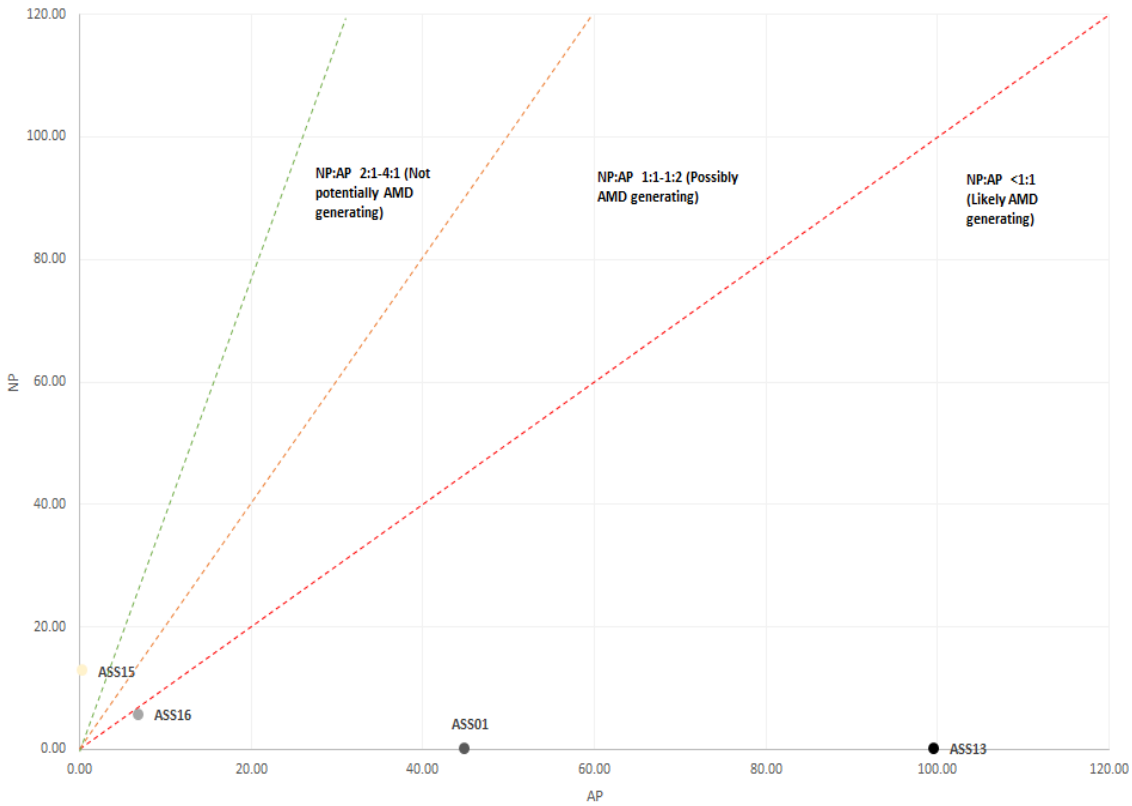


Figure 9-4 **Comparison graph: NP vs. AP.**

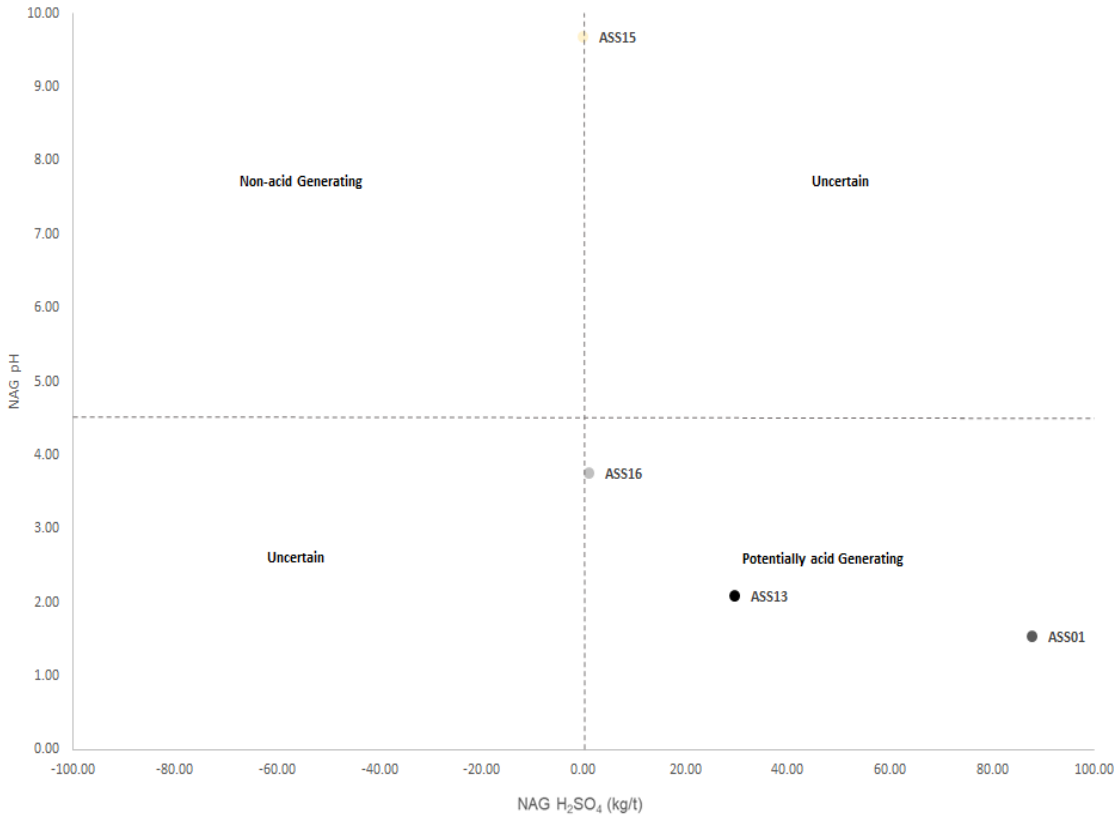


Figure 9-5 **Comparison graph: NAG pH vs NAG Value.**

Table 9-12 Summary table: ARD potential per sample analysed.

Sample	%S >0.3 NP/AP < 2.0	%S > 0.3 NP/AP > 2.0	%S < 0.1 - 0.3 NP/AP < 2.0	%S < 0.1 - 0.3 NP/AP > 2.0	%S < 0.1 NP/AP < 2.0	%S < 0.1 NP/AP > 2.0
ASS01						
ASS13						
ASS15						
ASS16						
Potential for ARD	Likely/possibly acid generating. High salt load.	Medium potential for acid generation. Medium to high salt load	Low to medium potential for acid generation. Low to medium salt load.	Very low potential for acid generation. Very low to low salt load.	No potential for acidic drainage. Very low salt load.	No potential for acidic drainage. Very low/no salt load.

9.4. Static leach test: Toxicity characteristic leaching procedure

A toxicity characteristic leaching procedure (TCLP) leach test was performed on composite samples of sulphide containing waste material to identify water soluble chemicals that could potentially be leached from the waste material[13]. The sample was added to a shake flask at a solid to liquid ratio of 1:4 and agitated for 24 hours. Accordingly, inductively coupled plasma optical emission spectrometry (ICP-OES) technique were utilised to analyse the composition of elements in samples obtained from the distilled water extraction. Refer to Table 9-13 for a summary of the leachate results. Elevated elements detected in the water leach include manganese (Mn) as well as sulphate ($S0_4$) for sample ASS01, manganese (Mn) for sample ASS13 and barium (Ba), manganese (Mn) as well as zinc (Zn) for sample ASS16. The remaining trace element concentrations detected were generally below detection limit.

Table 9-13 ICP-OES results of ditilled water leach.

Elements (mg/l)[ppm]	ASS01	ASS13	ASS16
As	< 0.5	< 0.5	< 0.5
B	< 5.0	< 5.0	< 5.0
Ba	< 0.5	< 0.5	**0.80**
Cd	< 0.5	< 0.5	< 0.5
Co	< 0.5	< 0.5	< 0.5
Cr	< 0.5	< 0.5	< 0.5
Cr^{6+}	< 0.05	< 0.05	< 0.05
Cu	< 0.5	< 0.5	0.65
Hg	< 0.005	< 0.005	< 0.005
Mn	**4.40**	**7.63**	**2.00**
Mo	< 1.0	< 1.0	< 1.0
Ni	< 0.5	< 0.5	< 0.5
Pb	< 1.0	< 1.0	< 1.0
Sb	< 0.5	< 0.5	< 0.5
Se	< 1.0	< 1.0	< 1.0
SO_4	**1420.00**	283.10	<20.0
V	< 0.5	< 0.5	< 0.5
Zn	< 0.5	< 0.5	**6.49**

Note: "- " indicate that no limits have been provided by the SANS 2015:241 guidelines.
"< " indicate that results analysed are below the detection limits.
Shaded cells exceed SANS 241:2015 drinking water guidelines.

9.5. Waste assessment

All waste material collected were submitted for analyses in order to assess the waste type and class. The assessment of waste must be undertaken in terms of the NEMA National Norms and Standards for the Assessment of Waste for Landfill Disposal (DEAT, 2010). The system is based on the Australian State of Victoria's waste classification system for disposal, which uses the Australian Standard Leaching Procedure (ASLP) to determine the leachable concentrations (LC) of pollutants in a particular waste (DEA, 2013a). The process includes identifying the chemical substances present in the waste through analysis of the total concentrations (TC) and leachable concentrations of samples taken. These results are compared to threshold limits i.e. leachable concentrations threshold (LCT) and total concentrations threshold (TCT) specified in R635

[13] It should be noted that leaching tests identify the elements that will leach out of waste but do not reflect the site-specific concentration of these elements in actual seepage as a different water/rock ratio and contact time will be present in the field.

and the outcome is used to establish the type of waste and the most suitable disposal method for it[14]. The waste assessment was conducted in line with the following approach as summarised below:

i. Wastes with any element or chemical substance concentration above the LCT3 or TCT2 values (LC >LCT3 or TC>TCT2) are Type 0 Wastes. Type 0 wastes (extremely hazardous waste), require treatment/stabilisation before disposal.

ii. Wastes with any element or chemical substance concentration above the LCT2 but below LCT3 values, or above the TCT1 but below TCT2 values (LCT2<LC ≤ LCT3 or TCT1<TC ≤ TCT2), are Type 1 Wastes (highly hazardous waste).

iii. Wastes with any element or chemical substance concentration above the LCT1 but below the LCT2 values and all concentrations below the TCT1 values (LCT1 < LC ≤ LCT2 and TC ≤ TCT1) are Type 2 Wastes (moderate hazardous waste).

iv. Wastes with any element or chemical substance concentration above the LCT0 but below LCT1 values and all concentrations below the TCT1 values (LCT0 < LC ≤ LCT1 and TC ≤ TCT1) are Type 3 Wastes (low hazardous waste).

v. Wastes with all elements and chemical substance concentration levels for metal ions and inorganic anions below the LCT0 and TCT0 values (LC ≤ LCT0 and TC ≤ TCT0) are Type 4 Wastes (near inert wastes).

Waste types and categories are summarised in Table 9-14 while the TC and LC threshold limits, according to Section 6 of R635, are presented in Table 9-15 and Table 9-16 below.

Table 9-14 Waste types.

Criteria	Waste Type
LC > LC3; or TC > TC2 (extremely hazardous waste)	Type 0
LCT2 < LC ≤ LCT3; or TCT1 < TC ≤ TCT2 (highly hazardous waste)	Type 1
LCT1 < LC ≤ LCT2; and TC ≤ TCT1 (moderate hazardous waste)	Type 2
LCT0 < LC ≤ LCT1; and TC ≤ TCT1 (low hazardous waste)	Type 3
LC ≤ LCT0; and TC ≤ TCT0 (near inert wastes)	Type 4

Figure 9-6 indicate a bar-chart comparison of the Total Concentration analysis of elements per sample whereas Figure 9-7 show a bar-chart comparison of Leachable Concentrations analysis per sample. Dominant total concentrations include boron (B), barium (Ba), manganese (Mn) and lead (Pb) whereas dominant leachate concentrations include manganese (Mn) boron (B), barium (Ba), lead (Pb), chromium (VI) (Cr^{6+}) and zinc (Zn). The results of the De-Ionised Water Leach Test and Total Concentration analysis of the samples are shown in Table 9-18 and Table 9-19. The following is noted regarding the results:

[14] It should be noted that this waste assessment does not serve to classify waste but rather aim to assess the potential environmental hazard of the waste generated.

9.5.1. Sample ASS01 (Tailings sludge)

The following elements fall above the prescribed thresholds in terms of the LC values: Mn (>LCT0), TDS (>LCT0) and $S0_4$ (>LCT0) while the following elements fall above the prescribed thresholds in terms of the TC values: As (>TCT0), B (>TCT0), Ba (>TCT0), Cd (>TCT0), Co (>TCT0), Cu (>TCT0), Hg (>TCT0), Mo (>TCT0), Pb (>TCT0), Sb (>TCT0) and Se (>TCT0). The sample analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly. Refer to Table 9-17 for a summary of leachate results compared to TC and LC thresholds.

9.5.2. Sample ASS13 (Coal product)

None of the leachable elements fall above the prescribed LCT thresholds, while the following elements fall above the prescribed thresholds in terms of the TC values: As (>TCT0), B (>TCT0), Ba (>TCT0), Cd (>TCT0), Co (>TCT0), Cu (>TCT0), Hg (>TCT0), Mo (>TCT0), Pb (>TCT0), Sb (>TCT0) and Se (>TCT0). The sample analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly. Refer to Table 9-17 for a summary of leachate results compared to TC and LC thresholds.

9.5.3. Sample ASS15 (Sandstone non- carbonaceous)

None of the leachable elements fall above the prescribed LCT thresholds, while the following elements fall above the prescribed thresholds in terms of the TC values: As (>TCT0), Ba (>TCT0), Cd (>TCT0), Cu (>TCT0), Pb (>TCT0) and Se (>TCT0). The sample analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly. Refer to Table 9-17 for a summary of leachate results compared to TC and LC thresholds.

9.5.4. Sample ASS16 (Shale carbonaceous)

None of the leachable elements fall above the prescribed LCT thresholds, while the following elements fall above the prescribed thresholds in terms of the TC values: As (>TCT0), Ba (>TCT0), Cu (>TCT0), Pb (>TCT0), Se (>TCT0), V (>TCT0) and Zn (>TCT0). The sample analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly. Refer to Table 9-17 for a summary of leachate results compared to TC and LC thresholds.

Table 9-15 Total Concentration Threshold (TCT) Limits (mg/kg).

Elements	TCT0 (mg/kg)	TCT1 (mg/kg)	TCT2 (mg/kg)
Metal ions			
As	5.80	500.00	2 000.00
B	150.00	15 000.00	60 000.00
Ba	62.50	6 250.00	25 000.00
Cd	7.50	260.00	1 040.00
Co	50.00	5 000.00	20 000.00
Cr (Total)	46 000.00	800 000.00	n.a
Cr (VI)	6.50	500.00	2 000.00
Cu	16.00	19 500.00	78 000.00
Hg	0.93	160.00	640.00
Mn	1 000.00	2 500.00	100 000.00
Mo	40.00	1 000.00	4 000.00
Ni	91.00	10 600.00	42 400.00
Pb	20.00	1 900.00	7 600.00
Sb	10.00	75.00	300.00
Se	10.00	50.00	200.00
V	150.00	2 680.00	10 720.00
Zn	240.00	160 000.00	640 000.00
Inorganic ions			
TDS			
Chloride			
Sulphate as SO_4			
NO_3 as N			
Fluoride	100.00	10 000.00	40 000.00
Cyanide	14.00	10 500.00	42 000.00

Notes: TCT1 limits, where appropriate, have been derived from the land remediation values for commercial/ industrial land determined by the Department of Environmental Affairs "Framework for the Management of Contaminant Land ", March 2010. The TCT2 limits by multiplying TCT1 by a factor of 4, as used by the Environmental Protection Agency, Australian State of Victoria. If South African limits for TCT1 were unavailable, in general, the limits published by the Environmental Protection Agency, Australian State of Victoria have been used. Some TC limits have been adjusted because of various attenuation factors that are observed in landfills. Where available, the TCT0 limits have been obtained from SA Soil Screening Values that are protective of water resources. If not available, the State Victoria value for fill material, (EPA Victoria, Classification of Wastes) has been selected. If limits were not available in these references a conservative value was obtained by dividing the TCT1 value by 100.

Table 9-16 Leachable Concentration Threshold (LCT) Limits (mg/l).

Elements	LCT0 (mg/l)	LCT1 (mg/l)	LCT2 (mg/l)	LCT3 (mg/l)
Metal ions				
As	0.01	0.50	1.00	4.00
B	0.50	25.00	50.00	200.00
Ba	0.70	35.00	70.00	280.00
Cd	0.00	0.15	0.30	1.20
Co	0.50	25.00	50.00	200.00
Cr(Total)	0.10	5.00	10.00	40.00
Cr(VI)	0.05	2.50	5.00	20.00
Cu	2.00	100.00	200.00	800.00
Hg	0.01	0.30	0.60	2.40
Mn	0.50	25.00	50.00	200.00
Mo	0.07	3.50	7.00	28.00
Ni	0.07	3.50	7.00	28.00
Pb	0.01	0.50	1.00	4.00
Sb	0.02	1.00	2.00	8.00
Se	0.01	0.50	1.00	4.00
V	0.20	10.00	20.00	80.00
Zn	5.00	250.00	500.00	2 000.00
Inorganic ions				
TDS	1 000.00	12 500.00	25 000.00	100 000.00
Chloride	300.00	15 000.00	30 000.00	120 000.00
Sulphate as SO_4	250.00	12 500.00	25 000.00	100 000.00
NO_3 as N	11.00	550.00	1 100.00	4 400.00
Fluoride	1.50	75.00	150.00	600.00
Cyanide	0.07	3.50	7.00	28.00

Notes: The LCT1 limits have, where possible, have been derived from the lowest value of the standard for human health effects listed for drinking water (LCT0) in South Africa (DWAF, SANS) by multiplying with a Dilution Attenuation Factor (DAF) of 50 as proposed by the Australian State of Victoria, "Industrial Water Resource Guideline: Solid industrial Waste Hazard Categorisation and Management", June 2009 (www.epa.vic..gov.aus). If no standard was available in South Africa then the limits given by the WHO or other appropriate drinking water standard, such as those published in the California Regulations have been used. LCT2 limits were derived by multiplying the LCT1 value with a factor of 2, and the LCT3 limits have been derived by multiplying the LCT2 value with a factor of 4. The factors applied represents a conservative assessment of the decrease in risk achieved by the increase in environmental protection provided by more comprehensive liner designs in higher classes of landfill and landfill operating requirements.

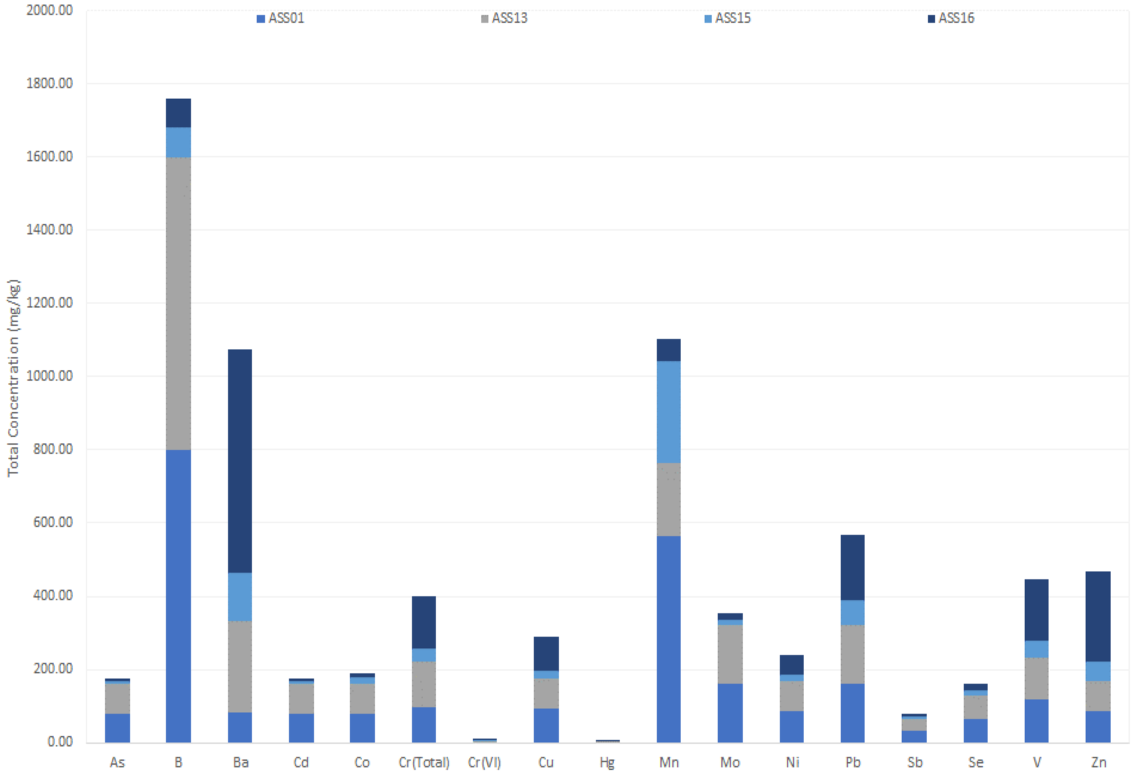


Figure 9-6 **Comparison of Total Concentration analysis of Elements.**

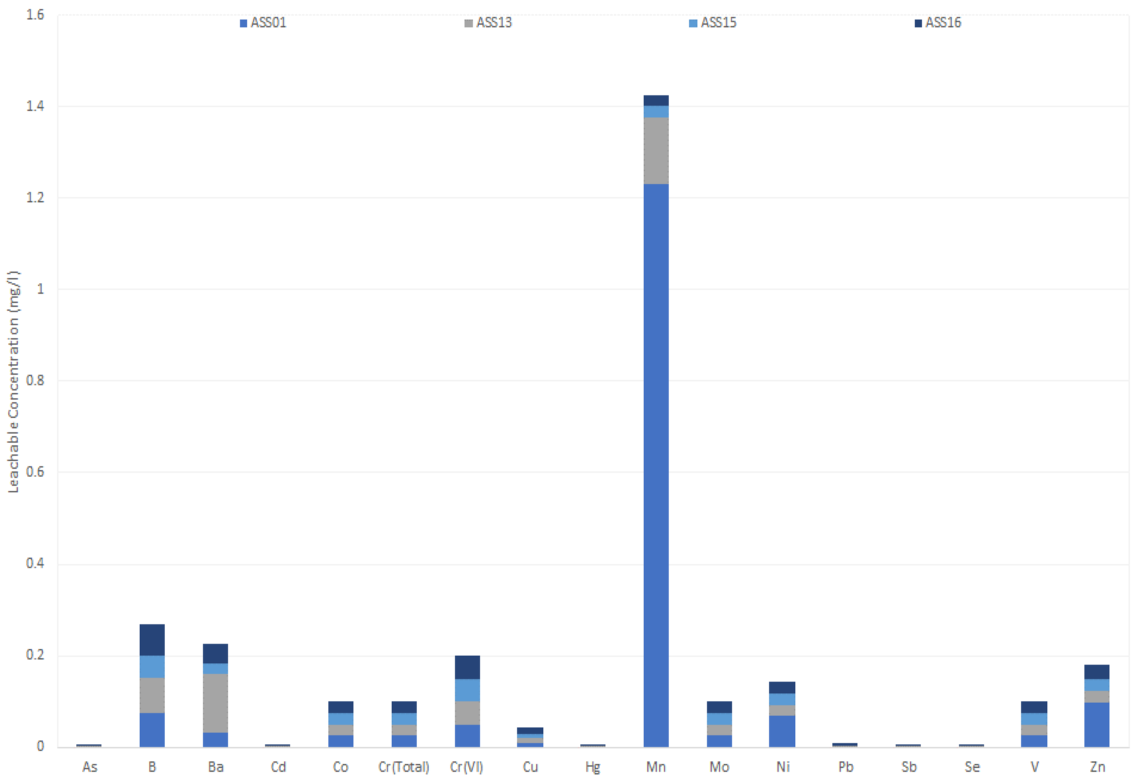


Figure 9-7 **Comparison of Leachable Concentrations analysis of samples.**

Table 9-17 Leachable Concentration (LC) and Total Concentration (TC) results of sample ASS01 (1:20 dilution).

