Level 3 Hydropedological Assessment for the Manungu Mining Project

Delmas, Mpumalanga, South Africa

September 2019

CLIENT

Prepared by:

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Johan van Tol is an Associate Professor in Soil Science at the University of the Free State and director of Digital Soil Africa. He is a NRF Y1 rated researcher and author of 35 peer reviewed publications. He presented his research at more than 60 national and international congresses and lead/involved in more than 12 externally funded research projects. He is *Pr.Sci.Nat* registered and has produced more than 35+ scientific consultancy reports mainly on hydropedology.		
Review	**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.		

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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

16th September 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

16th September 2019

1 Introduction

The Biodiversity Company was commissioned by Environmental Impact Management Services to conduct a specialist hydropedological level three (3) assessment to supplement the relevant applications and amendment applications to existing authorisations and/or licences pertaining to the Manungu mining project. The hydropedological site assessment was conducted from the 23rd to the 25th of July 2019.

This report presents the results of a hydropedological assessment on the environment associated with the proposed underground mining area as well as the proposed opencast mining area. This report should be interpreted after taking into consideration the findings and recommendations provided by the specialist herein. Further, this report should inform and guide the Environmental Assessment Practitioner (EAP) and regulatory authorities, enabling informed decision making, as to the ecological viability of the proposed project.

1.1 Project Area

Project area is approximately 8 km south of Delmas, Mpumalanga, South Africa (see Figure 1). The proposed project includes underground as well as opencast mining. The underground mining areas are approximately 530 ha in size with the proposed opencast mining area being approximately 445 ha in size. The proposed mining areas are situated between the R42 (to the west of the project area) and the R548 (to the east of the project area). The surrounding land use includes farming, mining and built-up areas with watercourses covering the valleys.

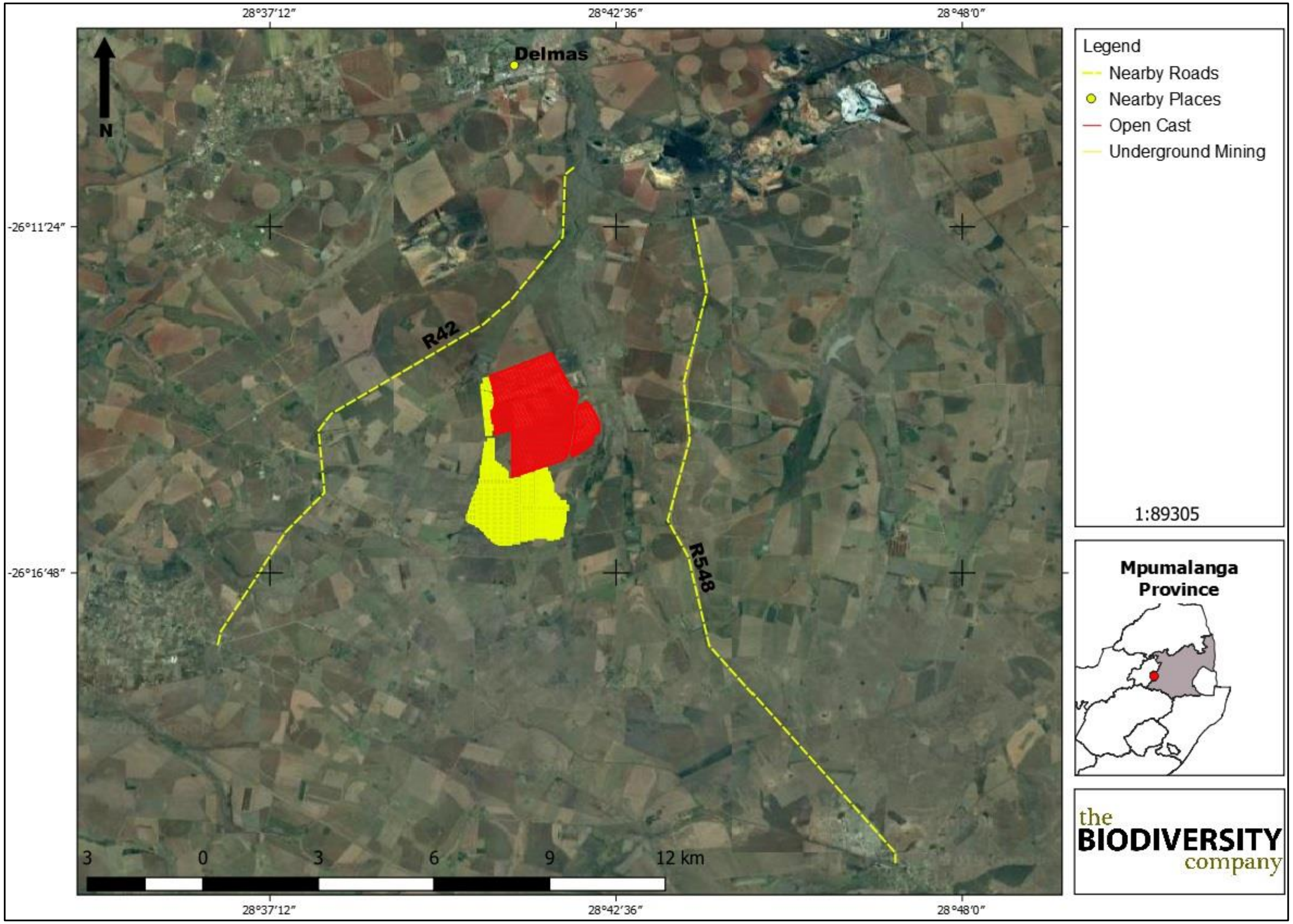

Figure 1: Spatial context of the Manungu project area.

1.1.1 Climate

This region is characterised by a strongly seasonal rainfall, dry winters and a mean annual precipitation of approximately 726 mm and is relatively uniform across the distribution of the Gm 12 vegetation type. Incidence of frost ranges between 13 to 42 days a year and occurs more at higher elevations, see Figure 2.

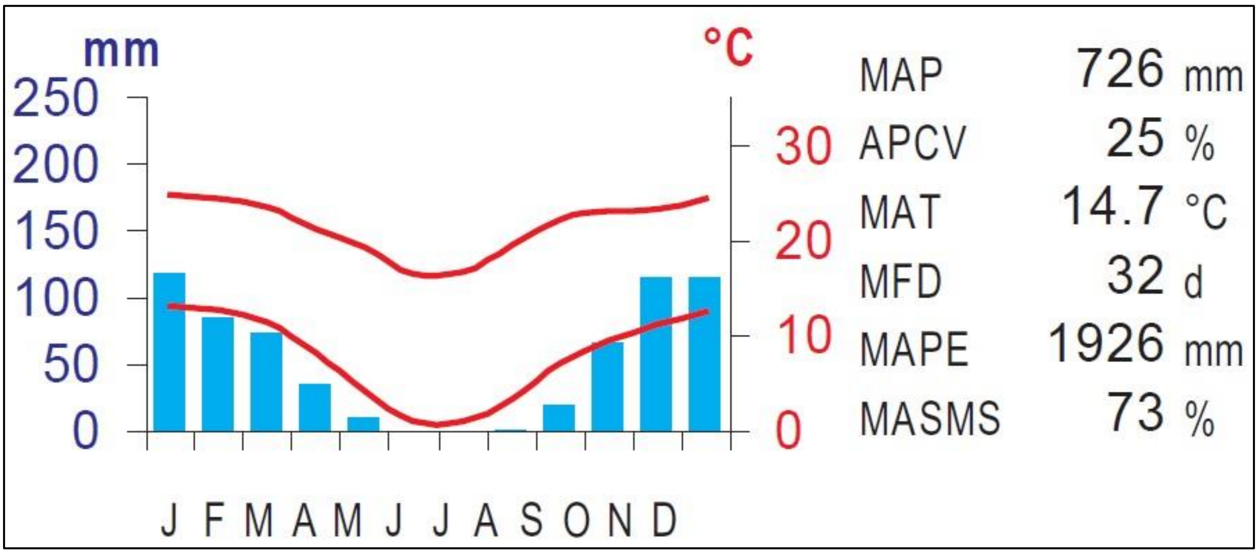

Figure 2: Climate for the project area (Mucina and Rutherford, 2006).

1.1.2 Vegetation

1.1.2.1 Soweto Highveld Grassland (Gm 8)

The project area is located within the Soweto Highveld Grassland (GM 8) vegetation type. The distribution of the Soweto Highveld Grassland (GM 8) vegetation type is restricted to Gauteng and Mpumalanga with small portions of this vegetation type occurring in the North-West and Free State provinces. This vegetation type is roughly delineated by the Vaal River, Perdekop in the south-east and the N17 between Johannesburg and Ermelo. The GM 8 vegetation type extends further westward as far as Randfontein and includes parts of Soweto. The GM 8 vegetation type surround parts to the south as well, including Vanderbijlpark, Vereeniging and Sasolburg, which is located in the northern most parts of the Free State (Mucina and Rutherford, 2006).

The vegetation within the GM 8 region is dominated by short to medium-high, dense, tufted grassland which mostly includes *Themeda triandra* within gently to moderately undulating landscapes on the Highveld plateau. Other grass species which occur to a lesser extent include *Eragrostis recemosa*, *Elionurus muticus*, *Tristachya leucothrix* and *Heteropogon contortus* (Mucina and Rutherford, 2006).