Elements	TC (mg/kg)	LC (mg/l)	Type 4 waste	TCT0 (mg/kg)	LCT0 (mg/l)	Type 3 waste	TCT1 (mg/kg)	LCT1 (mg/l)	Type 2 waste	TCT1 (mg/kg)	LCT2 (mg/l)	Type 1 waste	TCT2 (mg/kg)	LCT3 (mg/l)	Type 0 waste
Metal ions															
As	**<80.0**	<0.001		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	**<800.0**	0.075		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	**81.09**	0.032		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	**<80.0**	<0.001		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	**<80.0**	<0.025		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	97.40	<0.025		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	<2.0	<0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	**94.87**	<0.01		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	**1.32**	<0.001		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	563.20	**1.23**		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	**<160.0**	<0.025		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	87.12	0.068		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	**<160.0**	0.001		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	**<32.0**	0.001		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	**<64.0**	<0.001		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	117.30	<0.025		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	86.52	0.098		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	3.87	4.56													
TDS		**2042.00**			1000.00			12500.00			25000.00			100000.00	
Chloride		<2.0			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		**1184.00**			250.00			12500.00			25000.00			100000.00	
NO_3 as N		<2.22			11.00			550.00			1100.00			4400.00	
Fluoride	<0.5	<0.05		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	0.10	<0.07		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes
LCT0 < LC ≤ LCT1 and TC ≤ TCT1: Type 3 Wastes
LCT1< LC ≤ LCT2 and TC ≤ TCT1: Type 2 Wastes
LCT2< LC ≤ LCT3 or TCT1 < TC ≤ TCT2: Type 1 Wastes
LC > LCT3 or TC > TCT2: Type 0 Wastes

Table 9-18 Leachable Concentration (LC) and Total Concentration (TC) results of sample ASS13 (1:20 dilution).

Elements	TC (mg/kg)	LC (mg/l)	Type 4 waste	TCT0 (mg/kg)	LCT0 (mg/l)	Type 3 waste	TCT1 (mg/kg)	LCT1 (mg/l)	Type 2 waste	TCT1 (mg/kg)	LCT2 (mg/l)	Type 1 waste	TCT2 (mg/kg)	LCT3 (mg/l)	Type 0 waste
Metal ions															
As	**<80.0**	<0.001		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	**<800.0**	0.077		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	**250.20**	0.127		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	**<80.0**	<0.001		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	**<80.0**	<0.025		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	126.10	<0.025		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	<2.0	<0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	**<80.0**	0.010		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	**1.54**	<0.001		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	202.00	0.146		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	**<160.0**	<0.025		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	<80.0	<0.025		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	**<160.0**	<0.001		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	**<32.0**	0.001		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	**<64.0**	0.001		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	116.40	<0.025		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	<80.0	<0.025		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	7.90	8.00													
TDS		405.00			1000.00			12500.00			25000.00			100000.00	
Chloride		8.69			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		113.70			250.00			12500.00			25000.00			100000.00	
NO_3 as N		<0.5			11.00			550.00			1100.00			4400.00	
Fluoride	<0.5	0.11		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	0.10	<0.07		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes
LCT0 < LC ≤ LCT1 and TC ≤ TCT1: Type 3 Wastes
LCT1< LC ≤ LCT2 and TC ≤ TCT1: Type 2 Wastes
LCT2< LC ≤ LCT3 or TCT1 < TC ≤ TCT2: Type 1 Wastes
LC > LCT3 or TC > TCT2: Type 0 Wastes

Table 9-19 Leachable Concentration (LC) and Total Concentration (TC) results of sample ASS15 (1:20 dilution).

Elements	TC (mg/kg)	LC (mg/l)	Type 4 waste	TCT0 (mg/kg)	LCT0 (mg/l)	Type 3 waste	TCT1 (mg/kg)	LCT1 (mg/l)	Type 2 waste	TCT1 (mg/kg)	LCT2 (mg/l)	Type 1 waste	TCT2 (mg/kg)	LCT3 (mg/l)	Type 0 waste
Metal ions															
As	**<8.0**	<0.001		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	<80.0	0.048		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	**132.70**	<0.025		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	**<8.0**	<0.001		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	18.10	<0.025		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	34.82	<0.025		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	<2.0	<0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	**20.40**	<0.01		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	<0.16	<0.001		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	277.90	<0.025		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	<16.0	<0.025		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	17.76	<0.025		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	**71.04**	<0.001		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	<8.0	0.001		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	**<16.0**	<0.001		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	45.87	<0.025		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	56.17	<0.025		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	4.78	5.77													
TDS		28.00			1000.00			12500.00			25000.00			100000.00	
Chloride		2.07			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		4.75			250.00			12500.00			25000.00			100000.00	
NO_3 as N		<0.5			11.00			550.00			1100.00			4400.00	
Fluoride	<0.5	<0.05		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	0.12	<0.07		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes

LCT0 < LC ≤ LCT1 and TC ≤ TCT1: Type 3 Wastes

LCT1< LC ≤ LCT2 and TC ≤ TCT1: Type 2 Wastes

LCT2< LC ≤ LCT3 or TCT1 < TC ≤ TCT2: Type 1 Wastes

LC > LCT3 or TC > TCT2: Type 0 Wastes

Table 9-20 Leachable Concentration (LC) and Total Concentration (TC) results of sample ASS16 (1:20 dilution).

Elements	TC (mg/kg)	LC (mg/l)	Type 4 waste	TCT0 (mg/kg)	LCT0 (mg/l)	Type 3 waste	TCT1 (mg/kg)	LCT1 (mg/l)	Type 2 waste	TCT1 (mg/kg)	LCT2 (mg/l)	Type 1 waste	TCT2 (mg/kg)	LCT3 (mg/l)	Type 0 waste
Metal ions															
As	**<8.0**	0.003		5.80	0.01		500.00	0.50		500.00	1.00		2000.00	4.00	
B	<80.0	0.070		150.00	0.50		15000.00	25.00		15000.00	50.00		60000.00	200.00	
Ba	**611.80**	0.041		62.50	0.70		6250.00	35.00		6250.00	70.00		25000.00	280.00	
Cd	<8.0	<0.001		7.50	0.003		260.00	0.15		260.00	0.30		1040.00	1.20	
Co	10.07	<0.025		50.00	0.50		5000.00	25.00		5000.00	50.00		20000.00	200.00	
Cr(Total)	143.60	<0.025		46000.00	0.10		800000.00	5.00		800000.00	10.00		n.a	40.00	
Cr(VI)	<2.0	<0.05		6.50	0.05		500.00	2.50		500.00	5.00		2000.00	20.00	
Cu	**93.10**	0.012		16.00	2.00		19500.00	100.00		19500.00	200.00		78000.00	800.00	
Hg	<0.16	<0.001		0.93	0.006		160.00	0.30		160.00	0.60		640.00	2.40	
Mn	61.17	<0.025		1000.00	0.50		2500.00	25.00		2500.00	50.00		100000.00	200.00	
Mo	<16.0	<0.025		40.00	0.07		1000.00	3.50		1000.00	7.00		4000.00	28.00	
Ni	55.17	<0.025		91.00	0.07		10600.00	3.50		10600.00	7.00		42400.00	28.00	
Pb	**178.30**	0.006		20.00	0.01		1900.00	0.50		1900.00	1.00		7600.00	4.00	
Sb	<8.0	0.004		10.00	0.02		75.00	1.00		75.00	2.00		300.00	8.00	
Se	**<16.0**	0.003		10.00	0.01		50.00	0.50		50.00	1.00		200.00	4.00	
V	**166.40**	<0.025		150.00	0.20		2680.00	10.00		2680.00	20.00		10720.00	80.00	
Zn	**245.70**	0.032		240.00	5.00		160000.00	250.00		160000.00	500.00		640000.00	2000.00	
Inorganic ions															
pH	6.30	6.80													
TDS		30.00			1000.00			12500.00			25000.00			100000.00	
Chloride		3.31			300.00			15000.00			30000.00			120000.00	
Sulphate as SO_4		4.87			250.00			12500.00			25000.00			100000.00	
NO_3 as N		0.51			11.00			550.00			1100.00			4400.00	
Fluoride	<0.5	0.18		100.00	1.50		10000.00	75.00		10000.00	150.00		40000.00	600.00	
Cyanide	<0.1	<0.07		14.00	0.07		10500.00	3.50		10500.00	7.00		42000.00	28.00	

LC ≤ LCT0 and TC ≤ TCT0: Type 4 wastes

LCT0 < LC ≤ LCT1 and TC ≤ TCT1: Type 3 Wastes

LCT1< LC ≤ LCT2 and TC ≤ TCT1: Type 2 Wastes

LCT2< LC ≤ LCT3 or TCT1 < TC ≤ TCT2: Type 1 Wastes

LC > LCT3 or TC > TCT2: Type 0 Wastes

10. AQUIFER CLASSIFICATION AND GROUNDWATER MANAGEMENT INDEX

The most widely accepted definition of groundwater contamination is defined as the introduction into water of any substance in undesirable concentration not normally present in water e.g. microorganisms, chemicals, waste or sewerage, which renders the water unfit for its intended use (UNESCO, 1992). The objective is to formulate a risk-based framework from geological and hydrogeological information obtained as part of this investigation. Two approaches were followed in an estimation of the risk of groundwater contamination as discussed below. As part of the aquifer classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required. The GQM Index is obtained by multiplying the rating of the aquifer system management and the aquifer vulnerability. A summary of the GQM index for the greater study area is presented in Table 10-2 with cells shaded in blue indicating the rating of the aquifer. A **GQM Index = 4** was estimated for the aquifer system and according to this estimate, a "**Medium**" level groundwater protection is required for this aquifer system.

Equation 10-1 GMQ Index.

$$\textit{GQM Index} = \boldsymbol{Aquifer\ system\ management\ x\ Aquifer\ vulnerability}$$

10.1. Aquifer classification

The aquifer classification was guided by the principles set out in South African Aquifer System Management Classification (Parsons, 1995). Aquifer classification forms a very useful planning tool which can be applied to guide the management of groundwater systems. According to the aquifer classification map of South Africa the project area is underlain by a poor to "**Minor aquifer**" (DWS, 2013). The classifications and definitions for each aquifer system are summarised in Table 10-1 cells shaded in blue indicate the classification of the aquifer.

Table 10-1 Aquifer System Management Classes (After Parsons , 1995).

Sole source aquifer	An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there are no reasonable available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
Major aquifer system	Highly permeable formations, usually with a known probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150 mS/m).
Minor aquifer system	These can be fractured or potentially fractured rocks, which do not have a high primary permeability, or other formations of variable permeability. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and supplying base flow to rivers.
Non aquifer system	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.
Special aquifer system	An aquifer designated as such by the Minister of Water Affairs, after due process.

10.2. Aquifer vulnerability

Aquifer vulnerability can be defined as the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer. According to the aquifer vulnerability map of South Africa the project area is underlain by an aquifer system with a "**Moderate**" vulnerability rating (DWS, 2013).

10.3. Aquifer susceptibility

Aquifer susceptibility is a qualitative measure of the relative ease with which a groundwater body can be potentially contaminated by anthropogenic activities. According to the Aquifer susceptibility map of South Africa the project area is underlain by an aquifer system with a "**Medium**" susceptibility rating (DWS, 2013).

Table 10-2 Groundwater Quality Management Index.

Aquifer system Management qualification		Aquifer vulnerability Classification	
Class	Points	Class	Points
Sole Source Aquifer System	6	High	3
Major Aquifer System	4	**Moderate**	**2**
Minor Aquifer System	**2**	Low	1
Non-Aquifer System	0		
Special Aquifer System	0-6		
GQM INDEX	**Level of protection**		
<1	Limited Protection		
1 to 3	Low Level Protection		
3 to 6	**Medium Level Protection**		
6 to 10	High Level Protection		
>10	Strictly Non- Degradation		

10.4. Groundwater contamination risk assessment

The concept of groundwater vulnerability to contamination by applying the DRASTIC methodology was introduced by Aller et al. (1987) and refined by the US EPA (United States Environmental Protection Agency). DRASTIC is an acronym for a set of parameters that characterise the hydrogeological setting and combined evaluated vulnerability: Depth to water level, Nett Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone and Hydraulic Conductivity. This method provides a basis for evaluating the vulnerability to pollution of groundwater resources based on hydrogeological parameters.

Lynch *et al* (1994) suggests a considerable variation in terms of hydraulic conductivity in hard rock aquifers and revised this methodology to accommodate local aquifer conditions accordingly. Parameters used as part of the index are summarised in Table 10-4 while the aquifer risk matrix is summarised in Table 10-4 below. The DRASTIC index (DI) can be computed using the following formula.

Equation 10-2 DRASTIC Index (Di).

$$\mathbf{Di} = \boldsymbol{DrD\lambda + RrR\lambda + ArA\lambda + Sr\,S\lambda + TrT\lambda + IrI\lambda}$$

where:

D = Depth to Water Table

R = Recharge

A = Aquifer media.

S = Soil media.

T = Topographic aspect.

I = Impact of vadose zone media.

C = Conductivity.

Where **D, R, A, S, T, I**, and **C** are the parameters, r is the rating value, and λ the constant weight assigned to each parameter as summarised in Table 10-3 below (Lynch et al, 1994).

Table 10-3 Ratings assigned to groundwater vulnerability parameters (Lynch et al, 1994).

Depth to groundwater (D_R)		**Net Recharge (R_R)**	
Range (m)	**Rating**	**Range (mm)**	**Rating**
0 – 5	10	0 – 5	1
5 – 15	7	5 – 10	3
15 – 30	3	10 – 50	6
> 30	1	50 – 100	8
		> 100	9
Aquifer Media (A_R)		**Soil Media (S_R)**	
Range	**Rating**	**Range**	**Rating**
Dolomite	10	Sand	8 – 10
Intergranular	8	Shrinking and/or aggregated clay	7 - 8
Fractured	6	Loamy sand	6 - 7
Fractured and weathered	3	Sandy loam	5 - 6
Topography (T_R)		Sandy clay loam and loam	4 - 5
		Silty clay loam, sandy clay and silty loam	3 - 4
Range (% slope)	**Rating**	Clay loam and silty clay	2 – 3
0 – 2	10		
2 – 6	9		
6 – 12	5		
12 – 18	3		
> 18	1		

Impact of the vadose zone (I_R)	
Range	**Rating**
Gneiss,Namaqua metamorphic rocks	3
Ventersdorp, Pretoria, Griqualand West, Malmesbury, Van Rhynsdorp, Uitenhage, Bokkeveld, Basalt, Waterberg, Soutspansberg, Karoo (northern), Bushveld, Olifantshoek	4
Karoo (southern)	5
Table Mountain, Witteberg, Granite, Natal, Witwatersrand, Rooiberg, Greenstone, Dominion, Jozini	6
Dolomite	9
Beach sands and Kalahari	10

Table 10-4 DRASTIC Index.

Risk/ Vulnerability	DRASTIC Index (Di)
Low	50-87
Moderate	87-109
High	109-183

According to the DRASTIC index methodology applied, this mining activities and associated infrastructure's risk to groundwater pollution is rated as "**Medium**", **Di** = 102 due to the relatively shallow groundwater table/ piezometric head as well as fairly flat topographical slopes within the greater study area (Table 10-5).

Table 10-5 DRASTIC weighting factors.

Parameter	Range	Rating	Description	Relative weighting
Depth to water (D) (mbgl)	0 - 5	10	Refers to the depth to the water surface in an unconfined aquifer. Deeper water table levels imply lesser chance for contamination to occur. Depth to water is used to delineate the depth to the top of a confined aquifer.	5
	5 -15	**7**		
	15 - 30	3		
	> 30	1		
Net recharge (R) (mm/a)	0-5	1	Indicates the amount of water per unit area of land which penetrates the ground surface and reaches the water table. Recharge water is available to transport a contaminant vertically to the water table, horizontal with in an aquifer.	3
	5-10	3		
	10-50	**6**		
	50-100	8		
	> 100	9		
Aquifer media (A)	Dolomite	10	Refers to the consolidated or unconsolidated medium which serves as an aquifer. The larger the grain size and more fractures or openings within an aquifer, leads to higher permeability and lower attenuation capacity, hence greater the pollution potential.	4
	Intergranular	8		
	Fractured	6		
	Fractured and weathered	**3**		
Soil media (S)	Sand	10	Refers to the uppermost weathered portion of the vadose zone characterised by significant biological activity. Soil has a significant impact on the amount of recharge.	2
	Shrinking and/or aggregated clay	8		
	Loamy sand	6		
	Sandy loam	5		
	Sandy clay	**4**		
	Silty loam	3		
	Silty clay and clay loam	2		
Topography (T) (Slope %)	0 - 2	10	Refers to the slope of the land surface. It helps a pollutant to runoff or remain on the surface in an area long enough to infiltrate it.	1
	2 - 6	**9**		
	6 - 12	5		
	12 - 18	3		
	> 18	1		
Impact of vadose zone (I)	Gneiss, Namaqua metamorphic rocks	3	Is defined as unsaturated zone material. The significantly restrictive zone above an aquifer forming the confining layers is used in a confined aquifer, as the type of media having the most significant impact.	5
	Ventersdorp, Pretoria, Griekwaland West, Malmesbury, Van Rhynsdorp, Uitenhage, Bokkeveld, Basalt, Waterberg, Soutpansberg, Karoo (Northern), Bushveld, Olifantshoek	**4**		
	Karoo (Southern)	5		
	Table Mountain, Witteberg Granite, Natal, Witwatersrand, Rooiberg, Greenstone, Dominion, Jozini	6		
	Dolomite	9		
	Beach sands and Kalahari	10		
DRASTIC Index (Di) = 102				

11. HYDROGEOLOGICAL CONCEPTUAL MODEL

The hydrogeological conceptual model consists of a set of assumptions, which will aid in reducing the problem statement to a simplified and acceptable version. Data gathered during the desk study and site investigation has been incorporated to develop a conceptual understanding of the regional hydrogeological system. Figure 11-1 depicts a generalised hydrogeological conceptual model for similar environments and illustrate the concept of primary porous media aquifers and secondary fractured rock media aquifers. In porous aquifers, flow occurs through voids between unconsolidated rock particles whereas in double porosity aquifers, the host rock is partially consolidated, and flow occurs through the pores as well as fractures in the rock. In secondary aquifers the host rock is consolidated, and porosity is generally restricted to fractures that have formed after consolidation of the rock. The weathered zone aquifer and secondary rock aquifer in the area could be classified as double porosity aquifers. Figure 11-2 depicts a southwest-northeast cross section of the study area with relevant data and information included (refer to Figure 5-2 for spatial reference).

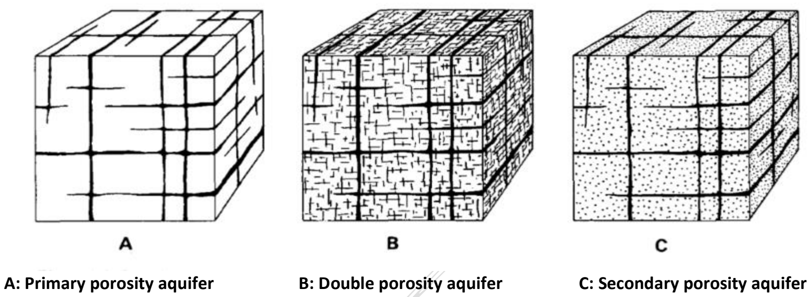


Figure 11-1 Generalised conceptual hydrogeological model (after Kruseman and de Ridder, 1994).

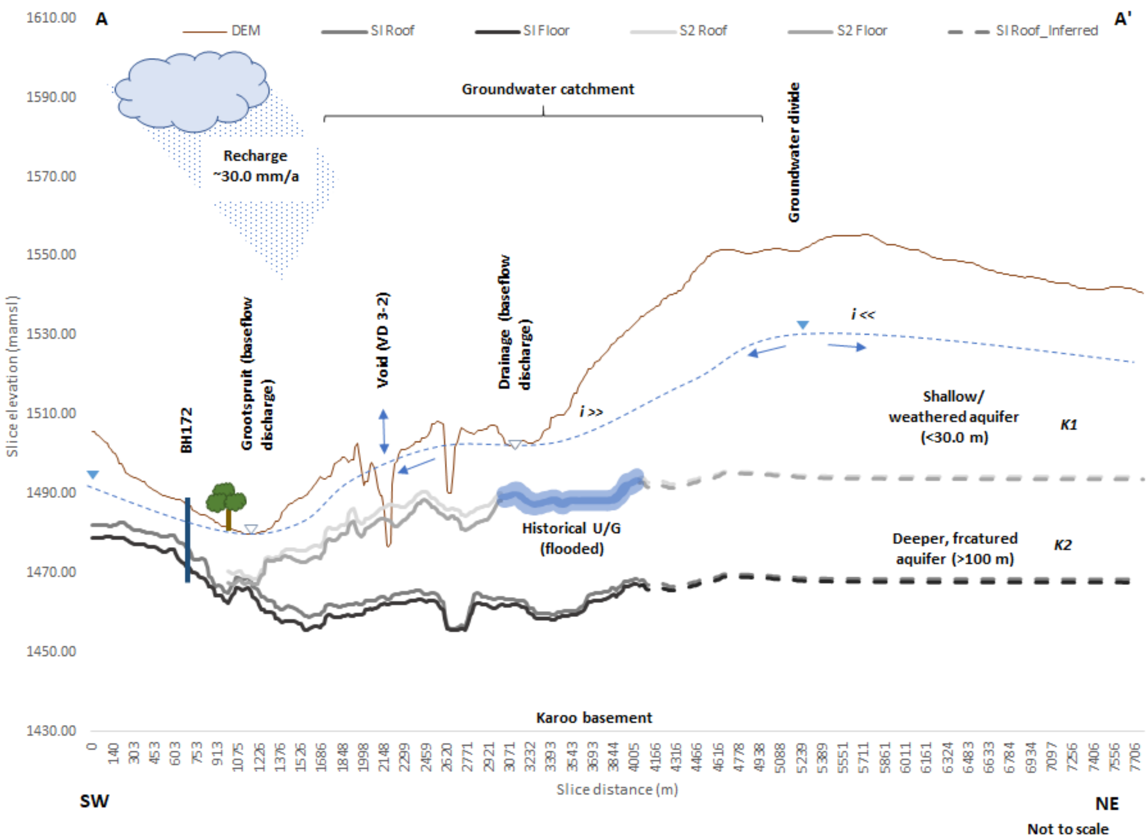


Figure 11-2 lHydrogeological conceptual model: Southwest-Northeast cross section (Figure 5-2).

12. CONCLUSIONS

The following conclusions were derived from the outcomes of this investigation:

1. The site is predominantly underlain by an intergranular and fractured aquifer system comprising mostly fractured and weathered compact sedimentary/ arenaceous rocks. It should be noted that the Ecca Group consists mainly of shales and sandstones that are very dense with permeability usually very low due to poorly sorted matrices.
2. On a local scale, two aquifer units can be inferred in the saturated zone:
   i. A shallow, weathered zone aquifer occurring in the transitional soil and weathered bedrock formations underlain by more consolidated bedrock. Due to higher effective porosity (*n*) this aquifer is most susceptible to impacts from contaminant sources.
   ii. An intermediate/deeper fractured where the underground mine void is situated.
3. Various neighbouring boreholes in close proximity (< 1.0 km) to the mining operations are utilized for domestic and livestock watering.
4. The unsaturated/ vadose zone within the study area is limited (< 8.0 mbgl) with shallow water levels of the weathered aquifer posing a risk to groundwater contamination.
5. Analysed data indicate that the regional groundwater elevation correlates moderately to the topographical elevation suggesting a dynamic environment. The inferred groundwater flow direction of the shallow aquifer mimics topography and is expected to be in a general southwestern direction towards the lower laying drainage system of the Grootspruit from where it will discharge as baseflow.
6. The groundwater gradient increases towards the west and southwest while a gentler gradient exists to the north. The latter will influence seepage rates from mine waste facilities and should be noted.
7. The regional ambient groundwater quality of the shallow aquifer is good and suggest an unimpacted groundwater system, however isolated monitoring localities within site boundary is indicative of an impacted groundwater system and shows signs of coal mine pollution and acid mine drainage (AMD).
8. The mine void water quality is acidic and extremely saline with pH < 3.0 and sulphate concentration > 1400 mg/l.
9. The hydrochemical signature of surface water locality ASW01, downstream sampling locality of the Grootspruit, suggest similar water environments to the mine void water which is potentially decanting as either interflow or baseflow at the lower laying zones or seepage from unrehabilitated discard dumps and other waste facilities.
10. The tailings sludge/ slurry sample analysed record intermediate sulphide content of 0.14% with a high negative NNP value of -45.0. The NPR ratio of zero suggest that the material does not consists of any buffering capacity and is likely to acid generating. The NAG pH is 1.53 with the NAG value 88.0 (at pH 7.0), indicating that the material has a high capacity for acid formation. It should be stated that although

the sample does consist of oxidisable sulphides, the content is relatively low and insufficient to sustain long term acid generation.

11. The coal sample analysed record a high sulphide content of 1.89% with a high negative NNP value of -99.69. The NPR ratio of zero suggest that the material does not have any buffering capacity and is likely to generate acid. The NAG pH is 2.07 with the NAG values 29.80 (at pH 7.0), also indicating a high capacity for acid formation. It should be stated that the sample has high oxidisable sulphides and has the potential to sustain long-term acid generation.
12. The sandstone sample (non-carbonaceous) analysed record a very low sulphide content of 0.01% with a positive NNP value of 12.29. The high NPR ratio of 30.98 suggest that the material consist of adequate buffering capacity and is likely to generate acid. The NAG pH is 9.69 with a low NAG value of 0.01 (at pH 7.0) which suggest that the material is non-acid forming.
13. The shale sample (carbonaceous) analysed record an intermediate sulphide content of 0.15% with a high slightly negative NNP value of -1.43. The small NPR ratio of 0.79 suggest that the material does not have adequate buffering capacity and is likely to generate acid. The NAG pH is 3.74 with the NAG values 1.17 (at pH 7.0), shows that the material does have a low capacity for acid formation. It should be stated that the sample has intermediate oxidisable sulphides, however, will not sustain long-term acid generation.
14. A Toxicity characteristic leaching procedure (TCLP) leach test was performed on composite samples of sulphide containing waste material suggest elevated concentrations of manganese (Mn) as well as sulphate ($S0_4$) for the tailings slurry sample, manganese (Mn) for the coal product sample and barium (Ba), manganese (Mn) as well as zinc (Zn) for the carbonaceous shale sample.
15. All waste samples analysed suggest that LCT0 < LC ≤ LCT1; and TC ≤ TCT1 and thus the material can be classed as a Type 3 waste (low hazardous waste) and should be managed accordingly.

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14. APPENDIX A: RAINFALL DATA (RAINFALL ZONE B2C)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1920	125.2	61.1	76.2	74.0	91.2	138.9	17.4	11.6	0.0	0.0	0.0	17.5	613.1
1921	58.0	107.9	74.1	51.5	69.1	90.7	0.6	29.0	13.7	0.0	44.6	15.0	554.3
1922	58.9	109.7	80.8	135.2	46.1	20.9	18.7	0.1	2.2	1.1	0.0	4.4	478.3
1923	18.0	84.7	78.4	56.9	60.4	124.3	30.7	23.4	0.0	0.0	2.2	18.7	497.7
1924	39.3	98.9	106.0	50.9	90.7	127.9	58.2	48.9	21.6	0.3	0.3	60.3	703.3
1925	20.6	69.2	63.5	50.0	40.8	27.9	5.6	35.1	1.8	12.9	0.0	13.4	340.8
1926	16.0	74.1	45.9	83.2	77.0	64.3	21.1	0.8	0.0	52.5	9.7	9.6	454.0
1927	100.2	32.9	55.7	110.0	45.5	40.5	15.4	0.9	0.0	0.0	20.1	8.0	429.1
1928	15.9	85.9	85.9	57.0	50.4	95.5	20.1	14.7	11.1	0.0	0.1	57.7	494.2
1929	116.3	98.3	113.0	96.8	95.3	64.4	24.0	1.9	0.0	21.2	10.7	0.2	642.1
1930	12.0	31.9	59.8	70.4	41.9	46.5	38.6	0.0	0.3	42.9	0.0	0.0	344.2
1931	39.3	61.5	57.7	135.4	60.4	52.5	7.7	11.9	0.1	0.0	0.0	23.5	450.0
1932	42.3	96.5	66.5	50.7	62.5	37.8	13.4	0.1	3.0	3.9	0.0	13.3	390.0
1933	4.6	169.0	116.6	151.8	100.9	56.5	38.5	19.7	8.6	14.1	18.4	24.1	722.9
1934	22.7	106.3	103.8	51.6	74.1	73.2	5.0	1.1	0.0	0.0	3.9	1.6	443.3
1935	17.4	32.9	75.2	122.9	99.7	96.3	41.4	87.9	0.0	0.1	0.0	22.9	596.8
1936	51.6	127.6	53.9	153.2	98.4	26.9	15.3	1.4	0.0	0.1	0.0	12.6	541.1
1937	59.8	17.0	127.9	114.9	39.8	42.8	81.5	3.2	5.9	9.6	7.0	11.7	521.1
1938	42.4	46.0	114.4	94.0	183.8	73.5	15.0	42.1	0.0	46.0	3.7	19.4	680.4
1939	47.5	147.8	123.3	60.3	63.1	58.9	22.8	26.3	58.2	0.0	1.4	57.1	666.6
1940	13.8	122.4	92.4	75.8	61.3	70.5	76.3	0.0	0.0	0.2	0.2	18.0	530.9
1941	36.7	20.1	87.9	107.4	64.5	67.0	17.7	29.9	17.7	0.0	12.1	25.0	485.9
1942	73.1	84.7	144.0	85.7	49.2	58.2	95.2	35.4	0.2	30.8	32.4	22.8	711.6
1943	55.6	84.2	92.2	107.4	148.2	51.9	5.0	3.7	30.2	0.0	0.0	23.8	602.2
1944	76.4	118.4	30.4	94.4	66.8	56.9	20.2	10.0	0.0	0.0	0.0	0.6	474.1
1945	32.7	48.9	72.6	136.7	128.8	71.5	12.0	5.8	0.0	0.0	0.0	0.2	509.2
1946	19.7	76.9	83.6	70.9	57.7	49.8	25.4	0.1	7.8	1.7	0.0	4.6	398.2
1947	26.5	101.6	127.6	128.2	31.7	75.3	14.5	8.5	0.0	0.1	0.0	11.8	525.7
1948	67.8	111.5	32.6	143.8	35.1	33.1	36.7	12.1	2.6	0.0	0.0	12.8	488.2
1949	51.2	113.4	101.8	74.1	51.1	48.5	71.6	14.3	0.6	0.4	0.0	4.9	531.9
1950	15.8	52.9	91.6	73.9	59.4	47.3	41.0	37.5	1.3	0.8	19.9	3.5	444.8
1951	96.5	10.1	83.3	53.5	76.6	23.0	17.4	6.3	2.5	16.2	0.2	0.6	386.1
1952	26.7	83.1	114.0	66.0	96.5	94.3	40.2	8.1	0.2	0.0	0.3	6.1	535.3
1953	34.1	154.5	73.2	95.1	76.8	45.7	35.4	9.0	0.0	0.0	0.3	12.0	536.0
1954	26.2	99.2	68.6	139.3	139.4	50.3	50.3	17.5	5.8	0.2	0.6	0.0	597.3
1955	52.0	84.8	147.2	55.2	111.9	60.6	0.1	81.3	9.9	2.8	0.0	45.8	651.5
1956	85.8	71.6	81.5	68.7	107.2	72.9	20.3	15.7	27.2	39.6	20.5	51.5	662.6
1957	52.9	31.6	34.8	117.1	34.5	42.2	98.4	3.8	0.1	0.0	0.0	46.1	461.5
1958	69.5	60.1	118.2	90.0	56.2	28.5	31.1	13.7	0.7	4.6	0.0	2.6	475.2
1959	20.4	138.7	95.7	59.9	49.3	54.5	77.3	7.3	2.1	0.5	8.1	5.1	518.9
1960	41.3	86.5	87.6	68.0	64.3	84.6	72.9	22.3	7.8	1.7	0.1	16.1	553.3
1961	51.8	63.9	88.6	73.8	56.3	44.7	38.0	0.7	2.8	0.0	6.2	9.8	436.5
1962	43.2	117.3	76.7	103.6	24.2	24.3	39.6	9.8	73.2	13.4	0.0	1.7	527.0
1963	50.3	78.0	40.5	148.3	43.3	24.6	12.7	3.0	5.2	0.0	4.3	2.3	412.6
1964	136.2	38.3	113.6	81.4	40.4	8.2	31.8	9.2	0.0	3.8	2.7	3.1	468.8
1965	10.5	76.1	65.5	55.2	46.9	5.8	13.7	6.3	3.5	0.0	0.4	7.3	291.4
1966	83.9	86.8	107.9	151.3	91.7	46.8	94.1	6.8	1.2	3.9	14.3	6.3	695.0
1967	75.3	97.4	79.4	84.4	50.7	97.5	37.2	13.8	0.2	2.2	7.0	1.6	546.7
1968	29.9	89.8	80.0	65.2	74.6	144.4	36.9	37.7	0.0	0.1	0.9	12.8	572.3
1969	103.5	98.1	115.4	75.7	57.3	33.0	31.9	6.7	0.7	3.1	11.6	8.4	545.5
1970	72.5	72.5	84.9	131.2	33.3	41.6	75.8	14.8	1.9	0.0	0.1	36.8	565.3
1971	35.7	121.1	100.8	126.1	37.8	82.8	12.2	6.8	0.4	0.0	4.2	23.1	551.0
1972	33.4	102.7	48.8	98.8	43.2	66.6	54.2	0.0	0.0	0.0	2.9	41.8	492.4
1973	55.4	61.1	130.2	95.1	47.5	20.0	45.0	2.1	0.9	9.0	0.8	10.9	478.0
1974	19.3	94.0	81.3	189.8	123.8	34.0	82.5	6.7	6.4	0.2	0.1	1.1	639.2
1975	30.8	123.8	90.4	95.8	72.7	73.2	28.9	31.2	0.0	0.0	0.0	8.5	555.4
1976	71.5	83.9	75.6	96.5	8.8	83.1	30.1	1.4	0.0	0.0	3.2	33.0	487.2
1977	40.4	76.8	49.3	150.8	90.0	60.2	16.3	1.1	0.0	0.5	11.1	24.4	521.0
1978	51.3	49.0	39.1	49.6	28.2	32.7	28.3	3.4	1.7	7.6	12.7	10.1	313.7
1979	67.7	116.4	58.6	115.9	119.1	52.9	11.1	0.8	0.0	0.0	0.1	31.4	573.9
1980	12.6	129.8	68.1	110.3	71.7	58.4	15.8	0.0	8.3	0.0	9.2	26.2	510.3
1981	56.6	54.9	62.2	116.7	38.3	62.7	9.1	0.6	0.7	16.3	0.0	3.6	421.8
1982	58.7	24.6	57.9	112.6	31.1	53.3	21.0	13.7	13.3	12.1	25.8	5.8	430.0
1983	76.5	135.5	89.1	70.1	29.9	93.0	3.5	0.1	12.9	9.3	5.8	4.0	529.7
1984	92.7	60.9	51.5	83.4	101.3	67.3	0.5	14.4	0.0	0.2	4.9	28.0	505.0
1985	65.9	31.5	102.8	70.0	43.6	42.4	25.9	0.0	9.2	0.0	0.5	1.5	393.4
1986	85.8	116.8	135.7	82.5	49.1	131.1	9.7	1.2	0.0	0.0	19.2	78.5	709.4
1987	48.3	145.1	109.5	68.4	32.0	69.4	16.0	3.2	9.6	0.5	6.4	21.1	529.6
1988	79.4	39.1	65.3	71.6	102.9	31.5	32.9	1.3	48.0	0.0	5.8	0.8	478.7
1989	33.0	118.0	112.0	45.4	92.4	94.1	87.2	2.0	0.0	1.0	0.9	2.9	588.9
1990	32.9	49.7	121.1	102.2	120.6	121.4	0.8	2.4	7.7	0.0	0.0	3.8	562.6
1991	37.5	48.8	102.3	74.6	62.2	35.6	9.5	0.0	0.5	0.0	15.8	6.3	393.1
1992	66.3	79.9	93.1	47.0	95.8	85.3	22.6	1.6	0.0	0.0	5.6	39.0	536.3
1993	125.5	103.6	68.1	69.6	93.1	50.4	6.8	0.0	0.0	0.0	0.0	12.3	529.4
1994	46.6	61.9	62.4	62.2	36.2	113.9	56.8	6.8	0.0	0.0	6.7	9.6	463.3
1995	66.7	140.9	174.1	166.2	238.9	84.8	54.8	6.8	0.0	0.3	5.8	1.6	940.9
1996	78.6	35.3	67.1	68.3	4.2	172.7	33.5	58.0	2.3	2.7	3.0	21.7	547.4
1997	57.6	111.0	49.9	80.9	43.8	42.2	4.6	0.0	0.0	0.0	0.0	48.9	438.7
1998	41.2	133.3	101.7	68.3	8.7	23.2	14.7	13.9	5.8	0.0	0.0	13.9	424.8
1999	34.7	144.9	161.0	174.2	140.1	129.1	51.5	14.1	1.7	0.4	0.0	14.9	866.5
2000	99.1	78.7	103.6	29.9	61.9	22.2	8.4	40.4	14.6	0.0	0.0	10.6	469.2
2001	72.2	109.4	61.1	39.9	47.1	13.4	23.5	14.2	7.8	0.0	6.5	12.1	407.3
2002	38.4	32.1	92.2	52.6	71.4	44.1	6.0	0.0	1.2	0.0	0.7	3.0	341.5
2003	61.6	51.1	93.2	80.1	153.6	189.5	21.9	4.4	4.5	12.2	0.7	0.0	672.9
2004	0.0	119.2	115.2	161.0	45.2	62.5	78.1	0.0	0.0	0.0	0.0	0.0	581.1
2005	24.1	85.0	59.3	191.0	135.1	55.0	0.0	0.0	0.0	0.0	0.0	0.0	549.6
2006	0.0	96.5	115.5	36.3	7.2	12.9	18.7	0.0	20.5	0.0	0.0	29.2	336.7
2007	162.3	95.8	131.7	215.5	22.8	195.3	0.0	30.9	0.0	0.0	0.0	0.0	854.3
2008	45.5	130.3	85.9	118.3	80.8	83.2	5.8	13.0	39.7	0.0	14.9	25.1	642.6
2009	89.7	149.2	117.4	134.0	102.2	73.7	130.1	0.0	0.0	0.0	0.0	0.0	796.3
Geometric mean	**52.6**	**86.4**	**87.7**	**94.1**	**70.1**	**64.9**	**31.6**	**12.3**	**6.1**	**4.5**	**4.9**	**15.6**	**530.8**
Minimum	**0.0**	**10.1**	**30.4**	**29.9**	**4.2**	**5.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**291.4**
Maximum	**162.3**	**169.0**	**174.1**	**215.5**	**238.9**	**195.3**	**130.1**	**87.9**	**73.2**	**52.5**	**44.6**	**78.5**	**940.9**
Standard deviation	**31.5**	**36.1**	**29.3**	**38.9**	**39.7**	**37.9**	**27.1**	**16.7**	**12.4**	**10.4**	**7.9**	**16.3**	**119.5**

15. APPENDIX B: WATER QUALITY ANALYSIS LABORATORY CERTIFICATES

17. APPENDIX C: GEOCHEMICAL ANALYSIS LABORATORY CERTIFICATES

18. APPENDIX D: SPECIALIST CURICULUM VITAE

Wetland Baseline and Impact Assessment for the proposed Mining Activities for the Elandsfontein Colliery

Emalahleni, Mpumalanga Province

October 2019

CLIENT

Prepared by:

The Biodiversity Company

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Report Name	**Wetland Baseline and Impact Assessment for the proposed Mining Activities and Associated Infrastructure for the Elandsfontein Colliery**
Submitted to	
The Client	
Report Reviewer	**Andrew Husted**
	Andrew Husted is Pr Sci Nat registered (400213/11) in the following fields of practice: Ecological Science, Environmental Science and Aquatic Science. Andrew is an Aquatic, Wetland and Biodiversity Specialist with more than 12 years' experience in the environmental consulting field. Andrew has completed numerous wetland training courses, and is an accredited wetland practitioner, recognised by the DWS, and also the Mondi Wetlands programme as a competent wetland consultant.
Report Writer and Fieldwork	**Ivan Baker**
	Ivan Baker is Cand. Sci Nat registered (119315) in environmental science and geological science. Ivan is a wetland and ecosystem service specialist, a hydropedologist and pedologist that has completed numerous specialist studies ranging from basic assessments to EIAs. Ivan has carried out various international studies following FC standards. Ivan completed training in Tools for Wetland Assessments with a certificate of competence and completed his MSc in environmental science and hydropedology at the North-West University of Potchefstroom.
Declaration	The Biodiversity Company and its associates operate as independent consultants under the auspice of the South African Council for Natural Scientific Professions. We declare that we have no affiliation with or vested financial interests in the proponent, other than for work performed under the Environmental Impact Assessment Regulations, 2017. We have no conflicting interests in the undertaking of this activity and have no interests in secondary developments resulting from the authorisation of this project. We have no vested interest in the project, other than to provide a professional service within the constraints of the project (timing, time and budget) based on the principals of science.

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Declaration

I, Ivan Baker declare that:

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

Ivan Baker

Wetland Ecologist

The Biodiversity Company

October 2019

1 Introduction

The Biodiversity Company was commissioned to conduct a wetland baseline and impact assessment, as part of the water use authorisation process for the relevant mining activities (open cast and underground) for the Elandsfontein Colliery.

A single wetland site visit was conducted from the 12th to the 16th of August 2019, which would constitute a late wet season survey due to the late rains experienced this year. The project was undertaken to meet the requirements of the National Environmental Management Act 107 of 1998, specifically Appendix 6. The project was also completed in accordance with the requirements of the Water Use Authorisation in terms of Section 21(c) and (i) of the National Water Act (Act 36 of 1998).