The conservation status of the GM 8 vegetation type is endangered with a target percentage of 24. Half of the area is already transformed into agriculture, mining, urban build-up etc. with a handful of conservation areas still up and running. These include Waldrift, Suikerbosrand and Rolfe's Pan Nature Reserve (just to name a few) (Mucina and Rutherford, 2006).

1.1.2.2 Eastern Highveld Grassland (Gm 12)

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 and 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. 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. (Mucina and Rutherford, 2006).

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 and Rutherford, 2006).

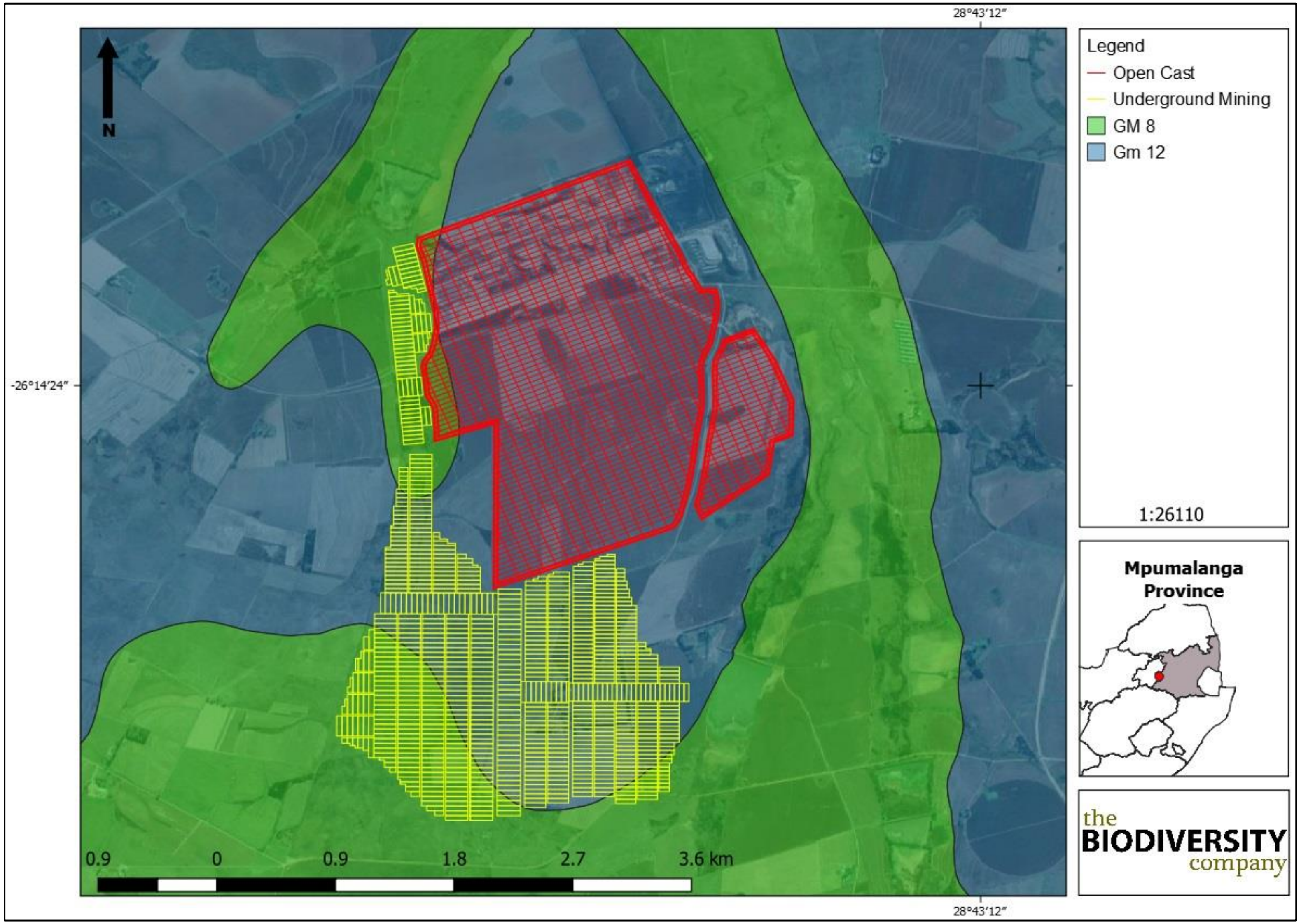

Figure 3: Vegetation types relevant to the project area and its surroundings

1.2 Background Information

1.2.1 Water Resource Assessment Report

The Biodiversity Company was commissioned to conduct specialist studies to supplement the various mining related applications. This water resource assessment comprises wetland and aquatic ecology specialist components. An assessment of the wetland systems was conducted from 15-19th January 2018, which constitutes a wet season survey. The assessment of the local river systems is included in an annual biomonitoring programme, with fieldwork being completed during 12th June 2017 (high flow) and 24th October 2017 (early high flow).