Aims and Objectives

The aim of the assessment was to determine the current state of the associated water resources in the area of study. This was achieved through the following:

- The delineation and assessment of wetlands within the Mining Right Area (MRA);
- The evaluation of the extent of site-related impacts;
- An impact assessment for the proposed development; and
- The prescription of mitigation measures and recommendations for identified risks.

1.1 Background

A wetland assessment was conducted by (Digby Wells, 2017), of which the concluded discussion follows;

Wetlands in the study area fall within the Quaternary Catchment B20G and are linked to tributaries of the Grootspruit River. Wetlands within the Anker Coal: Elandsfontein Colliery;s Mining Right boundary have been identified as nationally important for the maintenance of biodiversity, according to NFEPA (Nel et al., 2011). Although the NFEPA must have been based on information prior to development, it does hold relevance as this gives an indication of the suitability of the site as important habitat for wetland-dependant flora and fauna in its reference state.

Wetlands on site were comprised of channelled and unchannelled valley bottom wetlands with associated hillslope seeps. Wetlands in the northern and southern portions of the site function as natural sponges for the removal of contaminants from water. Wetlands in the central portion of the site, associated with former mining activities, have undergone irreversible alteration from their natural state. Agricultural activities were the former land use in the area and wetlands had been infringed upon by farm crops. Although these wetlands were not necessarily in a pristine ecological state, they retained ecological functionality and there is scope for improving their ecological categories by means of onsite wetland rehabilitation interventions.

Wetlands that were directly impacted by the mining activities on site were allocated a PES of F, which indicates that modifications have reached a critical level and ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota.

The following recommendations were concluded from this study:

- The Flora and Fauna Report for the Elandsfontein Baseline Environmental Studies (Digby Wells 2014) provides species-specific recommendations for the removal of alien invasive plants on site. Alien bushclumps in wetland areas should be removed, to allow for the spread of native species; and

- Vegetation should be monitored to ensure that wetland areas are colonised by native hydric plant species. If terrestrial grass species are found to colonise and spread over wetland areas, it may be an indication that the wetlands are experiencing desiccation. Water quality should be monitored up and downstream of the wetland to determine efficiency of contaminant removal by the wetland systems.

2 Terms of Reference

The following tasks were completed in fulfilment of the terms of reference for this assessment:

- The delineation, classification and assessment of wetlands within 500 m of the project area;

- Implementation of WET-Health for determination of Present Ecological State (PES) of wetland areas;

- Implementation of WET-EcoServices for determination of ecosystem services for the wetland areas;

- Determine the Environmental Importance and Sensitivity (EIS) of wetland systems;

- Conduct risk assessments relevant to the proposed activity;

- Recommendations relevant to associated impacts; and

- Report compilation detailing the baseline findings.

3 Knowledge Gaps

The following aspects were considered as limitations:

- The wetlands within the MRA were the focus for the study, these systems were groundtruthed and further assessed. Wetland areas beyond the MRA but within the 500 m regulated area were largely considered at a desktop level;

- The areas within (and especially surrounding drainage lines) the MRA have significantly been modified. This modifaction could lead to inacuracies pertaining to delineations and identification of wetland indicators. The majority of wetland areas were covered in tailing material/silt which renders the dominant soil form in such an instance as a Witbank soil form. The latter mentioned according to (DWAF, 2005) is classified as a terrestrial soil as opposed to hydromorphic soils;

- Some the delineated wetlands are characterised by artificial water inputs, which provides difficulties in identifying hydromorphic soils; and
- The GPS used for water resource delineations is accurate to within five meters. Therefore, the wetland delineation plotted digitally may be offset by at least five meters to either side.

4 Project Area

The project area is located approximately 14 km south-west of Emalahleni and approximately 13 km south-east of Balmoral, Mpumalanga, South Africa (see Figure 1). The dominant land uses surrounding the project area includes watercourses, cultivation, urban sprawls and mining.

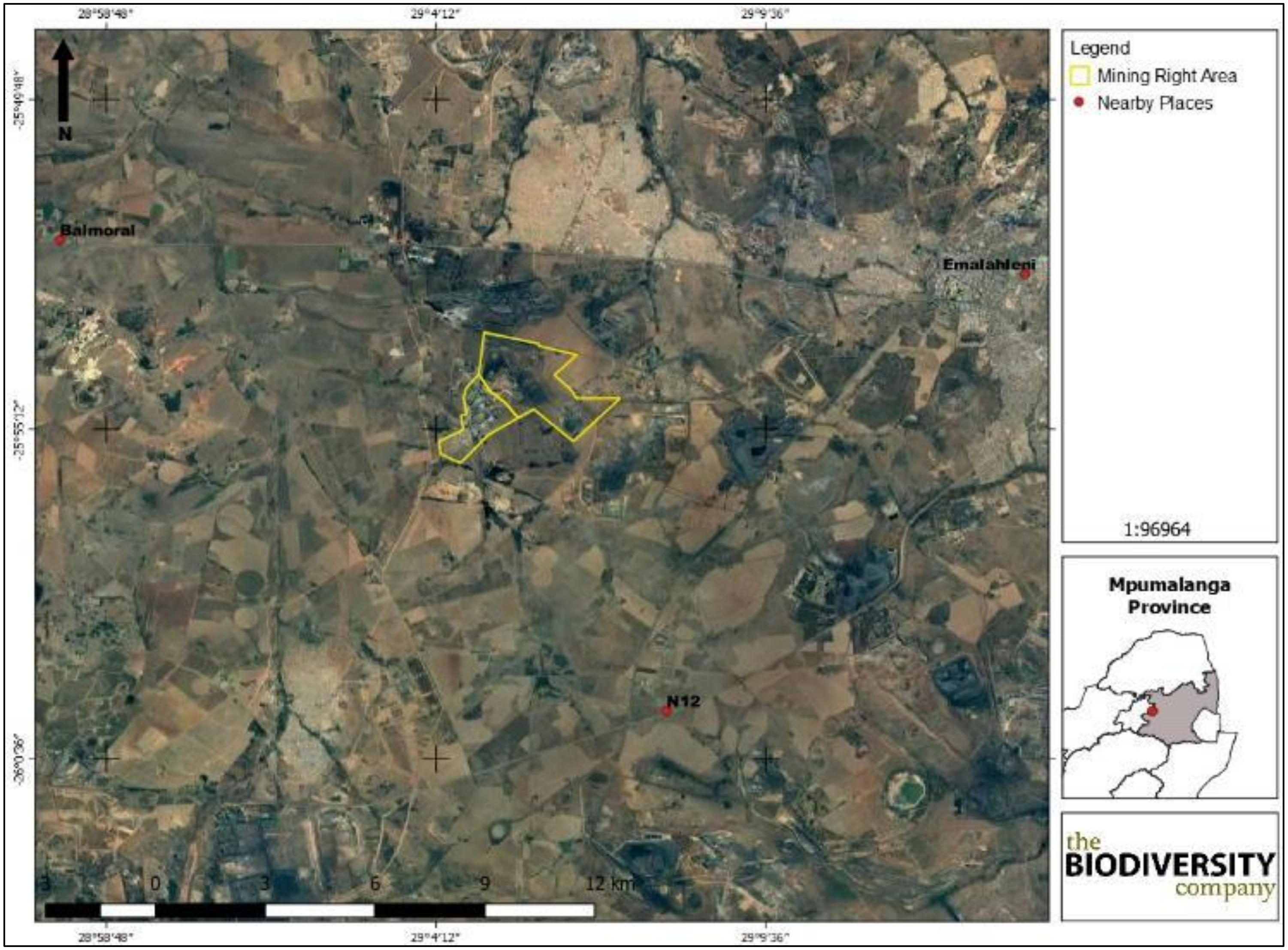

Figure 1: Locality map of the project area

4.1 Vegetation Types

The MRA is located within two vegetation types, including the Rand Highveld Grassland (Gm 11) Eastern Highveld Grassland (Gm 12). The distribution of the Rand Highveld Grassland ranges between the North-West, Gauteng, Free State and Mpumalanga provinces. This vegetation type can be found between rocky ridges specifically between Witbank and Pretoria. The Rand Highveld Grassland extends into these ridges in the Stoffberg area as well as west of Krugersdorp stretching all the way to Potchefstroom. The preferred altitude for this vegetation type is between 1300m and 1635m above sea level (Mucina & Rutherford, 2006).

Grass species commonly found in these regions include the genera *Themeda. Eragrostis, Elionurus* and *Heteropogon*. The diversity of herbs is high in these regions with rocky ridges and hills being colonized by sparse woodlands accompanied by a rich suite of shrubs with the genus *Rhus* making up the bulk thereof (Mucina & Rutherford, 2006). The sparse woodlands in this vegetation type includes species like *Protea caffra* subsp., *Caffra, Acacia caffra, P. Welwitschii* etc.

The project area falls within the Eastern Highveld Grassland (Gm 12) vegetation type. This vegetation type is located in the Gauteng and Mpumalanga province within the plains between Belfast and Johannesburg. This vegetation type also extends to Bethal, the western areas of Piet Retief and Ermelo. The altitude in which this vegetation type occurs ranges between 1 520 meters above sea level to 1 780 meters above sea level (Mucina & Rutherford, 2006).

The vegetation of this vegetation type is characterised by short and dense grasslands that occur in moderately undulating plains which include low hills and pan depressions (Mucina & Rutherford, 2006). Small scattered rocky outcrops are common in this area with wiry, sour grasses accompanied by some woody species which include *Celtis africana, Parinari capensis, Protea caffra* etc.

The conservation status of the Gm 12 vegetation type is endangered with a target percentage of 24. Half of the area is already transformed into agriculture, mining, urban etc. with a handful of conservation areas still up and running. These include Holkranse, Nooitgedacht Dam and Morgenstond (just to name a few) (Mucina & Rutherford, 2006).

4.2 Soils and Geology

According to the land type database (Land Type Survey Staff, 1972 - 2006), the project area is characterised by the Bb 13 and the Ba 5 land types. Figure 2 illustrates the respective terrain units relevant to the Bb 13 land type with the expected soils illustrated in

Table 1. Figure 3 illustrates the respective terrain units relevant to the Ba 5 land type with the expected soils illustrated in Table 2.

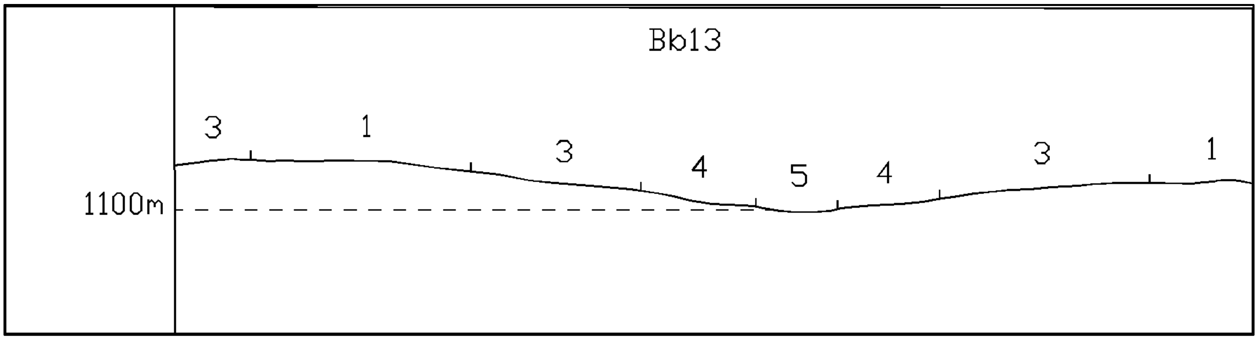

Figure 2: Illustration of land type Bb 13 terrain units (Land Type Survey Staff, 1972 - 2006)

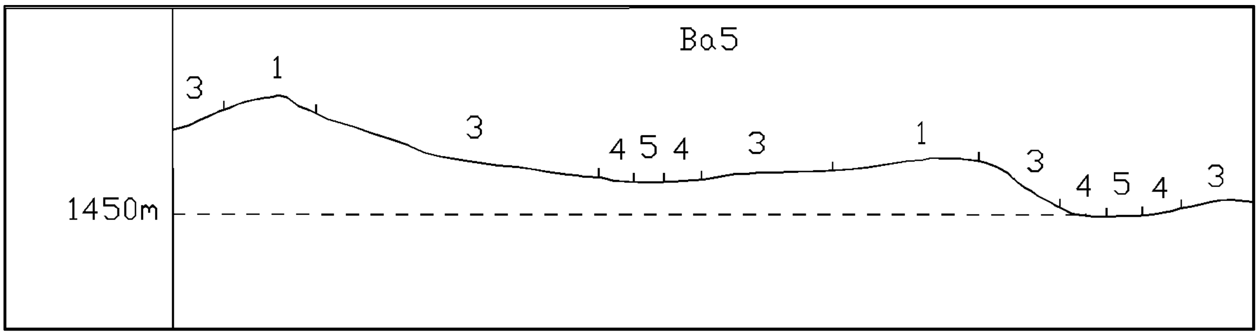

Figure 3: Illustration of land type Ba 5 terrain units (Land Type Survey Staff, 1972 - 2006)

Table 1: Soils expected at the respective terrain units within the Bb 13 land type (Land Type Survey Staff, 1972 - 2006)

Terrain units							
1 (40%)		**3 (45%)**		**4 (10%)**		**5 (5%)**	
Clovelly	45	Avalon	35	Avalon	30	Karspruit	40
Glencoe	25	Clovelly	35	Longlands	25	Kroonsdad	30
Hutton	15	Hutton	10	Kroonstad	15	Furnwood	20
Avalon	15	Glencoe	10	Glencoe	10	Longlands	10
		Longlands	5	Wasbank	10		
		Kroonstad	5	Furnwood	10		

Table 2: Soils expected at the respective terrain units within the Ba 5 land type (Land Type Survey Staff, 1972 - 2006)

Terrain units							
1 (20%)		**3 (60%)**		**4 (15%)**		**5 (5%)**	
Hutton	60	Hutton	40	Hutton	25	Rensburg	50
Glenrosa	20	Avalon	15	Avalon	15	Katspruit	30
Clovelly	10	Glencoe	10	Longlands	15	Swartland	20
		Glenrosa	10	Kroonstad	10		
		Clovelly	5	Bonheim	10		
		Longlands	5	Clovelly	10		
		Swartland	5	Swartland	5		
		Wasbank	5	Glencoe	5		
		Mispha	5	Wasbank	5		

The geology of this vegetation type is characterised by the Pretoria group and the Witwatersrand Subgroup's quartzite ridges as well as the Rooiberg Group's Selons River Formation which is from the Transvaal Supergroup. The parent geology from this vegetation type supports shallow soils like Glenrosa and Mispah which typically forms on slopes and ridges where topsoil is likely to wash off (Mucina & Rutherford, 2006).

4.3 Climate

The climate for the Rand Highveld Grassland is characterised by a summer rainfall with a mean annual precipitation of 654mm which is slightly lower in the western parts of this vegetation type see (Figure 4). These areas are known to have warm-temperate conditions with dry winters. The likelihood of frost however is greater in the western parts with the incidence of frost ranging from 30 to 40 days compared to the east which has a frost incidence of 10 to 35 days (Mucina & Rutherford, 2006). This vegetation type is also classified as endangered even though very little conservation has been done for this vegetation type.

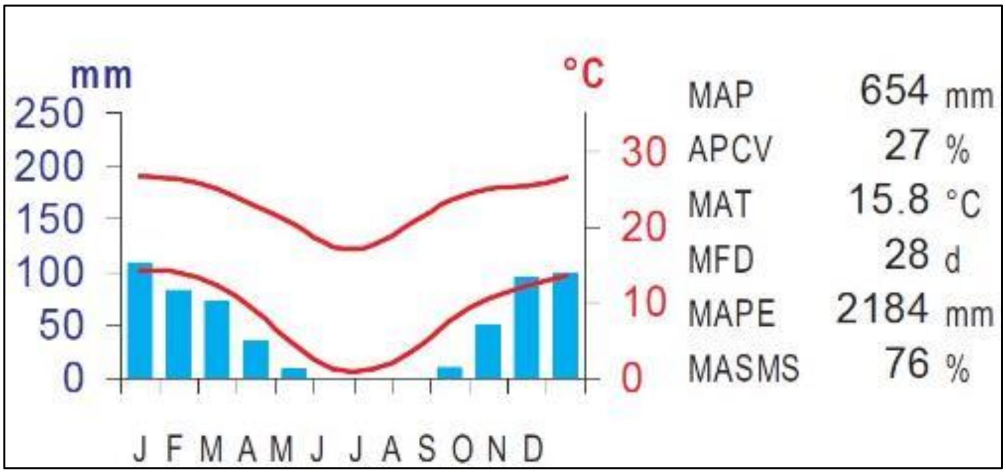

Figure 4: Climate for the Rand Highveld Grassland (Mucina & Rutherford, 2006)

4.4 River lines and Mpumalanga Highveld Grassland Wetlands

Various non-perennial and perennial streams have been identified within the proposed project area by means of the “2529” quarter degree square topographical river line data set. The Mpumalanga Highveld Grassland Wetland Layer indicates an additional wetland within the MRA, namely a floodplain wetland with various other wetland types located within the MRA’s surroundings (see Figure 5).

4.5 NFEPA Wetlands

Two types of NFEPA wetlands were identified within the MRA, namely channelled valley bottom wetlands as well as seeps (see Figure 6). The channelled valley bottom wetlands are classified as natural and the seeps are classified as artificial.

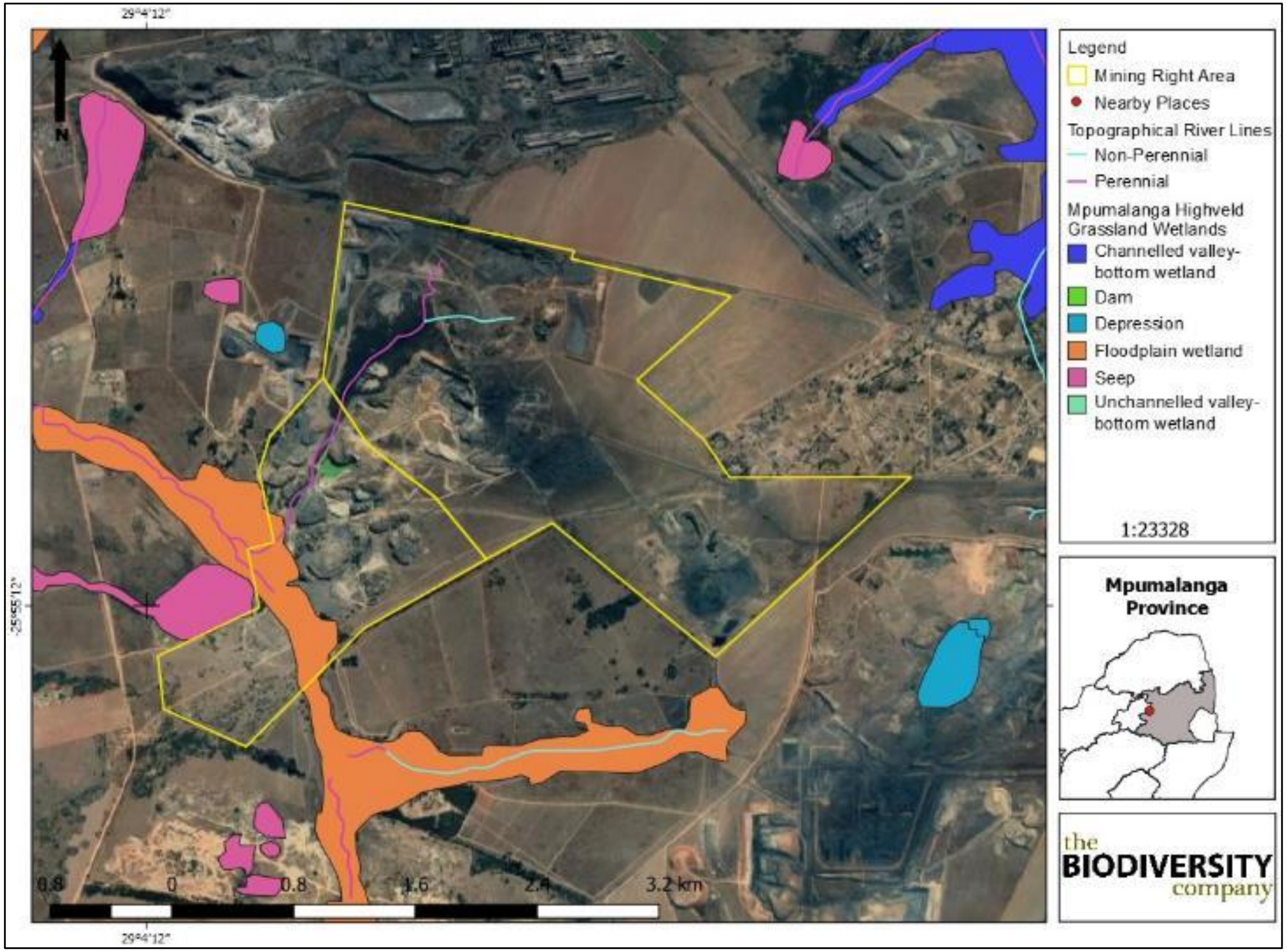

Figure 5: Illustration of topographical river lines and the Mpumalanga Highveld Grassland Wetlands

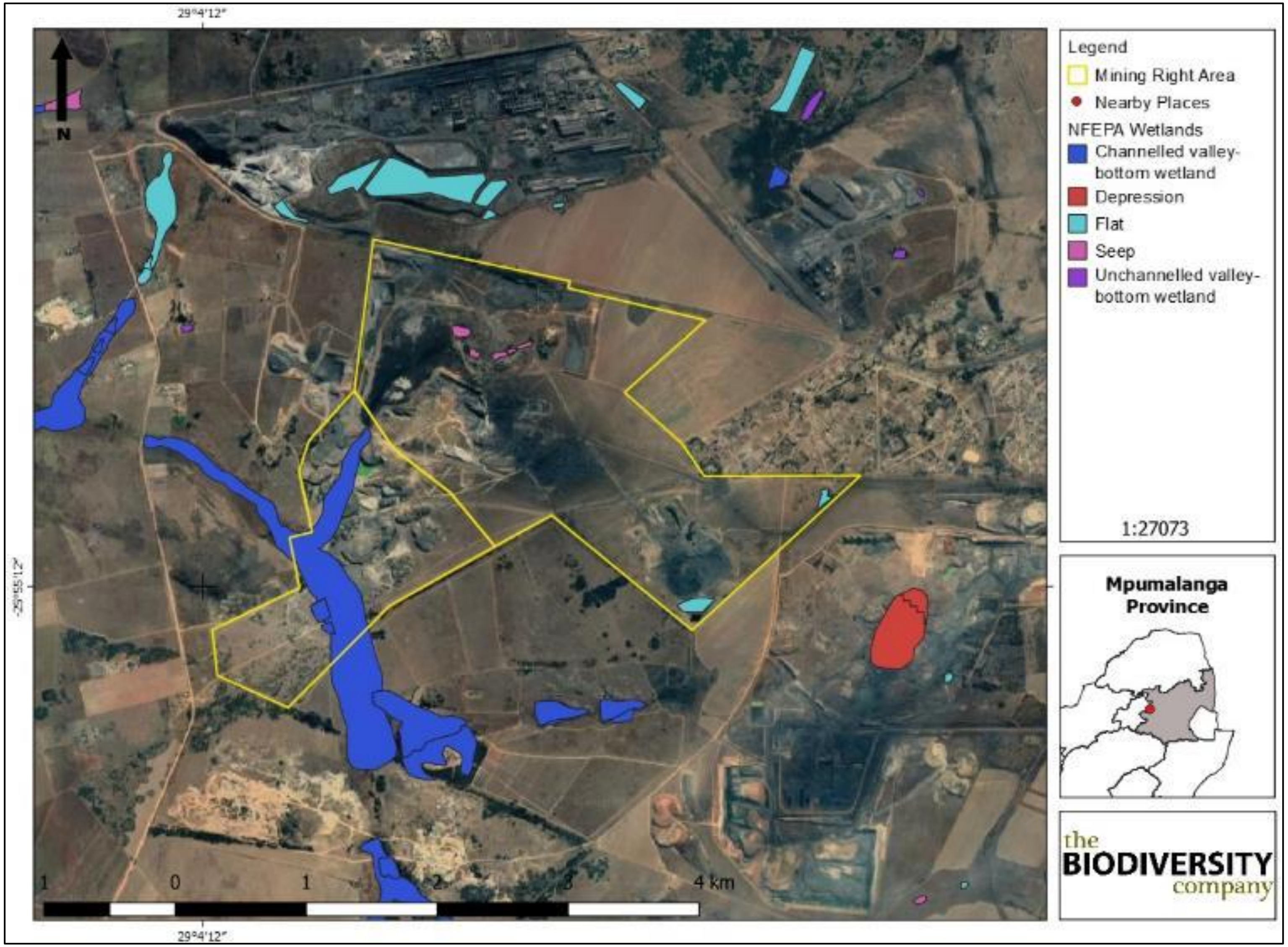

Figure 6: NFEPA wetlands within the project area and its surroundings

5 Key Legislative Requirements

5.1 National Water Act (NWA, 1998)

The DWS is the custodian of South Africa's water resources and therefore assumes public trusteeship of water resources, which includes watercourses, surface water, estuaries, or aquifers. The National Water Act (Act No. 36 of 1998) (NWA) allows for the protection of water resources, which includes:

- The maintenance of the quality of the water resource to the extent that the water resources may be used in an ecologically sustainable way;
- The prevention of the degradation of the water resource;
- The rehabilitation of the water resource;

A watercourse means;

- A river or spring;
- A natural channel in which water flows regularly or intermittently;
- A wetland, lake or dam into which, or from which, water flows; and
- Any collection of water which the Minister may, by notice in the Gazette, declare to be a watercourse, and a reference to a watercourse includes, where relevant, its bed and banks.

The NWA recognises that the entire ecosystem and not just the water itself, and any given water resource constitutes the resource and as such needs to be conserved. No activity may therefore take place within a watercourse unless it is authorised by the DWS. Any area within a wetland or riparian zone is therefore excluded from development unless authorisation is obtained from the DWS in terms of Section 21 (c) and (i).

5.2 National Environmental Management Act (NEMA, 1998)

The National Environmental Management Act (NEMA) (Act 107 of 1998) and the associated Regulations as amended in April 2017, states that prior to any development taking place within a wetland or riparian area, an environmental authorisation process needs to be followed. This could follow either the Basic Assessment Report (BAR) process or the Environmental Impact Assessment (EIA) process depending on the scale of the impact.

6 Methodology

6.1 Wetland Identification and Mapping

The wetland areas are delineated in accordance with the DWAF (2005) guidelines, a cross section is presented in Figure 7. The outer edges of the wetland areas were identified by considering the following four specific indicators:

- The Terrain Unit Indicator helps to identify those parts of the landscape where wetlands are more likely to occur;

- The Soil Form Indicator identifies the soil forms, as defined by the Soil Classification Working Group (2018), which are associated with prolonged and frequent saturation.
    - The soil forms (types of soil) found in the landscape were identified using the South African soil classification system namely; Soil Classification: A Taxonomic System for South Africa Soil Classification Working Group (2018),
- The Soil Wetness Indicator identifies the morphological "signatures" developed in the soil profile as a result of prolonged and frequent saturation; and
- The Vegetation Indicator identifies hydrophilic vegetation associated with frequently saturated soils.

Vegetation is used as the primary wetland indicator. However, in practise the soil wetness indicator tends to be the most important, and the other three indicators are used in a confirmatory role.

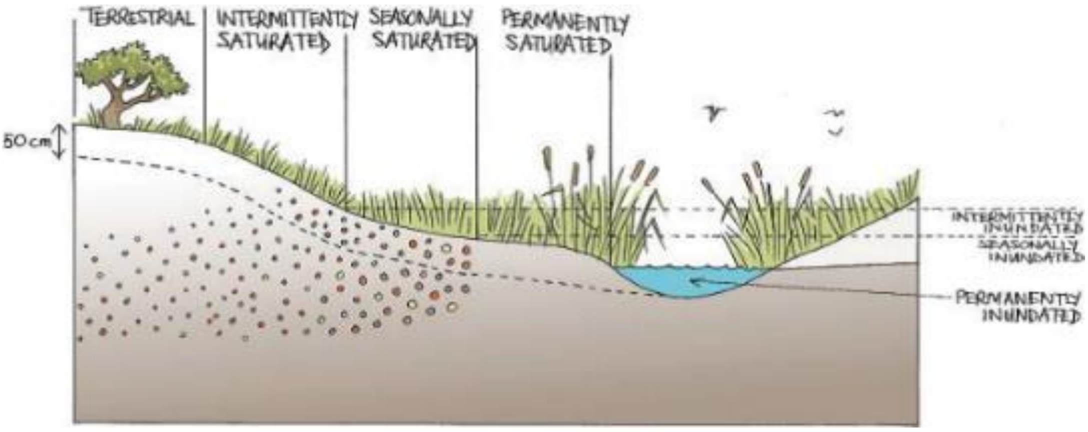

Figure 7: Cross section through a wetland, indicating how the soil wetness and vegetation indicators change (Ollis et al., 2013)

6.2 Wetland Delineation

The wetland indicators described above are used to determine the boundaries of the wetlands within the project area. These delineations are then illustrated by means of maps accompanied by descriptions.

6.3 Wetland Functional Assessment

Wetland Functionality refers to the ability of wetlands to provide healthy conditions for the wide variety of organisms found in wetlands as well as humans. Eco Services serve as the main factor contributing to wetland functionality.

The assessment of the ecosystem services supplied by the identified wetlands was conducted per the guidelines as described in WET-EcoServices (Kotze *et al.,* 2008). An assessment was undertaken that examines and rates the following services according to their degree of importance and the degree to which the services are provided (Table 3).

Table 3: Classes for determining the likely extent to which a benefit is being supplied

Score	Rating of likely extent to which a benefit is being supplied
< 0.5	Low
0.6 - 1.2	Moderately Low
1.3 - 2.0	Intermediate
2.1 - 3.0	Moderately High
> 3.0	High

6.4 Determining the Present Ecological Status (PES) of wetlands

The overall approach is to quantify the impacts of human activity or clearly visible impacts on wetland health, and then to convert the impact scores to a Present Ecological Status (PES) score. This takes the form of assessing the spatial extent of impact of individual activities/occurrences and then separately assessing the intensity of impact of each activity in the affected area. The extent and intensity are then combined to determine an overall magnitude of impact. The Present State categories are provided in Table 4.

Table 4: The Present Ecological Status categories (Macfarlane, et al., 2008)

Impact Category	Description	Impact Score Range	PES
None	**Unmodified, natural**	**0 to 0.9**	**A**
Small	**Largely Natural** with few modifications. A slight change in ecosystem processes is discernible and a small loss of natural habitats and biota may have taken place.	**1.0 to 1.9**	**B**
Moderate	**Moderately Modified.** A moderate change in ecosystem processes and loss of natural habitats has taken place, but the natural habitat remains predominantly intact.	**2.0 to 3.9**	**C**
Large	**Largely Modified.** A large change in ecosystem processes and loss of natural habitat and biota has occurred.	**4.0 to 5.9**	**D**
Serious	**Seriously Modified.** The change in ecosystem processes and loss of natural habitat and biota is great, but some remaining natural habitat features are still recognizable.	**6.0 to 7.9**	**E**
Critical	**Critical Modification.** The modifications have reached a critical level and the ecosystem processes have been modified completely with an almost complete loss of natural habitat and biota.	**8.0 to 10**	**F**

6.5 Determining the Ecological Importance and Sensitivity of Wetlands

The method used for the EIS determination was adapted from the method as provided by DWS (1999) for floodplains. The method takes into consideration PES scores obtained for WET-Health as well as function and service provision to enable the assessor to determine the most representative EIS category for the wetland feature or group being assessed. A series of determinants for EIS are assessed on a scale of 0 to 4, where 0 indicates no importance and 4 indicates very high importance. The mean of the determinants is used to assign the EIS category as listed in Table 5 (Rountree & Kotze, 2013).

Table 5: Description of Ecological Importance and Sensitivity categories

EIS Category	Range of Mean	Recommended Ecological Management Class
Very High	3.1 to 4.0	**A**
High	2.1 to 3.0	**B**
Moderate	1.1 to 2.0	**C**
Low Marginal	< 1.0	**D**

6.6 Ecological Classification and Description

The National Wetland Classification Systems (NWCS) developed by the South African National Biodiversity Institute (SANBI) will be considered for this study. This system comprises a hierarchical classification process of defining a wetland based on the principles of the hydrogeomorphic (HGM) approach at higher levels, and then also includes structural features at the lower levels of classification (Ollis *et al.,* 2013).

6.7 Determining Buffer Requirements

The "Preliminary Guideline for the Determination of Buffer Zones for Rivers, Wetlands and Estuaries" (Macfarlane *et al.,* 2009) was used to determine the appropriate buffer zone for the proposed activity.

6.8 Risk Assessment

The Department of Water and Sanitation (DWS) risk matrix assesses impacts in terms of consequence and likelihood. The significance of the impact is calculated according to Table 6.

Table 6: Significance ratings matrix

Rating	Class	Management Description
1 – 55	(L) Low Risk	Acceptable as is or consider requirement for mitigation. Impact to watercourses and resource quality small and easily mitigated. Wetlands may be excluded.
56 – 169	M) Moderate Risk	Risk and impact on watercourses are notably and require mitigation measures on a higher level, which costs more and require specialist input. Wetlands are excluded.
170 – 300	(H) High Risk	Always involves wetlands. Watercourse(s)impacts by the activity are such that they impose a long-term threat on a large scale and lowering of the Reserve.

7 Results and Discussion

7.1 Wetland Delineation and Description

The wetland areas were delineated in accordance with the DWAF (2005) guidelines (see Figure 12). During the field survey, one main unchanneled valley bottom (HGM 1) and two hillslope seeps (HGM 2 and 3) were identified. The unchanneled valley bottom originates from drainage lines, which likely has been modified to channel flow. Various mining components are located within close proximity to HGM 1, which increases modification to the wetland in various ways, including increased inputs from water stored in waste impoundments and evaporation/attenuation ponds.

Significant modification and degradation has resulted in surface and sub-surface flow dynamics being altered with an input of Transported Technosols (see Section 7.4.1- "Hydromorphic Soils") that according to DWAF (2005) cannot be classified as a hydromorphic soil form. A large portion of the upper reaches of HGM 1 has therefore been determined to be artificial and therefore irrelevant to the wetland assessment (see Figure 13).

Figure 8: Example of unchanneled valley bottom wetlands identified within the MRA (HGM 1)

A hillslope seep (see Figure 9) approximately 0.88 ha is size (although only delineated within the MRA) has been identified and is surrounded by cropfields which is the main contributor to the modifcation of this wetland. The wetland area was burnt prior to the assessment which has resulted in limitation in regard to hydrophytes, ultimately rendering hydromorphic soils the main indicator.

Figure 9: HGM 2- Hillslope Seep

The second hillslope seep (HGM 3) surrounds HGM 1, which emphasises the role of this wetland in regard to the regulation of sub-surface flows into HGM 1 (see Figure 10). This system too has been heavily modified by surrounding mining activities, which favours conditions for non-obligate wetland plants like *Imperata cylindrica*. It is well documented by the likes of (Sieben *et al.,* 2014) that *Imperata cylindrica* prefers sandy soils and thrives in disturbed areas, ultimately limiting the use of *Imperata cylindrica* as a wetland indicator for this wetland. Transects were carried out to determine the extent of the delineations, during which the focus was shifted to hydromorphic soils, which according to DWAF (2005) is the most important factor relating to wetland identification.

Figure 10: Indication of Imperata cylindrica across the entire hillslope relevant to HGM 3

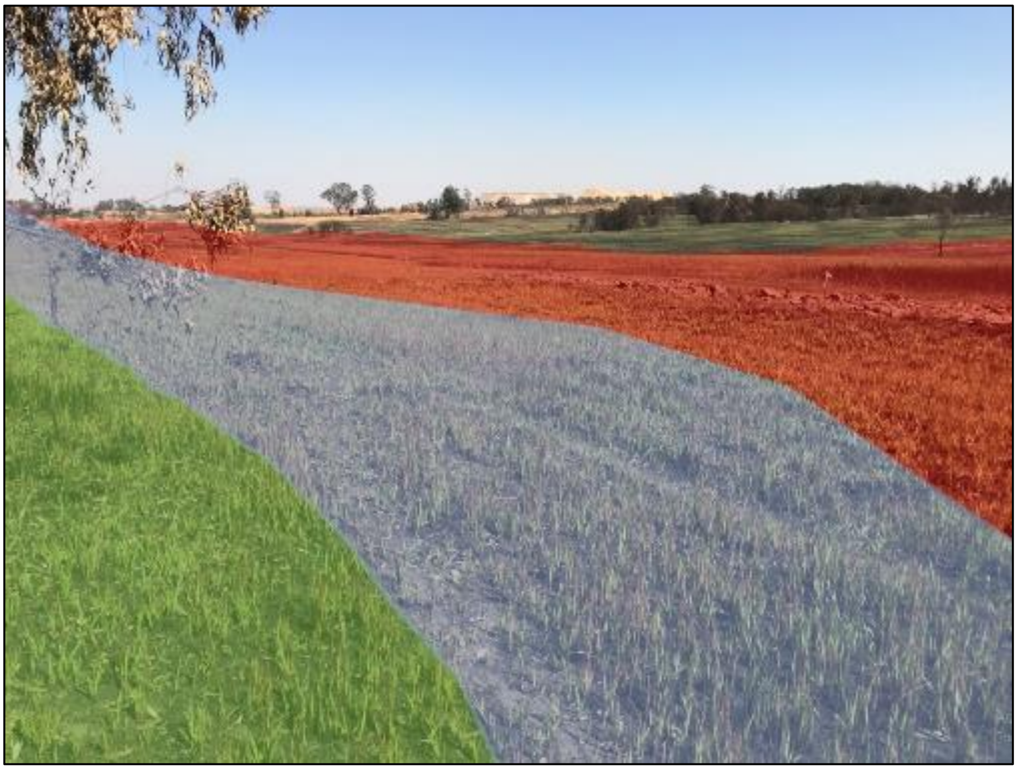

Figure 11: Conceptual illustrations of delineations adjacent to HGM 1. Red: HGM 1. Blue: HGM 2. Green: Terrestrial.

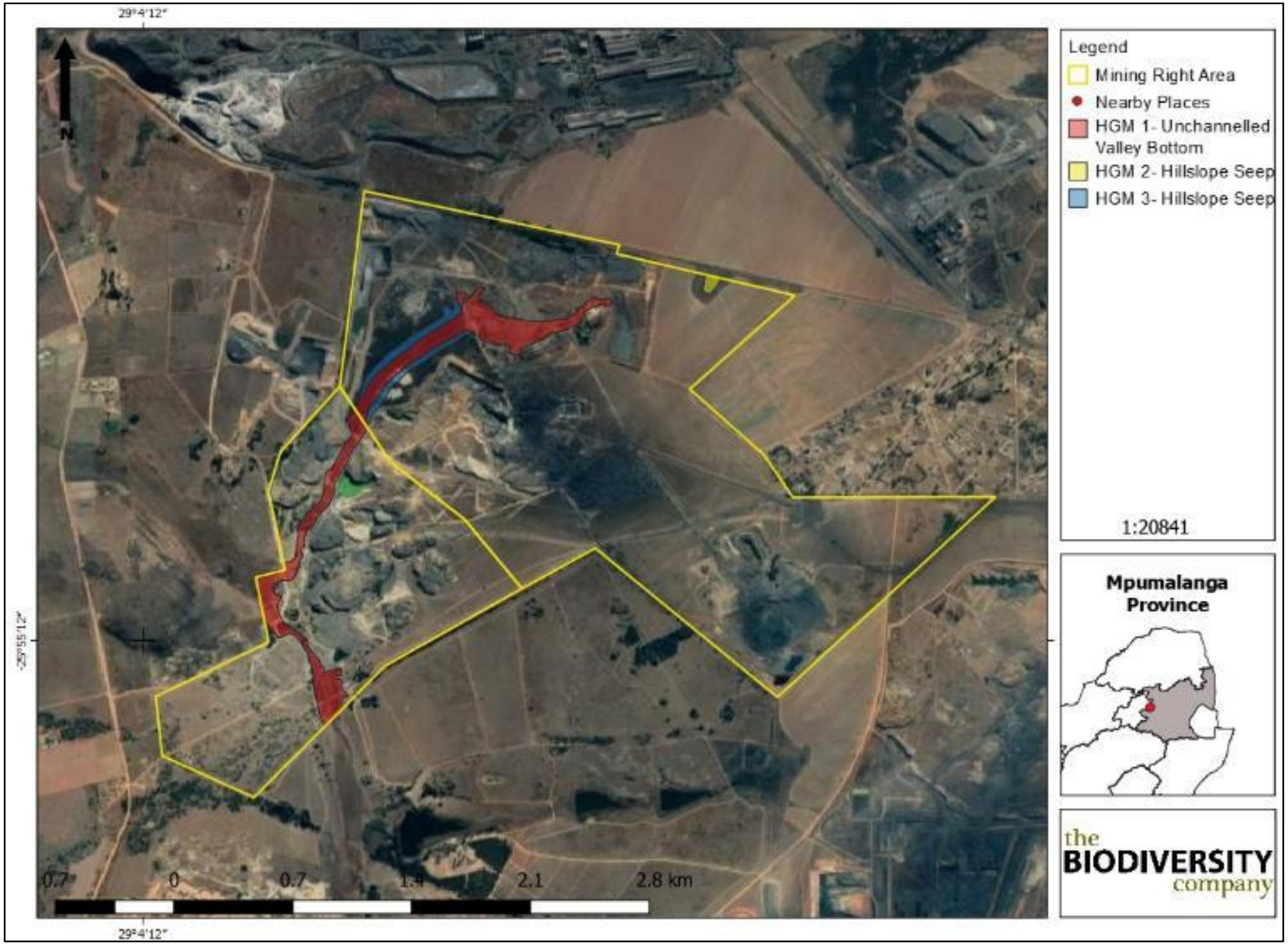

Figure 12: Delineation of wetlands within the MRA

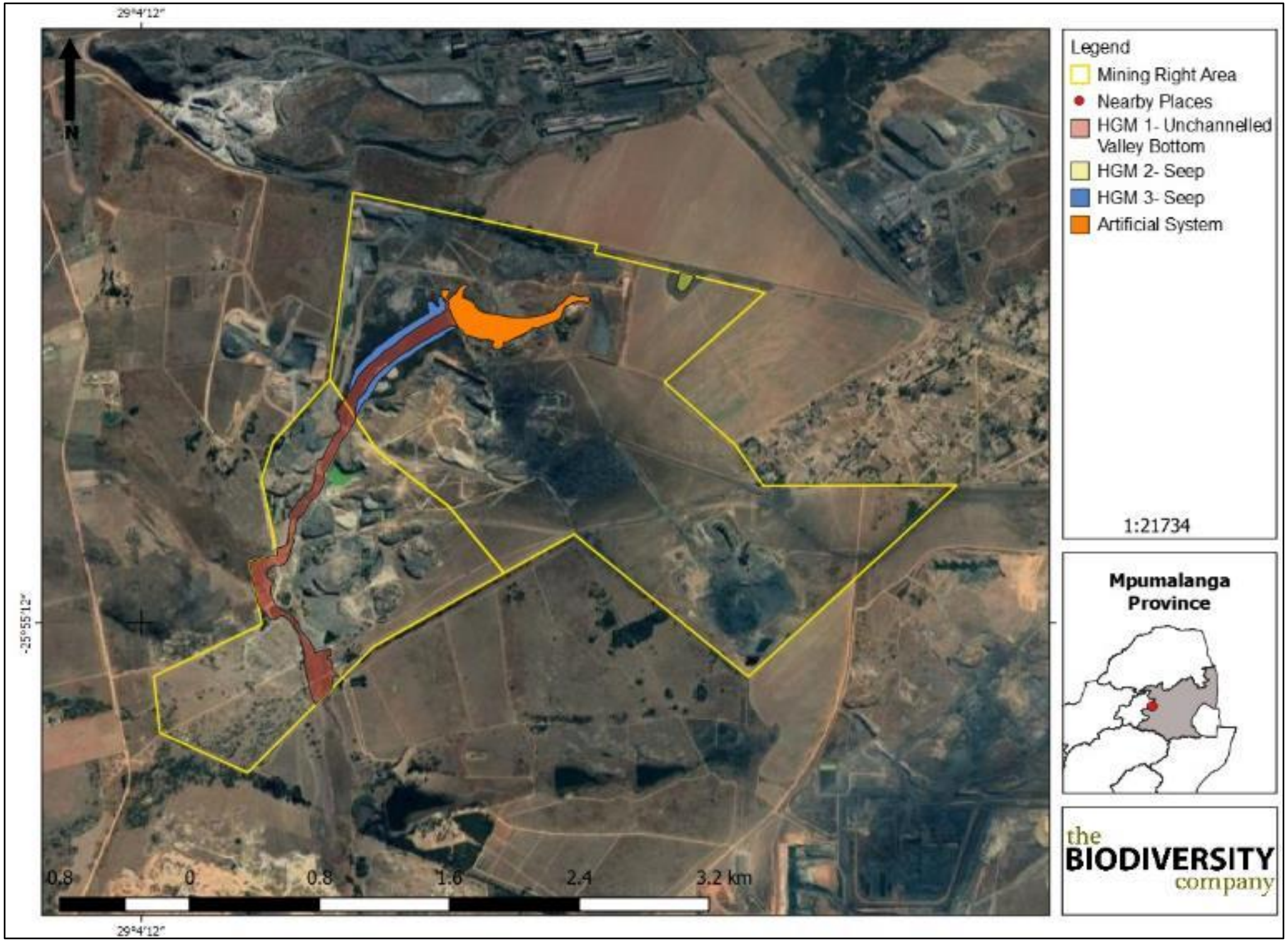

Figure 13: Portion of HGM 1 classified as artificial

7.2 Wetland Unit Identification

The wetland classification as per SANBI guidelines (Ollis *et al.,* 2013) is presented in Table 7. Two wetland types were identified within the project area, namely an unchanneled valley bottom wetland (HGM 1) and two hillslope seeps (HGM 2 and 3).