According to the 2017 Manungu aquatic biomonitoring survey results, the Present Ecological Status (PES) assessment derived a largely modified ecological category (class D) for the Bronkhorstspruit. This PES is below the attainable ecological management class (class C).

The modified status can be attributed to a combination of flow modification, habitat and water quality related drivers and riparian areas associated with the Bronkhorstspruit and each associated tributary system. The overlying influence of low water levels in the project area with no river flow between sites has impacted aquatic macroinvertebrate and fish communities. The modification stems from a combination of agricultural and mining activities present within Bronkhorstspruit catchment and cannot be directly attributed to mining related activities at Manungu Colliery.

A total of five (5) hydrogeomorphic (HGM) types were identified and delineated for the project. A total of 16 HGM units were identified for the project. The overall wetland health for the wetlands varied from Moderately Modified (class C) to Largely Modified (class D) system, with the majority of the wetlands rated a Class D. The Ecological Importance and Sensitivity of the two valley bottom wetland types was rated as high (class B), with the remaining wetland types being rated as moderate (class C).

All of the wetland types had overall moderately low level of service, with the exception of the unchannelled valley bottom system which had an intermediate level of service. It is evident from the study that the most benefits are associated with the indirect benefits, which includes the enhancement of water quality. The level of indirect benefits for all the systems ranged from low to moderately low. The hydrological / functional importance was rated as Moderate (class C) for all the wetland systems. The direct human benefits were rated as low (class D) for all the wetland systems.

The recommended buffer width is 45 m and 65 m for the construction and operational phases respectively. It is recommended that the larger buffer width of 65 m be implemented from the onset of the construction phase of the project.

The proposed project could result in the loss and modifications of water resources, notably the loss of selected pans (and associated seeps) and portions of the unchanneled valley bottom system to the east of the project area. It is permissible that the proposed opencast mining area result in the mining of the depressions within this area, but the mine plan must be amended to avoid the eastern valley bottom wetland and the associated buffer. The loss of wetlands is expected for the mining of the opencast area, and it is possible that underground mining may also result in the loss of wetland systems. The significance of the loss is regarded as high, and because avoidance is not possible for this project, mitigation has not been considered and the significance remains high for the systems proposed to be mined by opencast methods.

The impacts associated with the proposed underground mining method are considerably less significant when compared to the proposed opencast mining methods. This compounded with the placement of new infrastructure, access routes and mining activities will have a significant impact on the local environment and ecological processes. Careful consideration must be afforded each of the recommendations provided herein. In the event that environmental authorisation is issued for this project, proven ecological (or environmental) controls and mitigation measures must be entrenched in the management framework.

1.2.2 Baseline Soil Conditions

Soil samples have been collected in the past to determine the baseline conditions of soil resources. The results are presented in Table 1 and Table 2 as well as Figure 4.

Table 1: Laboratory result for relevant sampling sites

Sample	pH (KCl)	Bray I (mg/kg)	K (mg/kg)	Na (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Exc. H+ cmol(+)/kg	%Ca	%Mg	%K	%Na	Acid.V (%)
Site 1 (Topsoil)	5,74	11	161	6	732	141	0,00	69,69	21,96	7,84	0,51	0,00
Site 1 (Subsoil)	5,97	15	109	9	684	145	0,00	69,34	24,16	5,68	0,82	0,00
Site 2 (Topsoil)	5,15	15	166	13	639	149	0,00	65,24	24,99	8,66	1,11	0,00
Site 2 (Subsoil)	4,96	3	64	12	724	172	0,00	69,00	26,92	3,12	0,97	0,00
Site 3 (Topsoil)	5,60	60	699	12	1095	310	0,00	55,55	25,77	18,14	0,54	0,00
Site 3 (Subsoil)	5,23	10	452	13	1289	476	0,00	55,75	33,76	9,99	0,49	0,00
Site 4 (Topsoil)	4,60	13	366	8	889	270	0,00	58,24	29,02	12,28	0,46	0,00
Site 4 (Subsoil)	4,50	8	217	13	985	309	0,04	60,73	31,23	6,86	0,70	0,48
Site 5 (Topsoil)	4,77	9	319	14	1024	396	0,00	55,42	35,10	8,82	0,66	0,00
Site 5 (Subsoil)	5,12	2	186	20	1250	581	0,00	53,98	41,16	4,10	0,76	0,00
Site 6 (Topsoil)	4,94	58	312	5	579	116	0,00	62,06	20,40	17,11	0,43	0,00
Site 6 (Subsoil)	5,32	12	132	10	923	217	0,00	68,16	26,21	4,98	0,65	0,00
Site 7 (Topsoil)	5,35	13	271	10	989	323	0,00	59,37	31,79	8,33	0,52	0,00
Site 7 (Subsoil)	5,39	5	182	8	812	289	0,00	58,61	34,16	6,71	0,52	0,00
Site 8 (Topsoil)	5,43	41	370	12	862	202	0,00	61,87	23,79	13,58	0,75	0,00
Site 8 (Subsoil)	5,34	15	205	13	1338	361	0,00	65,39	28,93	5,13	0,55	0,00