Table 7: Wetland classification as per SANBI guideline (Ollis et al., 2013)

Wetland System	Level 1	Level 2		Level 3	Level 4		
	System	DWS Ecoregion/s	NFEPA Wet Veg Group/s	Landscape Unit	4A (HGM)	4B	4C
HGM 1	Inland	Highveld	Mesic Highveld Group 4	Valley Floor	Unchanneled Valley Bottom	N/A	N/A
HGM 2	Inland	Highveld	Mesic Highveld Group 4	Hillslope	Hillslope Seep	Without Channelled Outflow	N/A
HGM 3	Inland	Highveld	Mesic Highveld Group 4	Hillslope	Hillslope Seep	Without Channelled Outflow	N/A

7.3 Wetland Unit Setting

HGM 1, as mentioned in Figure 14, is located on the "valley floor" landscape unit. Unchanneled valley bottom wetlands are typically found on valley-floors where the landscape does not allow high energy flows. Figure 14 presents a diagram of the HGM 1, showing the dominant movement of water into, through and out of the system.

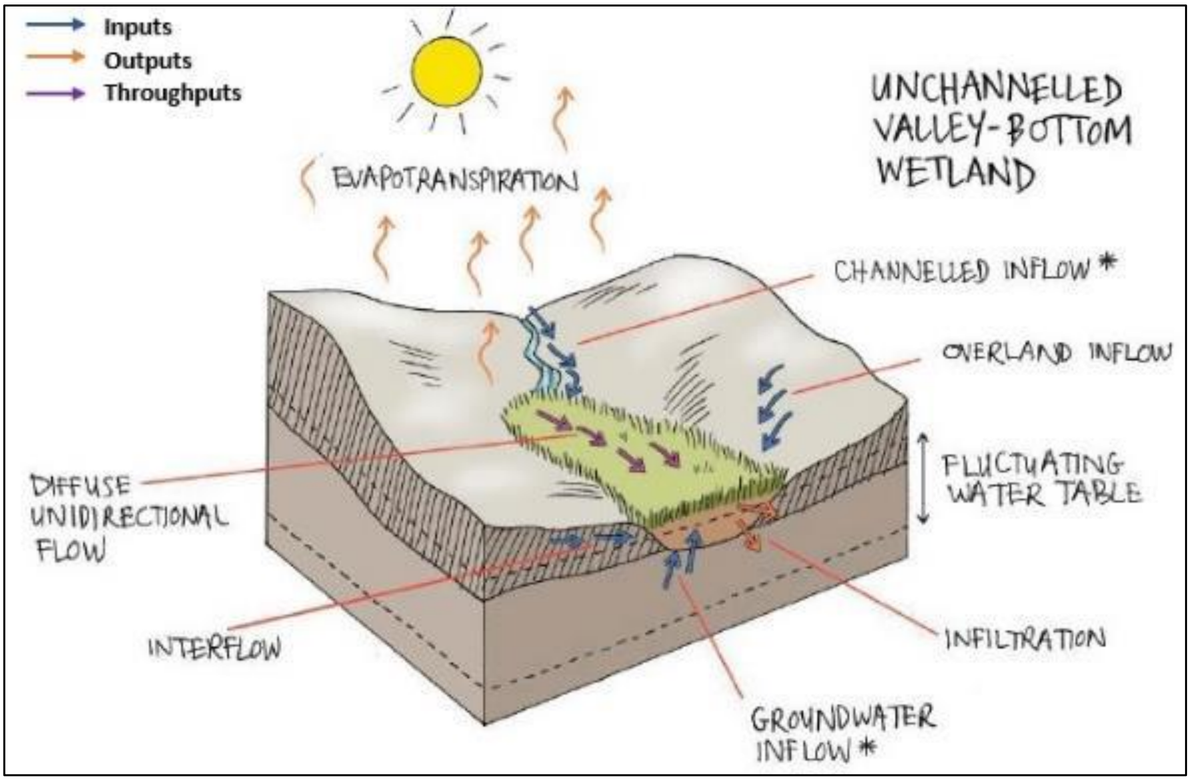

Figure 14: Amalgamated diagram of the HGM type, highlighting the dominant water inputs, throughputs and outputs, SANBI guidelines (Ollis et al. 2013)

HGM 2 and 3 are located within slopes, as indicated in Figure 15. Hillslope seeps are characterised by colluvial movement of material. These systems are fed by very diffuse sub-surface flows which seep out at very slow rates, ultimately ensuring that no direct surface water connects this wetland with other water courses within the valleys. Figure 15 presents a diagram of HGM 2 and 3, showing the dominant movement of water into, through and out of the system.

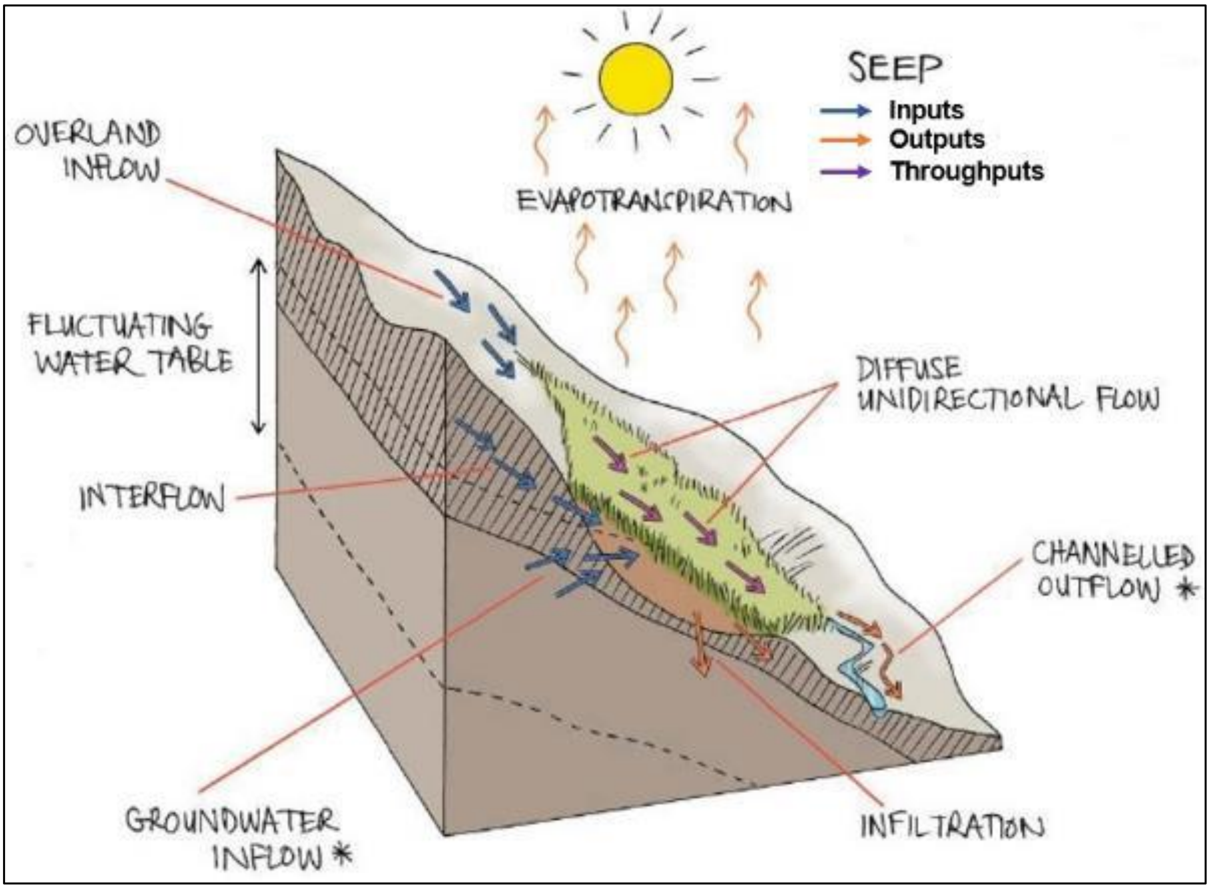

Figure 15: Amalgamated diagram of the HGM type, highlighting the dominant water inputs, throughputs and outputs, SANBI guidelines (Ollis et al., 2013)

7.4 Wetland Indicators

7.4.1 Hydromorphic Soils

According to (DWAF, 2005), soils are the most important characteristic of wetlands in order to accurately identify and delineate wetland areas. Three dominant soil forms were identified within all three identified HGM units, namely the Tshiombo (see Figure 16) and Dundee soil forms as well as Transported Technosols (see Figure 17).

The Dundee soil form consists of an Orthic topsoil on top of a stratified alluvium horizon. The soil family group identified for the Dundee soil form on-site is “2222” due to the chromic colour of the topsoil, the brown colour of the subsoil, the non-calcareous nature of the soil form as well as the pressence of alluvial wetness.

The Tshiombo soil form consists of an Orthic topsoil on top of a Neocutanic horizon, which in turn is underlain by an unconsolidated material with signs of wetness. The soil family group identified for the Tshiombo soil form is “212” due to the chromic colour of the topsoil, the brown colour of the Neocutanic horizon as well as the luvic textural contrast of the Neocutanic horizon.

Transported Technosols is defined by the Soil Classification Working Group (2018) as being soil material that has been intentionally transported and includes anthropogenic material. These soils include waste material (waste rock, tailings material etc.) The Transported Technosols on-site have been identified as a Witbank soil form with the family group “1100”, which emphasises anthropogenic material covering natural soil.

Orthic A topsoils are mineral horizons that have been exposed to biological activities and varying intensities of mineral weathering. The climatic conditions and parent material ensure a wide range of properties differing from one Orthic A topsoil to another (i.e. colouration, structure etc) (Soil Classification Working Group, 2018).

The Neocutanic horizon is associated with recent depositions and unconsolidated soils. Any soil form can develop out of a Neocutanic horizon, depending on the climatic and topographical conditions). Some properties pertaining to other diagnostic soil horizons will be present within a Neocutanic horizon but will lack main properties necessary to classify the relevant soil type.

The stratified alluvium horizon is formed via alluvial or colluvial processes. This soil type is stratified and closely resembles the parent material of this soil type. Stratified alluvium generally is fertile and is often therefore used for cultivation purposes.

Figure 16: Neocutanic horizons with signs of wetness

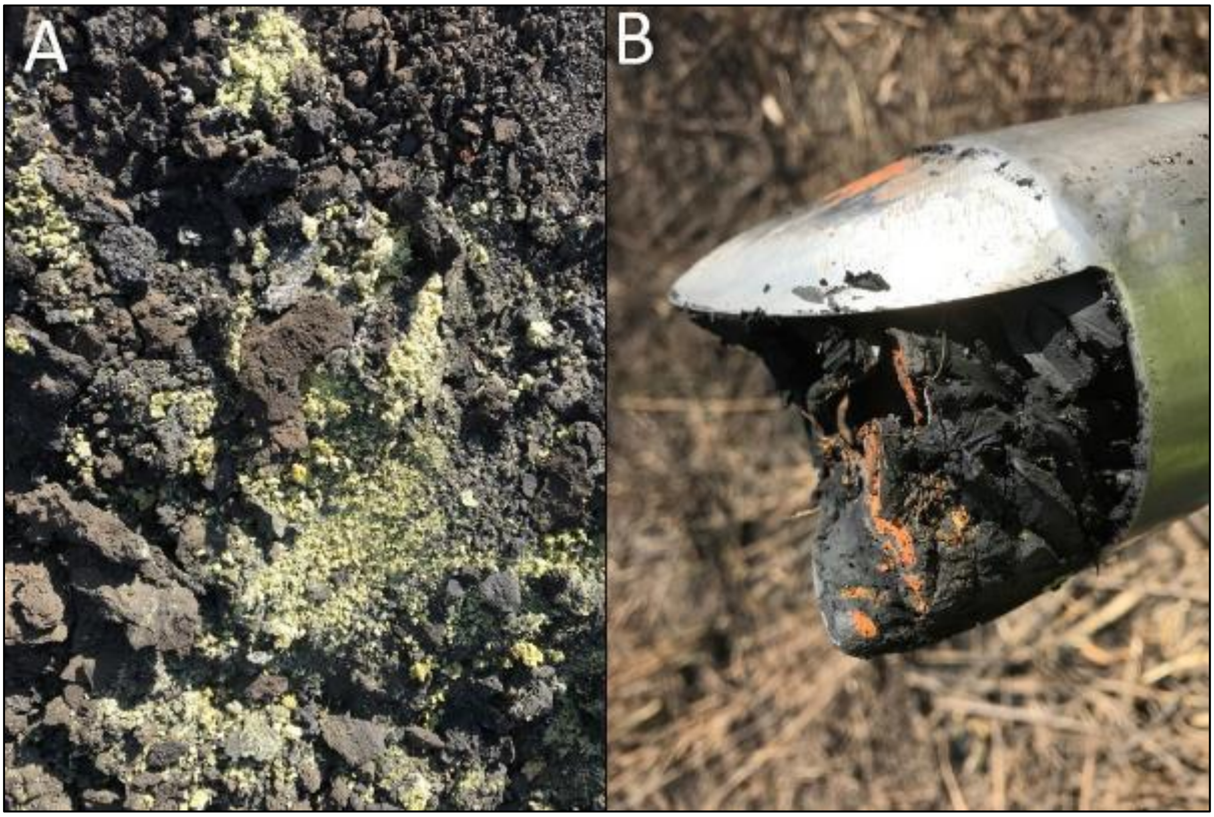

Figure 17: Transported Technosols identified within wetlands. A: Overburden material with salt precipitation. B: Coal from waste impoundments identified within wetlands (including signs of wetness)

7.4.2 Hydrophytes

Vegetation plays a considerable role in identifying, classifying and accurately delineating wetlands (DWAF, 2005). During the site visit, four dominant hydrophyte species were identified, including *Schoenoplectus spp., Imperata cylindrica, Phragmites australis* and *Typha capensis* (see Figure 18).

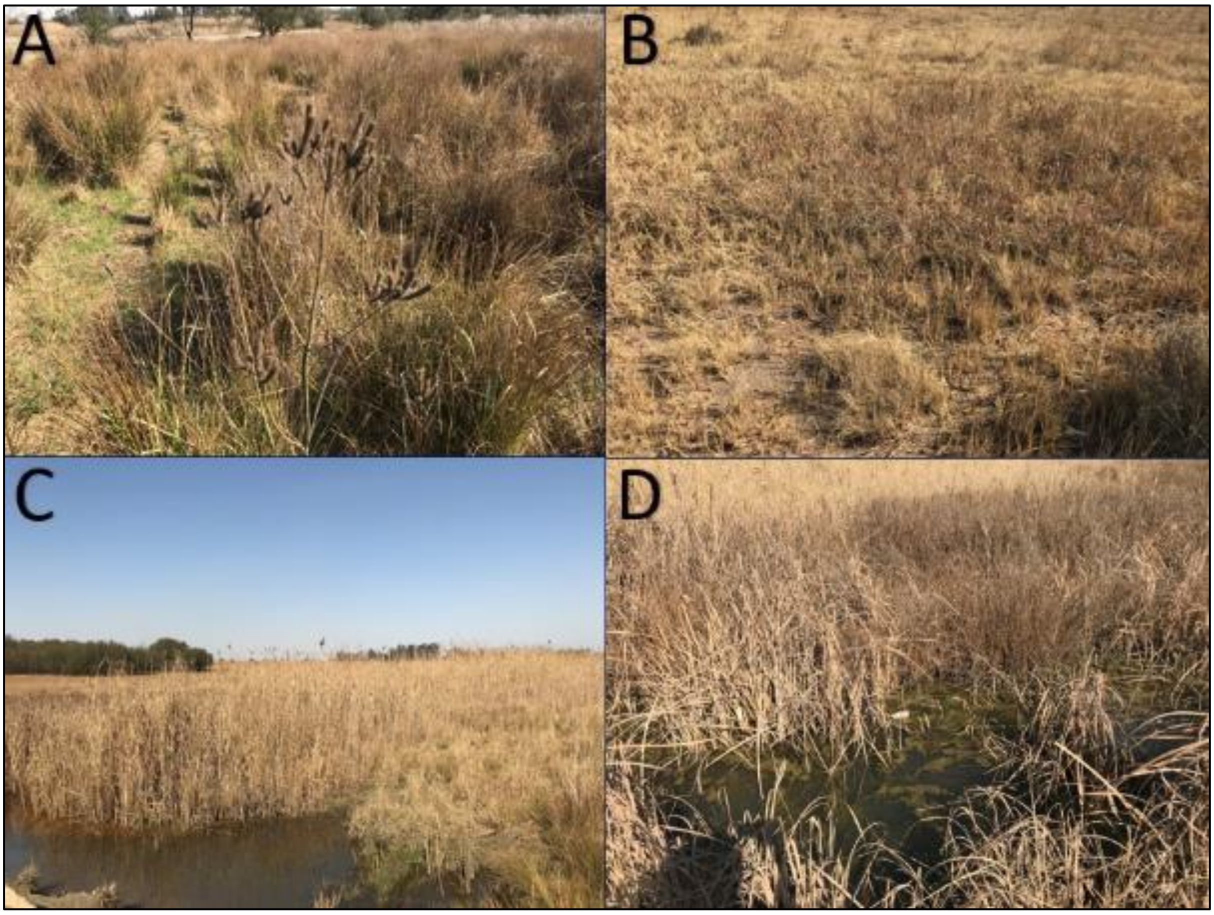

Figure 18: Hydrophytes identified within the delineated wetlands. A: Verbena and Schoenoplectus spp. B: Imperata cylindrica. C: Phragmites Australis. Typha capensis

7.5 General Functional Description

Unchanneled valley bottoms are characterised by sediment deposition, a gentle gradient with streamflow generally being spread diffusely across the wetland, ultimately ensuring prolonged saturation levels and high levels of organic matter. The assimilation of toxicants, nitrates and phosphates are usually high for unchanneled valley bottom wetlands, especially in cases where the valley is fed by sub-surface interflow from slopes. The shallow depths of surface water within this system adds to the degradation of toxic contaminants by means of sunlight penetration.

Hillslope seeps are well documented by (Kotze et al., 2008) to be associated with sub-surface ground water flows. These systems tend to contribute to flood attenuation given their diffuse nature. This attenuation only occurs while the soil within the wetland is not yet fully saturated. The accumulation of organic material and sediment contributes to prolonged levels of saturation due to this deposition slowing down the sub-surface movement of water. Water typically accumulates in the upper slope (above the seep). The accumulation of organic matter additionally is essential in the denitrification process involved with nitrate assimilation. Seeps generally also improve the quality of water by removing excess nutrient and inorganic pollutants originating from agriculture, industrial or mine activities. The diffuse nature of flows ensures the assimilation of nitrates, toxicants and phosphates with erosion control being one of the Eco Services provided very little by the wetland given the nature of a typical seep's position on slopes.

It is however important to note that the descriptions of the above-mentioned functions are merely typical expectations. All wetland systems are unique and therefore, the ecosystem services rated high for these systems on site might differ slightly to those expectations.

7.6 Ecological Functional Assessment

The ecosystem services provided by the wetland units identified on site were assessed and rated using the WET-EcoServices method (Kotze *et al.,* 2008). The summarised results for HGM 1, 2 and 3 are shown in Table 8. The average ecosystem services score has been determined to be "Intermediate" for HGM 1 and "Moderately Low" for HGM 2 and 3.

Table 8: The ecosystem services being provided by the HGM types

Wetland Unit					HGM 1	HGM 2	HGM 3
Ecosystem Services Supplied by Wetlands	Indirect Benefits	Regulating and supporting benefits	Flood attenuation		2.3	1.9	1.7
			Streamflow regulation		2.1	1.8	1.7
			Water Quality enhancement benefits	Sediment trapping	2.4	2.0	2.1
				Phosphate assimilation	2.6	2.3	2.2
				Nitrate assimilation	2.5	2.2	2.3
				Toxicant assimilation	2.6	2.1	2.0
				Erosion control	2.4	1.9	1.8
			Carbon storage		1.8	1.6	1.6
	Direct Benefits	**Biodiversity maintenance**			1.1	1.4	1.2
		Provisioning benefits	Provisioning of water for human use		0.2	0.3	0.4
			Provisioning of harvestable resources		0.0	0.0	0.0
			Provisioning of cultivated foods		0.0	0.0	0.0
		Cultural benefits	Cultural heritage		0.0	0.0	0.0
			Tourism and recreation		0.0	0.0	0.0
			Education and research		0.6	0.8	1.0
Average Eco Services Score					1.4	1.2	1.2

Table 9 illustrates the ecosystem services rated "High" for the delineated wetlands with summarised descriptions of these ecosystem services. For HGM 1, seven ecosystem services have been rated high with HGM 2 and 3 characterised by three ecosystem services rated "High".