Site 9 (Topsoil)	5,25	27	354	13	1310	391	0,00	61,11	29,91	8,45	0,53	0,00
Site 9 (Subsoil)	5,80	2	187	34	1716	1284	0,00	43,47	53,35	2,43	0,75	0,00
Site 10 (Topsoil)	5,30	11	215	9	749	134	0,00	68,97	20,18	10,11	0,75	0,00
Site 10 (Subsoil)	4,93	3	144	28	1310	445	0,00	61,28	34,14	3,45	1,12	0,00

Table 2: Laboratory result for relevant sampling sites (continued)

Sample	Ca:Mg (1.5-4.5)	(Ca+Mg)/K (10.0-20.0)	Mg:K (3.0-4.0)	S-Waarde cmol(+)/kg	Na:K	T cmol(+)/kg	Density (g/cm^3)	S AmAC (mg/kg)
Site 1 (Topsoil)	3,17	11,69	2,80	5,25	0,07	5,25	1,18	3,68
Site 1 (Subsoil)	2,87	16,47	4,26	4,93	0,15	4,93	1,14	4,73
Site 2 (Topsoil)	2,61	10,43	2,89	4,90	0,13	4,90	1,35	22,17
Site 2 (Subsoil)	2,56	30,78	8,64	5,25	0,31	5,25	1,17	9,86
Site 3 (Topsoil)	2,16	4,48	1,42	9,85	0,03	9,85	1,19	10,14
Site 3 (Subsoil)	1,65	8,96	3,38	11,56	0,05	11,56	1,05	7,55
Site 4 (Topsoil)	2,01	7,10	2,36	7,63	0,04	7,63	1,14	11,51
Site 4 (Subsoil)	1,94	13,40	4,55	8,07	0,10	8,11	1,13	14,24
Site 5 (Topsoil)	1,58	10,26	3,98	9,24	0,07	9,24	1,09	19,74
Site 5 (Subsoil)	1,31	23,19	10,03	11,57	0,19	11,57	1,07	32,51
Site 6 (Topsoil)	3,04	4,82	1,19	4,67	0,03	4,67	1,43	3,91
Site 6 (Subsoil)	2,60	18,93	5,26	6,77	0,13	6,77	1,16	6,56
Site 7 (Topsoil)	1,87	10,95	3,82	8,33	0,06	8,33	1,19	4,43
Site 7 (Subsoil)	1,72	13,82	5,09	6,93	0,08	6,93	1,18	7,99
Site 8 (Topsoil)	2,60	6,31	1,75	6,97	0,06	6,97	1,38	5,84
Site 8 (Subsoil)	2,26	18,38	5,64	10,23	0,11	10,23	1,08	5,56

Site 9 (Topsoil)	2,04	10,77	3,54	10,72	0,06	10,72	1,28	10,80
Site 9 (Subsoil)	0,81	39,87	21,97	19,73	0,31	19,73	1,15	13,56
Site 10 (Topsoil)	3,42	8,82	2,00	5,43	0,07	5,43	1,35	5,58
Site 10 (Subsoil)	1,80	27,63	9,89	10,69	0,33	10,69	1,10	27,96