Table 9: Ecosystem services scored "High" for the delineated wetlands

EcoService	HGM 1	HGM 2	HGM 3	Justification of High Score
Flood attenuation	✓			The slope of the wetland, the size of the wetland relevant to it's sub-catchment as well as the surface roughness within HGM 1 contributes to this ecosystem service score.
Streamflow regulation	✓			This high score is attributed to the presence of other watercourses downstream of the wetland, the reduction in evapotranspiration due to frosting as well as the presence of underlying geology with strong sub-surface flow connotations.
Sediment trapping	✓		✓	The high score determined for "Sediment Trapping" is mainly described to the evidence of sediment trapping (see Figure 19) as well as the fact that there are no dams upstream of the wetlands to trap sediments before entering the relevant wetlands.
Phosphate assimilation	✓	✓	✓	The high scores rated for the assimilation of phosphates, nitrates and other toxicants are high due to the potential of contamination via these parameters. The higher the potential for contamination is, the higher these wetlands are rated due to the importance of these systems to assimilate contaminants.
Nitrate assimilation	✓	✓	✓	
Toxicant assimilation	✓	✓		
Erosion control	✓			The slope of the wetland and the high density of hydrophytes within HGM 1 contributes to the high level of erosion control within HGM 1.

Figure 19: Sediment inputs and trapping within HGM 1

7.7 The Ecological Health Assessment

The PES for the assessed HGM types is presented in Table 10. The overall PES classes for HGM 1, 2 and 3 has been determined to be “Critically Modified”, “Largely Modified” and “Moderately Modified” respectively.

Table 10: Summary of the scores for the wetland PES

Wetland	Hydrology		Geomorphology		Vegetation	
	Rating	Score	Rating	Score	Rating	Score
HGM 1	E: Seriously Modified	8.3	E: Seriously Modified	6.5	F: Critically Modified	9.2
Overall PES Score	8.0		Overall PES Class		F: Critically Modified	
HGM 2	D: Largely Modified	5.1	C: Moderately Modified	2.3	F: Critically Modified	9.1
Overall PES Score	5.7		Overall PES Class		D: Largely Modified	
HGM 3	C: Moderately Modified	3.9	B: Largely Natural	1.8	D: Largely Modified	4.6
Overall PES Score	3.5		Overall PES Class		C: Moderately Modified	

The hydrology score for all three HGM units (especially HGM 1) has been affected by increased overland flow from the surrounding land use (mining) as well as the presence of drains and gullies (see Figure 20). The geomorphology component of HGM 1 has been modified the most, predominantly by the presence of drains and gullies (as mentioned) as well as wetland crossings (Figure 21). The vegetation component has been affected by means of the surrounding land use. Mining activities and components have resulted in a large-scale degradation and removal of vegetation. See Figure 22 for a comparison of vegetation patterns in 2010 compared to 2019.

Figure 20: Components contributing to an increase of water inputs within delineated wetlands. A: Artificial surfaces within close proximity to HGM 1. B: Drainage lines/gullies within the wetland's catchments

Figure 21: Example of a wetland crossing (blue arrow indicating position and direction of flow)

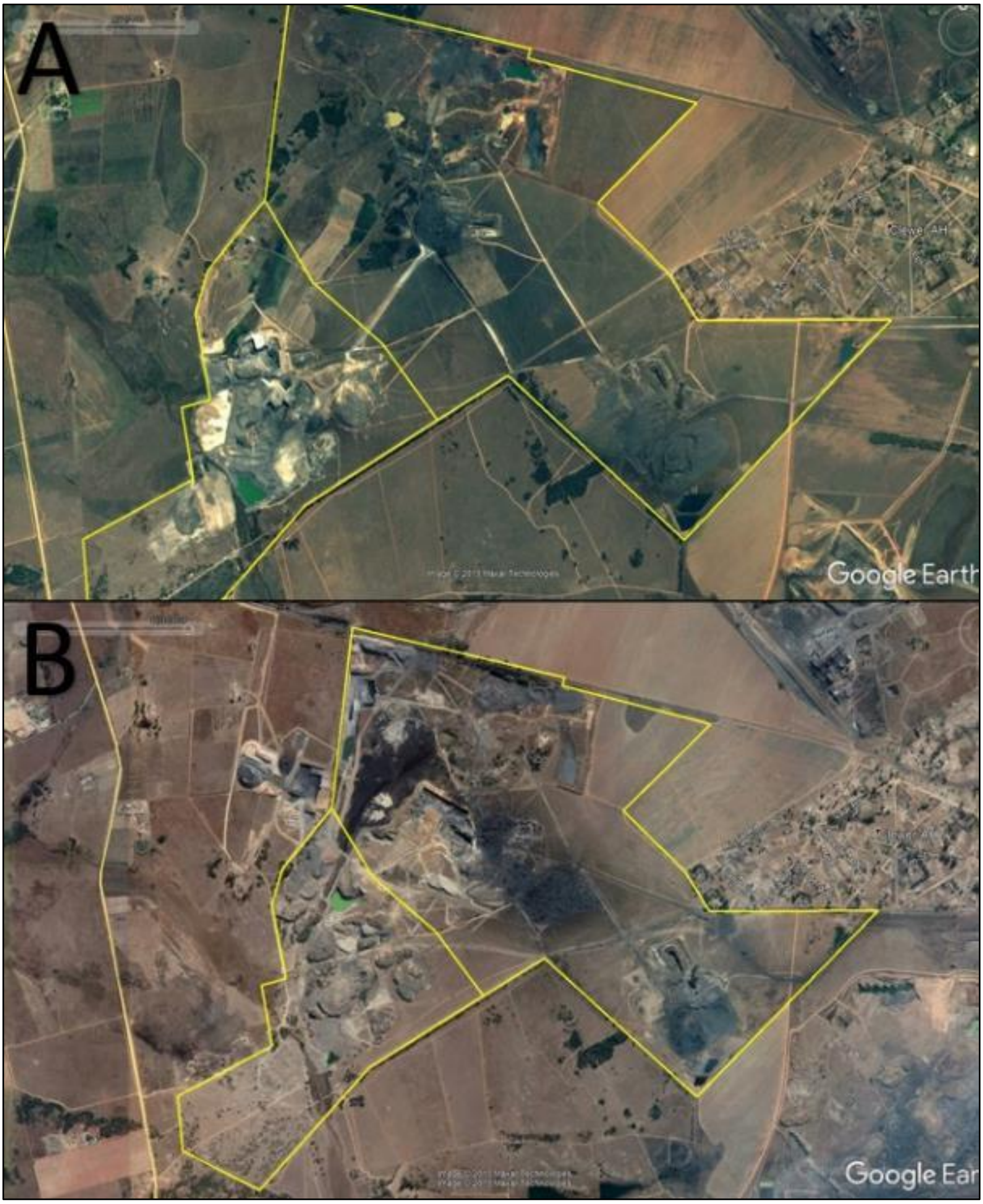

Figure 22: Loss of vegetation over 9 years. A: Aerial imagery in 2010. B: Aerial imagery 2019.

7.8 The Ecological Importance & Sensitivity Assessment

The wetland EIS assessment was applied to the HGM units described in the previous section in order to assess the levels of sensitivity and ecological importance of the wetlands. The results of the assessment are shown in Table 11.

Table 11: The EIS results for the delineated HGM types

Wetland Importance & Sensitivity	Importance		
	HGM 1	HGM 2	HGM 3
Ecological importance and sensitivity	**2.3**	**1.6**	**1.7**
Hydrological/functional importance	**2.0**	**1.6**	**1.2**
Direct human benefits	**0.3**	**0.2**	**0.3**

A "High" level of EIS have been scored for HGM 1, with HGM 2 and 3 being scored "Intermediate". The "High" score relevant to HGM 1 is attributed to the sensitivity of unchanneled valley bottom wetlands to low flows. Furthermore, the modification and deterioration of water quality from contaminated mine water (see Figure 23) has resulted in a loss of habitat and the use of watercourses as breeding sites.

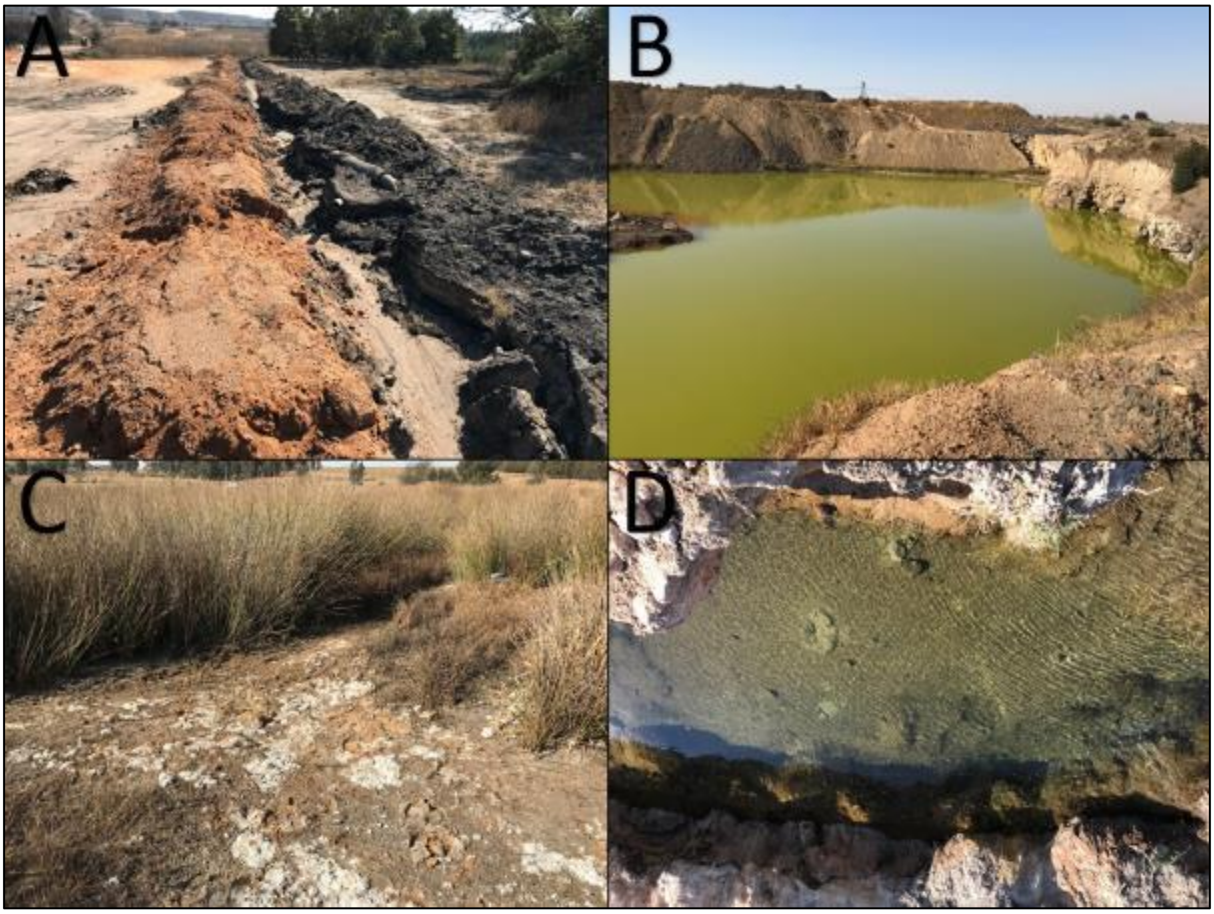

Figure 23: Sources of water contamination. A: Pathway for polluted surface water to the receptor (wetland). B: Stagnating, contaminated water in close proximity to HGM 1. C: Salt precipitation within HGM 1. D: Potential AMD.

The Hydrological/Functional Importance has been rated "Moderate" for all HGM units. The HGM units have been rated "Moderate" given the ability of the units to enhance water quality to a degree (see section "7.6") for a detailed description of the indirect benefits gained from relevant ecosystem services. The following ecosystem services all contribute to the high hydrological/functional importance determined for the delineated wetland;

- Sediment trapping;
- Streamflow regulation;
- The assimilation of phosphates, nitrates and other toxicants;
- Flood attenuation; and
- Erosion control.

The Direct Human Benefits have been scored “Low” for all three HGM units due to very little to no signs or potential for cultural and religious activities or the potential for sustenance.

7.9 Buffer Requirements

The “Preliminary Guideline for the Determination of Buffer Zones for Rivers, Wetlands and Estuaries” (Macfarlane *et al.,* 2014) was used to determine the appropriate buffer zone for the proposed activity. The buffer zones calculated for the proposed open cast activities are 106 m with no buffer requirement for underground mining activities. Figure 24 illustrates the extent of the post-mitigation buffer zones (106 m) relevant to the delineated wetlands for the proposed open cast mining activities.

Table 12: Pre- and post- mitigation threat ratings for the proposed open cast mining activities

Phase	Threat	Pre-Mitigation Threat Rating	Post-Mitigation Threat Rating
		Open Cast Mining	
Construction Phase	Alterations to flow volumes	High	Moderate
	Alterations of patterns of flows	High	Moderate
	Increase in sediment inputs and turbidity	High	Moderate
	Increased nutrient inputs	High	Moderate
	Inputs of toxic organic contaminants	High	Moderate
	Inputs of toxic heavy metals	High	Moderate
	Alterations of acidity (pH)	Moderate	Low
	Increased inputs of salts	Moderate	Low
	Change in water temperature	Moderate	Low
	Pathogen inputs	Very Low	Very Low
Operational Phase	Alterations to flow volumes	Very High	High
	Alterations of patterns of flows	Very High	High
	Increase in sediment inputs and turbidity	Very High	High
	Increased nutrient inputs	Very High	Very High
	Inputs of toxic organic contaminants	Very High	High
	Inputs of toxic heavy metals	Very High	High
	Alterations of acidity (pH)	Very High	High
	Increased inputs of salts	Very High	High
	Change in water temperature	Moderate	Moderate
	Pathogen inputs	Very Low	Very Low

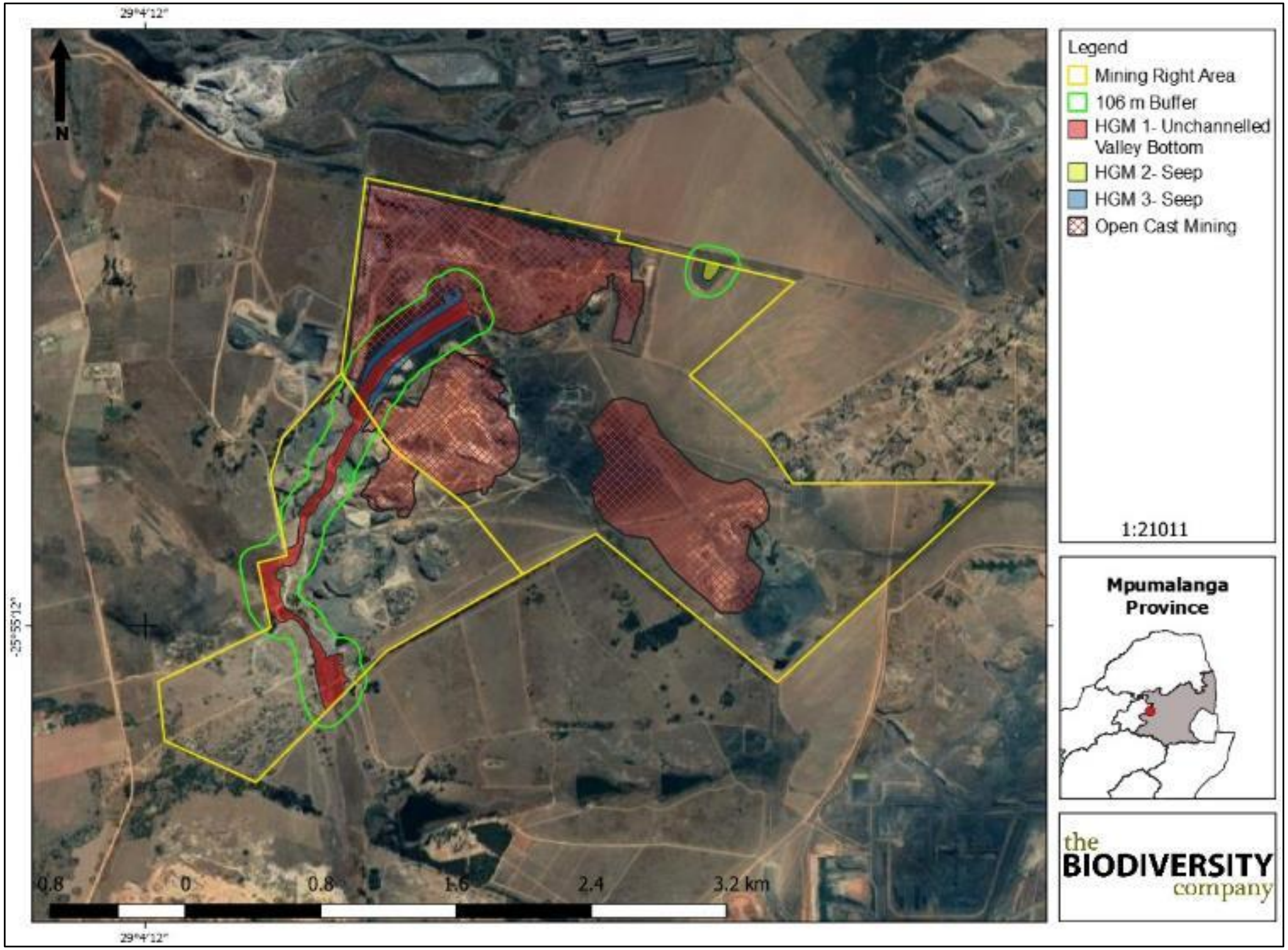

Figure 24: Open cast pit buffer requirement

8 Risk Assessment

The impact assessment considered both direct and indirect impacts, to the wetland systems. The mitigation hierarchy as discussed by the Department of Environmental Affairs (DEA) (2013) will be considered for this component of the assessment (Figure 25). In accordance with the mitigation hierarchy, the preferred mitigatory measure is to avoid impacts by considering options in project location, sitting, scale, layout, technology and phasing to avoid impacts. Section 7.9- “Buffer Requirements” illustrates the extent of the recommended buffer zones within the project area. It is evident from the buffer’s extent that some of the identified wetlands are located within the proposed open cast buffer zones. Therefore, according to the mitigation hierarchy (DEA, 2013), avoiding wetlands will not be possible for all the delineated systems. The next step therefor will be to minimise the expected impacts.

Even though none of the wetlands will be undermined by the proposed underground mining areas (see Figure 26), some recommendations will be made in Section 9- “Recommendations” to ensure the conservation of the delineated wetlands.

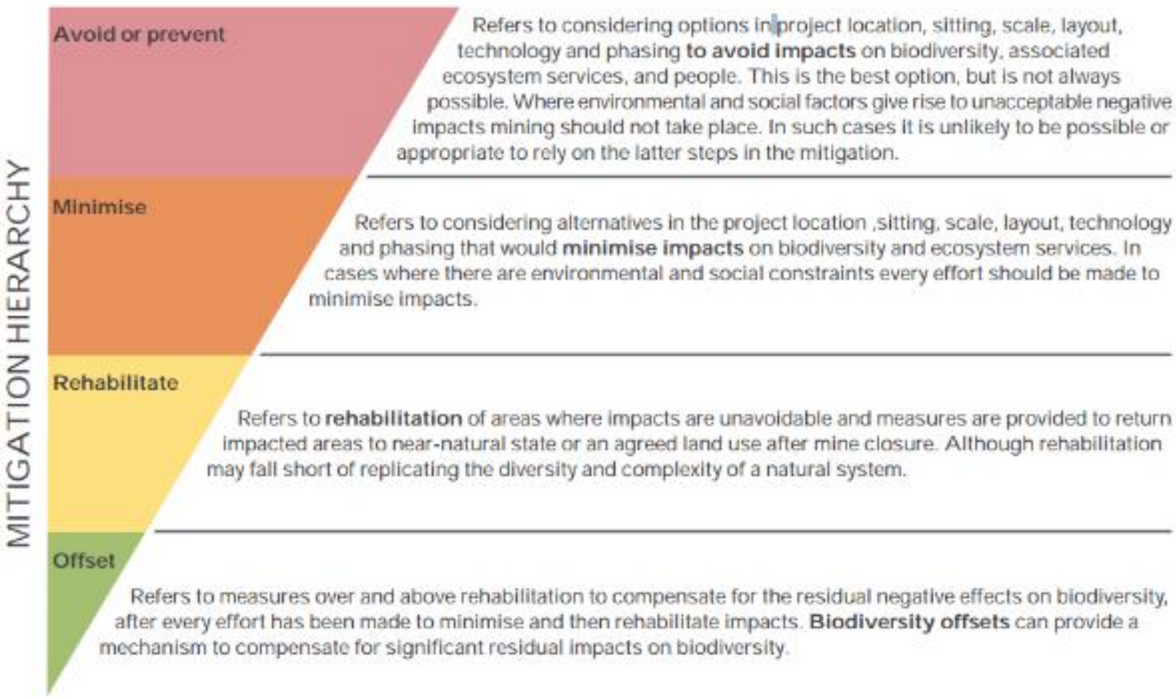

Figure 25: The mitigation hierarchy as described by the DEA (2013)

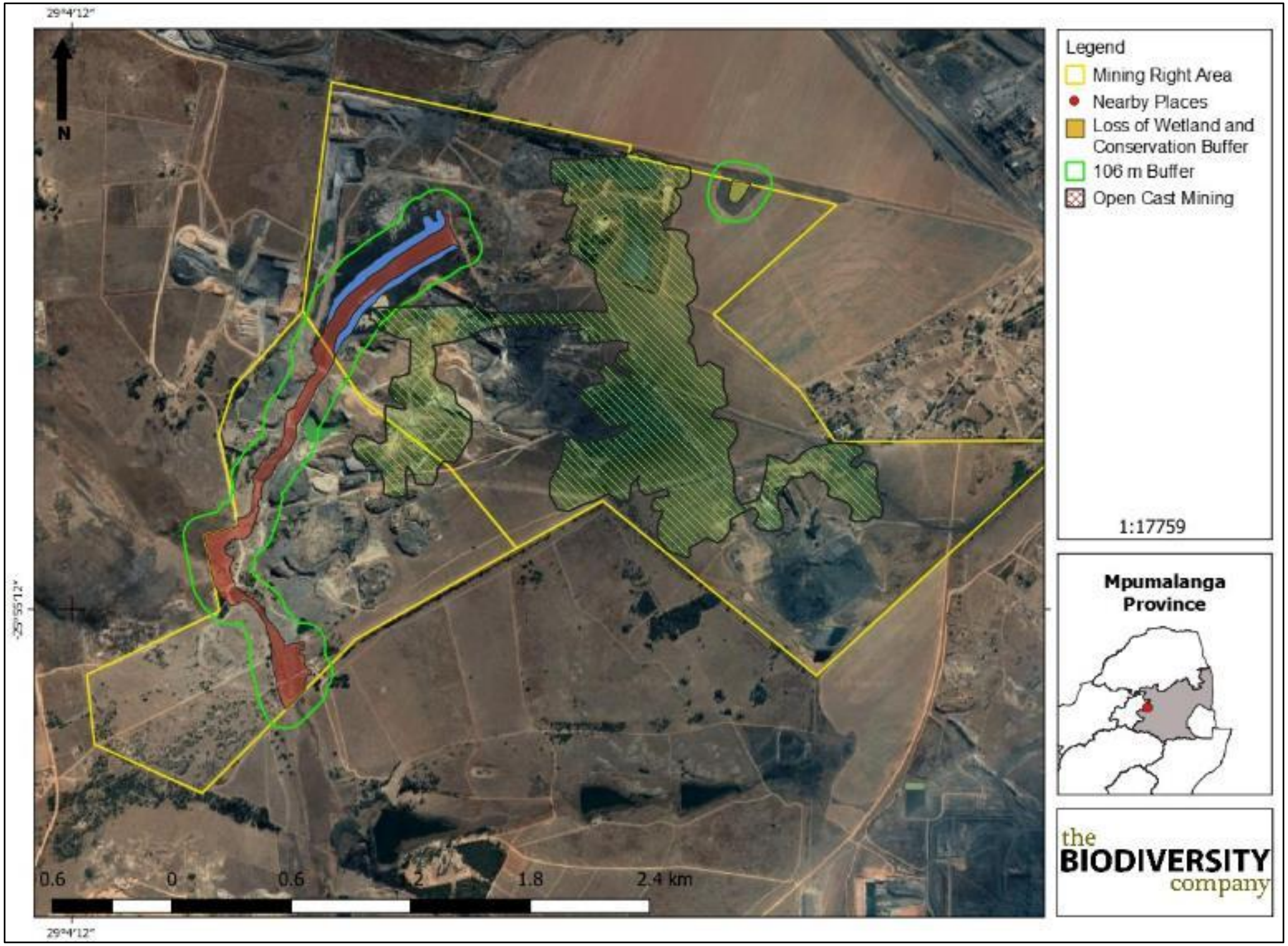

Figure 26: Extent of underground mining areas

8.1 Potential Impacts Anticipated

Pre-mitigation aspects during the construction phase have been scored with “Low” to “High” significance ratings, of which some are expected to be decreased to a “Low” significance rating by means of relevant mitigation measures and recommendations.