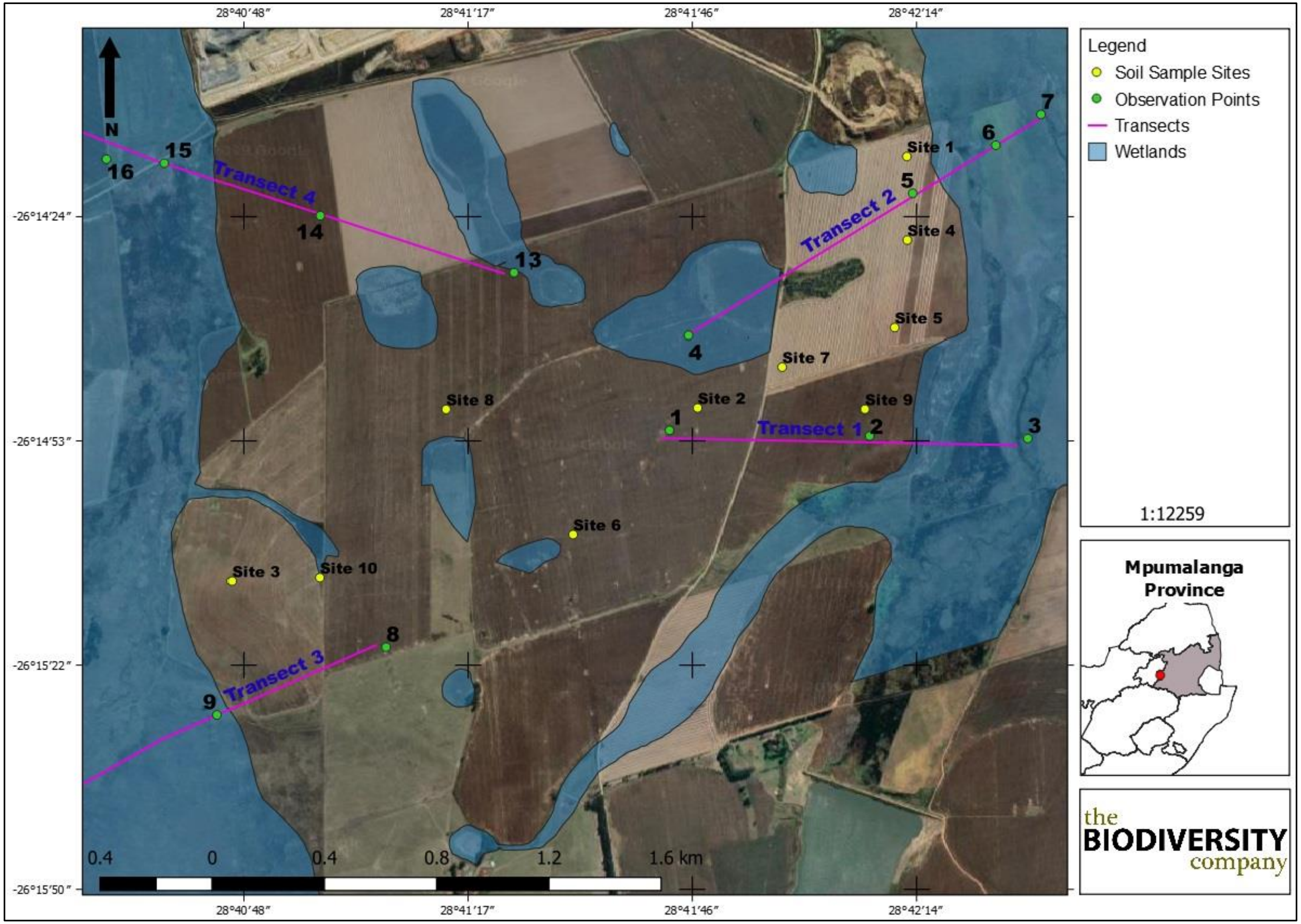

Figure 4: Soil sampling sites

1.3 Scope of Work

A hydropedology assessment on a local scale, a hillslope scale or a catchment scale must be completed in cases where the infiltration or sub-surface hydrology is expected to be affected by a proposed activity. A wide variety of services must be provided (i.e. modelling, classification of soil, hydropedological soil types and hillslope hydrology), depending on the intensity of the proposed activity. Underground mining is likely to affect/degrade the natural soil reserves, fractured rock and groundwater. The following terms of reference has been identified to meet the criteria of such a hydropedology assessment:

- Conduct field work to acquire information regarding soil physical properties and morphology of soils;
- Conduct undisturbed sampling for representative soil horizons to determine hydraulic properties;
- Conduct *in-situ* saturated hydraulic conductivity tests of the bedrock layers identified in selected excavated pits;
- Construct conceptual models of hydrological response for each of the transects based on hydropedological interpretations;
- Assess and quantify dominant hydropedological flow paths through the dominant soil forms/associations and hillslopes;
- Determine the extent of disturbance to the natural hydropedological model; and
- Compile a report which includes recommendations and conclusions regarding the proposed activity to ultimately inform and guide the Environmental Assessment Practitioner (EAP) and regulatory authorities, enabling informed decision making.

2 Limitations

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, adits, evaporation ponds etc) have been included into this report given the irrelevance of these components to a level 3 assessment;
- It has been assumed that the extent of the underground areas and the opencast 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.

3 Literature Review

3.1 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 5). The latter mentioned enables effective water resource management regarding wetlands and sub-surface flows in general.