Construction Phase

The following aspects have been scored “Moderate” or “High” post-mitigation significance ratings during the construction phase;

Open Cast Mining

- Excavating the open cast pit;
- Storage of chemicals, mixes and fuel;
- Construction of haul roads for the open cast pit; and
- Acid Mine Drainage (AMD) pollution related to the open cast pit.

Underground Mining

- None

Operational Phase

As for the operational phase, the following aspects have been scored “Moderate” or “High” post-significance ratings;

Open Cast Mining

- AMD pollution relevant to the operation of open cast mining; and
- Dust pollution related to open cast mining.

Underground Mining

- Subsidence;
- Groundwater pollution; and
- Cracking of bedrock.

Decommissioning and Closure

- Decant (AMD).

Table 13: Aspects and impacts relevant to the proposed activity

Phase	Activity	Aspect	Impact
Construction	Open cast Mining	Removal of vegetation	• Direct loss of wetlands; • Erosion of wetlands and their catchments; • Loss of vegetation; • Decrease in functionality; • Water quality impairment; • Compaction; • Altering hydromorphic soils; • Drainage patterns change; • Altering overland flow characteristics; • Loss of interflow; • Deposition of dust; • Salinization; and • AMD.
		Stripping of topsoil	
		Traffic	
		Ablution facilities	
		Construction of haul roads	
		AMD related pollution	
		Domestic and industrial waste	
		Storage of chemicals, mixes and fuel	
		Spills and leaks	
		Erosion from disturbances within the wetland	
		Siltation of watercourses	
	Underground Mining	Subsidence	• Indirect loss of wetlands; • Loss of vegetation; • Decrease in functionality; • Water quality impairment; • Compaction; • Drainage patterns change; • Loss of interflow; • Salinization; and • AMD.
		Groundwater pollution	
		Cracking of bedrock	
		Increased Surface Traffic	
Operational	Open cast Mining	Excavating open cast pit	• Direct loss of wetlands; • Erosion of wetlands and their catchments; • Loss of vegetation; • Decrease in functionality;
		Traffic	
		AMD related pollution	
		Domestic and industrial waste	
		Storage of chemicals, mixes and fuel	

<table>
<tr><td rowspan="7"></td><td rowspan="3"></td><td>Spills and leaks</td><td rowspan="3">Water quality impairment;
Compaction;
Altering hydromorphic soils;
Drainage patterns change;
Altering overland flow characteristics;
Loss of interflow;
Deposition of dust;
Salinization; and
AMD.</td></tr>
<tr><td>Erosion from disturbances within the wetland</td></tr>
<tr><td>Siltation of watercourses</td></tr>
<tr><td rowspan="4">Underground Mining</td><td>Subsidence</td><td rowspan="4">Indirect loss of wetlands;
Loss of vegetation;
Decrease in functionality;
Water quality impairment;
Compaction;
Drainage patterns change;
Loss of interflow;
Salinization; and
AMD.</td></tr>
<tr><td>Groundwater pollution</td></tr>
<tr><td>Cracking of bedrock</td></tr>
<tr><td>Increased Surface Traffic</td></tr>
<tr><td rowspan="5">Decommissioning and Closure</td><td rowspan="2">Backfilling of voids</td><td>Dust Precipitation</td><td rowspan="5"></td></tr>
<tr><td>Change in topography</td></tr>
<tr><td rowspan="2">Shaping/contouring the landscape</td><td>Dust Precipitation</td></tr>
<tr><td>Change in topography</td></tr>
<tr><td>Decant</td><td>Acid Mine Drainage</td></tr>
</table>

Table 14: DWS Risk Impact Matrix for the proposed project

Andrew Husted (*Pr. Scinat* 400213/11)								
Severity								
Aspect	**Flow Regime**	**Physico and Chemical (Water Quality)**	**Habitat (Geomorph and Vegetation)**	**Biota**	**Severity**	**Spatial scale**	**Duration**	**Consequence**
Construction Phase								
Open cast Mining								
Removal of vegetation	2	2	3	3	**2,5**	2	2	**6,5**
Striping of topsoil	5	3	5	4	**4,25**	2	2	**8,25**
Traffic	2	2	2	3	**2,25**	2	2	**6,25**
Ablution facilities	2	4	2	3	**2,75**	2	2	**6,75**
Construction of haul roads	4	2	3	3	**3**	2	2	**7**
AMD related pollution	2	3	3	3	**2,75**	3	5	**10,75**
Domestic and industrial waste	2	3	3	3	**2,75**	2	3	**7,75**
Storage of chemicals, mixes and fuel	**2**	**3**	**3**	**3**	**2,5**	**2**	**2**	**9**
Spills and leaks	1	4	3	3	**3**	**3**	**3**	**7,75**
Erosion from disturbances within the wetland	2	3	3	2	**2,75**	3	2	**7,5**
Underground Mining								
Subsidence	5	2	4	4	**3,75**	1	2	**6,75**

Groundwater pollution	2	4	4	4	**3,5**	3	2	**8,5**
Cracking of bedrock	3	3	4	3	**3,25**	3	1	**7,25**
Increased Surface Traffic	3	3	3	3	**3**	1	2	**6**
Operational Phase								
Open cast Mining								
AMD pollution	1	4	2	3	**2,5**	4	5	**11,5**
Dust pollution	1	3	2	2	**2**	3	4	**9**
Increased overland flow	3	2	2	2	**2,25**	2	2	**6,25**
Underground Mining								
Subsidence	5	2	4	4	**3,75**	1	5	**9,75**
Groundwater pollution	2	4	4	4	**3,5**	3	5	**11,5**
Cracking of bedrock	3	2	3	3	**2,75**	2	4	**8,75**
Increased Surface Traffic	3	3	3	3	**3**	1	5	**9**
Decommissioning								
Dust Precipitation (From Backfilling)	1	3	2	2	**2**	2	2	**6**
Change in topography (From Backfilling)	2	2	2	2	**2**	1	2	**5**
Dust Precipitation (From Shaping/Contouring)	1	3	2	2	**2**	2	2	**6**
Change in topography (From Shaping/Contouring)	3	2	3	3	**2,75**	1	2	**5,75**
Acid Mine Drainage	1	5	5	5	**4**	4	5	**13**

Table 15: DWS Risk Assessment Continued

Andrew Husted (*Pr. Scinat* 400213/11)								
Aspect	**Frequency of activity**	**Frequency of impact**	**Legal Issues**	**Detection**	**Likelihood**	**Sig.**	**Without Mitigation**	**With Mitigation**
Construction Phase								
Open cast Mining								
Removal of vegetation	2	2	1	2	7	45,5	Low	Low
Stripping of topsoil	1	4	5	1	11	90,75	Moderate	Moderate
Traffic	2	2	1	2	7	43,75	Low	Low
Ablution facilities	2	2	1	2	7	47,25	Low	Low
Construction of haul roads	2	4	5	2	13	91	Moderate	Moderate
AMD related pollution	2	5	5	2	14	150,5	Moderate	Moderate
Domestic and industrial waste	2	3	1	2	8	62	Moderate	Low
Storage of chemicals, mixes and fuel	2	3	1	3	9	78,75	Moderate	Moderate
Spills and leaks	2	3	1	3	9	69,75	Moderate	Low
Erosion from disturbances within the wetland	3	3	1	2	9	67,5	Moderate	Low
Underground Mining								
Subsidence	2	5	5	1	13	87,75	Moderate	Low
Groundwater pollution	2	5	5	3	15	127,5	Moderate	Low
Cracking of bedrock	1	3	5	2	11	79,75	Moderate	Low

Increased Surface Traffic	5	1	5	1	12	**72**	**Moderate**	**Low**
Operational Phase								
Open cast Mining								
AMD pollution	4	4	5	4	17	**195,5**	**High**	**Moderate**
Dust pollution	4	4	1	4	13	**117**	**Moderate**	**Moderate**
Increased overland flow	3	3	1	3	10	**62,5**	**Moderate**	**Low**
Underground Mining								
Subsidence	4	5	5	1	15	**146,25**	**Moderate**	**Moderate**
Groundwater pollution	2	5	5	3	15	**172,5**	**High**	**Moderate**
Cracking of bedrock	4	4	1	4	13	**113,75**	**Moderate**	**Moderate**
Increased Surface Traffic	5	1	5	1	12	**108**	**Moderate**	**Low**
Decommisisoning and Closure								
Dust Precipitation (From Backfilling)	**1**	**2**	**5**	**3**	**11**	**66**	Moderate	Low
Change in topography (From Backfilling)	1	2	1	2	**6**	**30**	Low	Low
Dust Precipitation (From Shaping/Contouring)	1	2	5	3	**11**	**66**	Moderate	Low
Change in topography (From Shaping/Contouring)	1	2	1	2	**6**	**34,5**	Low	Low
Acid Mine Drainage	4	4	5	4	**17**	**221**	High	Moderate
In accordance with General Notice 509 “Risk is determined after considering all listed control / mitigation measures. Borderline Low / Moderate risk scores can be manually adapted downwards up to a maximum of 25 points (from a score of 80) subject to listing of additional mitigation measures detailed below								

8.2 Mitigation Measures

The following mitigation measures will be required to ensure the decrease in those significance ratings expected to decrease from “Moderate” to “Low” as stipulated in Section 9.0- “

8.2.1 General

The following mitigation measures are aimed to conserve wetlands in general;

- The recommended buffer zone has to be respected at all times (except for those sections of the proposed open cast areas and associated haul roads located within the delineated wetlands;
- The contractors used for the construction should have spill kits available prior to construction to ensure that any fuel, oil or hazardous substance spills are cleaned-up and discarded correctly;
- It is deemed important that all wetland areas be demarcated as sensitive areas, and no construction activity, laydown yards, camps or dumping of construction material are to be permitted within the sensitive zones (where possible);
- During construction activities, all rubble generated must be removed from the site;
- Construction vehicles and machinery must make use of existing access routes as much as possible, before adjacent areas are considered for access;
- All chemicals and toxicants to be used for the construction must be stored outside the channel system and in a bunded area;
- All machinery and equipment should be inspected regularly for faults and possible leaks, these should be serviced off-site;
- All contractors and employees should undergo induction which is to include a component of environmental awareness. The induction is to include aspects such as the need to avoid littering, the reporting and cleaning of spills and leaks and general good “housekeeping”;
- Adequate sanitary facilities and ablutions on the servitude must be provided for all personnel throughout the project area. Use of these facilities must be enforced (these facilities must be kept clean so that they are a desired alternative to the surrounding vegetation);
- All removed soil and material must not be stockpiled within the wetland system. All stockpiles must be protected from erosion, stored on flat areas where run-off will be minimised, and be surrounded by bunds;
- Any exposed earth should be rehabilitated promptly by planting suitable vegetation (vigorous indigenous grasses) to protect the exposed soil;
- No dumping of construction material on-site may take place; and
- All waste generated on-site during construction must be adequately managed. Separation and recycling of different waste materials should be supported.

8.2.2 Construction of Open cast Pit

The following mitigation measures are aimed to conserve wetlands during the construction of the proposed open cast pit;

- The extent of the proposed open cast pit should not differ from the extent as presented in the provided GIS data (shapefiles) shared with the consultants responsible for this assessment;
- All infrastructure components (i.e. stockpiles, haul roads, buildings etc) associated with the mining activities must be located within the extent of the open cast mining area shared with the consultant; and
- Basic rock cladding must be applied to areas characterised by signs of erosion within and around the relevant wetland.

8.2.3 Operation of the Open cast Pit

To ensure that overland flow is not increased during the proposed operational phase of the open cast pit, the following mitigation measures have been recommended;

- Monitor signs of erosion and compaction around the proposed open cast pit within the first week of every month during the rainfall season (November to March) and rip/reseed/apply rock cladding where required;
- The stormwater management plan must incorporate the installation of a pollution control facility to tend to contaminate surface water from precipitation. The water from this system must be reintroduced in a diffuse manner back into the wetland after sanitisation;
- All invasive species must be eradicated from the relevant wetlands annually;
- The surroundings of the proposed pit must be revegetated after construction with indigenous vegetation; and
- Relevant stormwater systems must be installed for the proposed pit and associated infrastructure (including all roads) to ensure that no additional overland flow be channelled to surrounding wetlands.

9 Recommendations

Given the “Moderate” and “High” significance ratings determined post-mitigation, minimisation (the second step according to the mitigation hierarchy (DEA, 2013)) is deemed not to be feasible. The next step will be to rehabilitate degraded areas. It is the specialist’s opinion that rehabilitation will not be sufficient given the current state of modification and degradation as well as the fact that the wetland itself is proposed to be mined with its buffer zone impeded into in most cases.

It is firstly recommended that the proposed open cast mining areas be amended to adhere to the delineated wetland’s buffer zone to ensure avoidance. If the latter mentioned is not feasible, it is recommended that a wetland offset strategy (which according to (DEA, 2013) is the last resort) be compiled for the proposed activities and the relevant delineated wetlands. The wetland offset would then need to be focussed on the extent of the wetland and associated buffer zone that will be lost, as indicated in Figure 27. The wetland offset must incorporate onsite rehabilitation and must be incorporated in the future plans for the mine.

Minimisation of significance ratings for the underground mining areas can be achieved by conducting a subsidence, geotechnical and groundwater assessment to determine the significance of relevant aspects. The mitigation measures and recommendations within these reports must be strictly adhered to ensure the conservation of wetland areas.

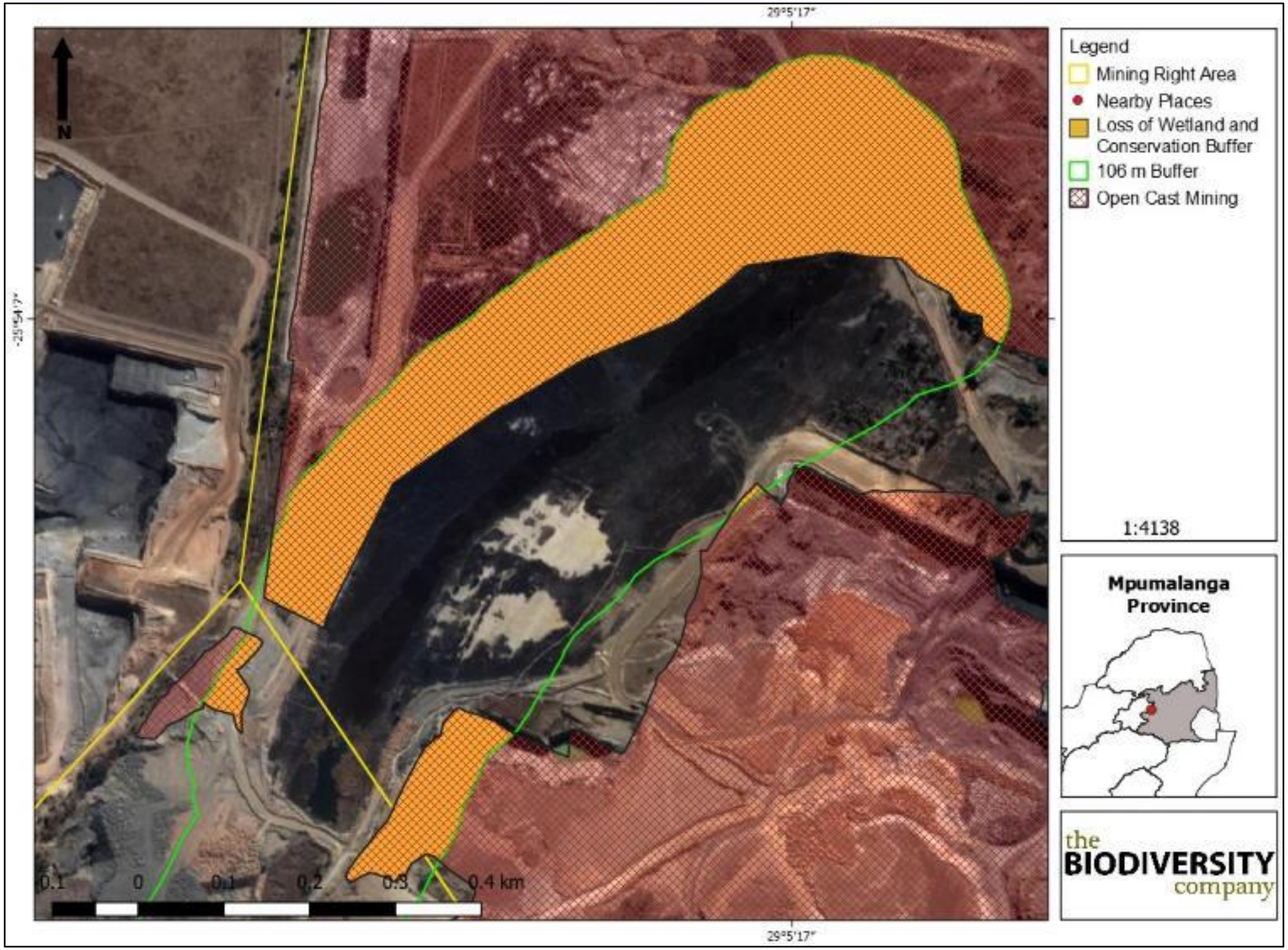

Figure 27: Extent of wetland and associated buffer zone that will be lost

10 Conclusion

10.1 Baseline Ecology

Three HGM units were identified, of which two have been largely modified by current and historic mining activities impeding into the wetland's buffer zones and, in some cases, into the wetland itself. Severe limitations exist in regard to wetland identification, which has resulted in a section characterised by signs of wetness to be classified as an "artificial system" given the presence of transported Technosols as well as altered surface and sub-surface flow dynamics.

The delineated wetlands do provide a moderate to high level of service, especially in regard to indirect benefits (water quality and flow regulation). Significant wetland habitat degradation has taken place due to impaired water quality, which has resulted in a lack of unique species.

A buffer zone 106 m in size has been calculated for all the wetlands on-site due to the high level of threats associated with open cast mining. No buffer zones are required for the underground mining activities due to the fact that very little to no surface impacts are associated with underground mining activities as well as the fact that the open cast mining's calculated buffer zone will conserve the wetland for any mining activity.

10.2 Impact Assessment

Pre-mitigation aspects during the construction phase have been scored "Low" to "High" significance ratings, of which some are expected to be decreased to a "Low" significance rating by means of relevant mitigation measures and recommendations. The following aspects have been scored "Moderate" or "High" post-mitigation significance ratings during the construction phase;

Open Cast Mining

- Excavating the open cast pit;
- Storage of chemicals, mixes and fuel;
- Construction of haul roads for the open cast pit; and
- Acid Mine Drainage (AMD) pollution related to the open cast pit.

Underground Mining

- None

As for the operational phase, the following aspects have been scored "Moderate" or "High" post-significance ratings;

Open Cast Mining

- AMD pollution relevant to the operation of open cast mining; and
- Dust pollution related to open cast mining.

Underground Mining

- Subsidence;
- Groundwater pollution; and
- Cracking of bedrock.

10.3 Specialist Recommendation

Given the fact that avoidance is not an option, the fact that “Moderate” and High” post-mitigation significance ratings have been determined, a wetland offset has been recommended. The latter mentioned will be required carry out the proposed activities within the calculated buffer zones and delineated wetlands. The offset strategy must include onsite rehabilitation and must be incorporated into the mine’s future plans.

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