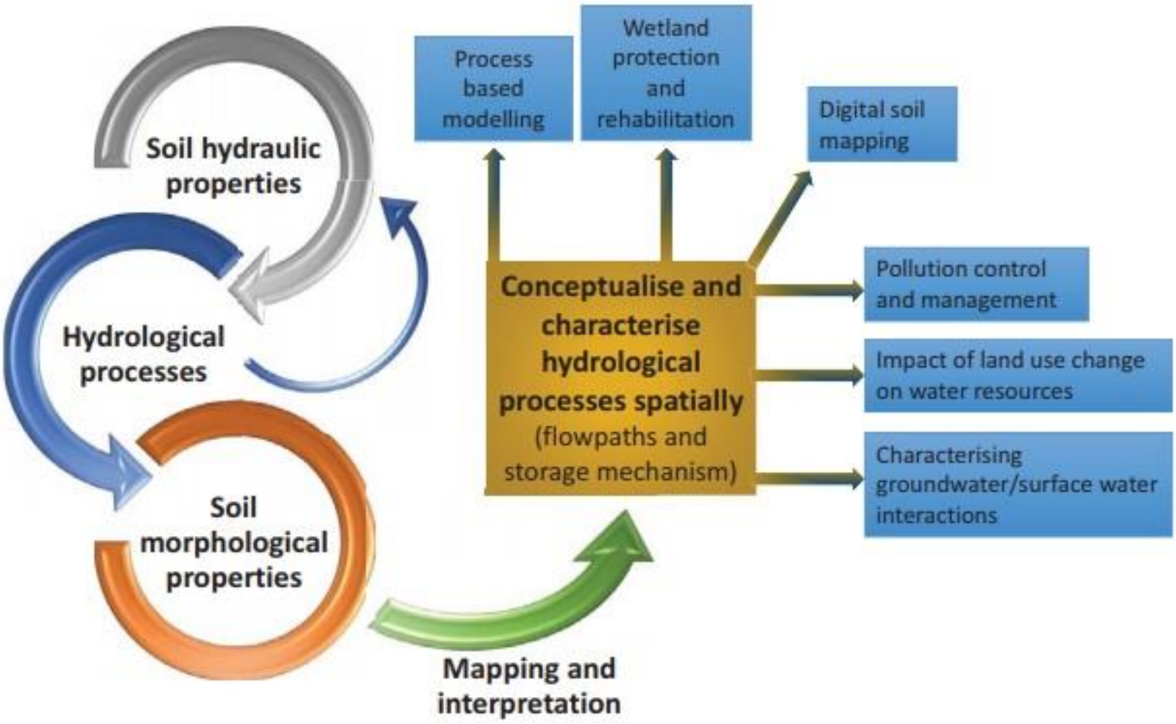

Figure 5: Illustration of the interactive nature of hydropedology and its potential applications (van Tol et al., 2017).

As can be seen in Figure 6, the hydropedological behaviour of soil types can differ significantly. Figure 6 (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 6 (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 6 (b-i).

Figure 6 (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.

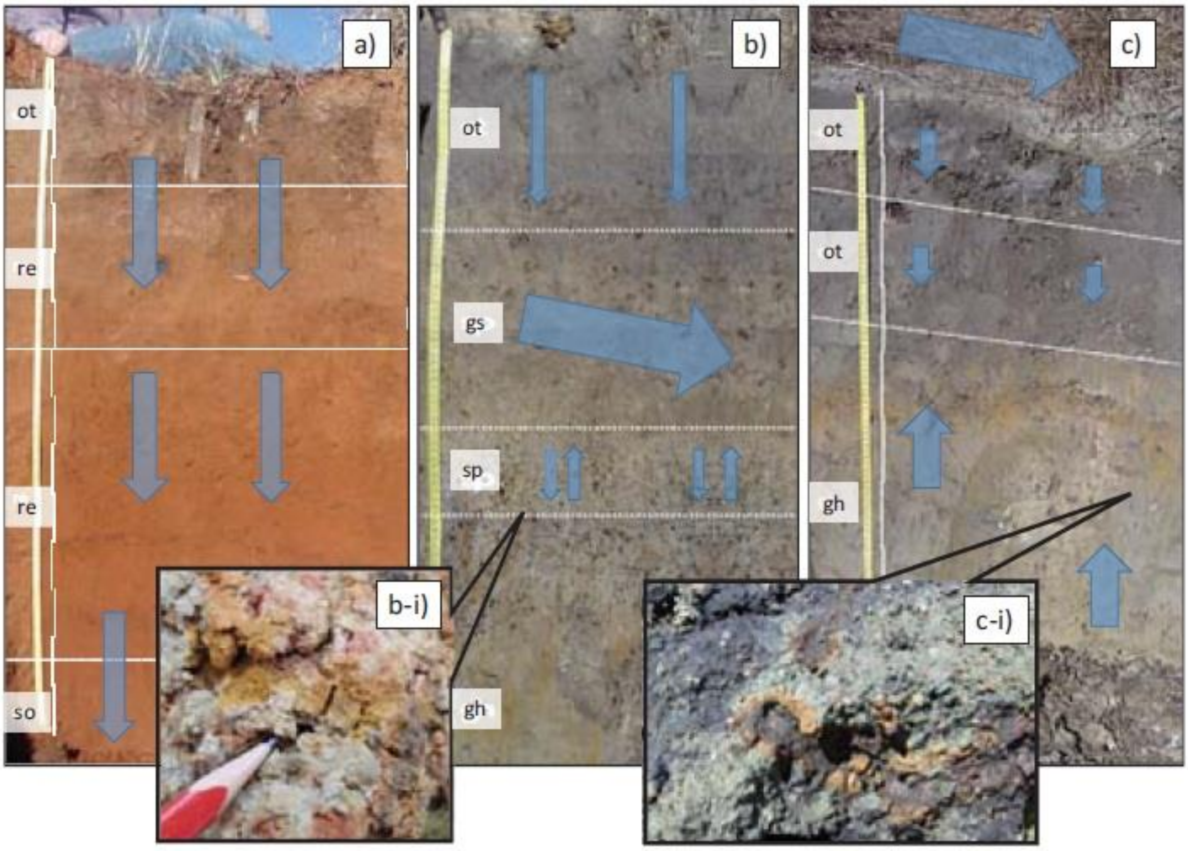

Figure 6: Illustration of different hydropedological soil types (van Tol et al., 2017).

A typical example of the hydropedological processes through a hillslope is illustrated in Figure 7. 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.

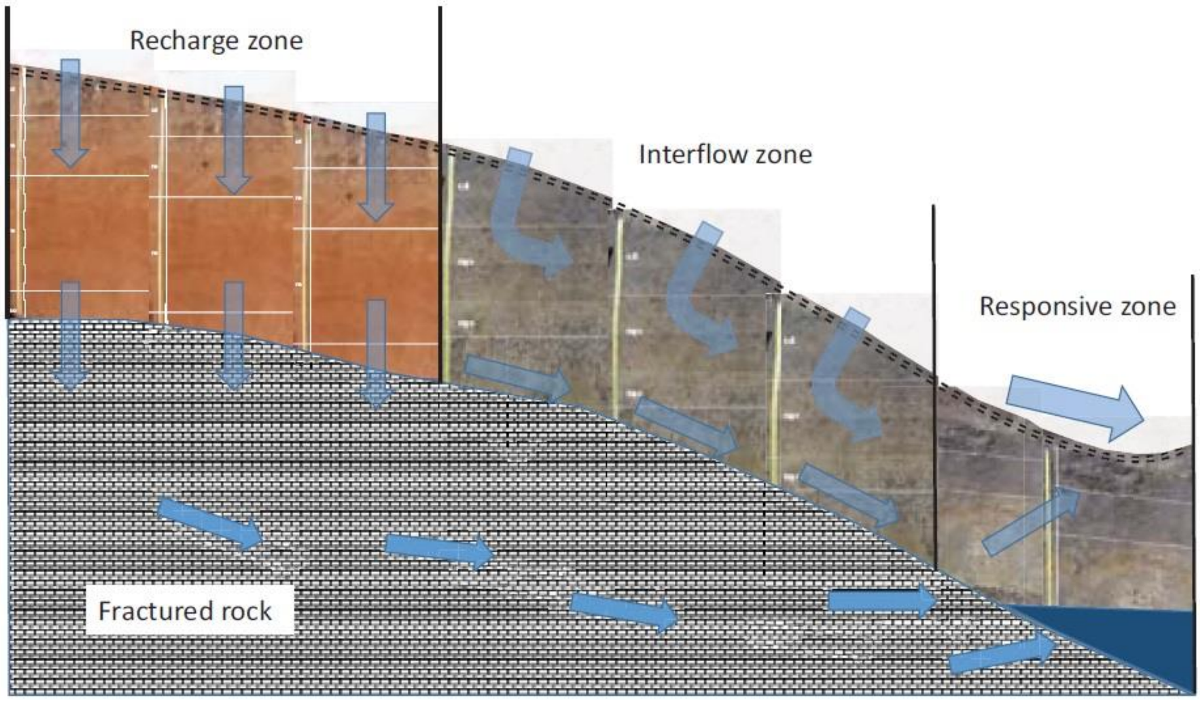

Figure 7: Theoretical example of various sub-surface flow paths (van Tol et al., 2017).

4 Methodology

4.1 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).

4.2 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 nine pits in total have been excavated up to refusal with 8 auger points to improve the accuracy of soil distribution and hydropedological patterns (see Figure 8). Observation points that were excavated include Observations 1, 2, 5, 8, 9, 12, 13, 14 and 17.

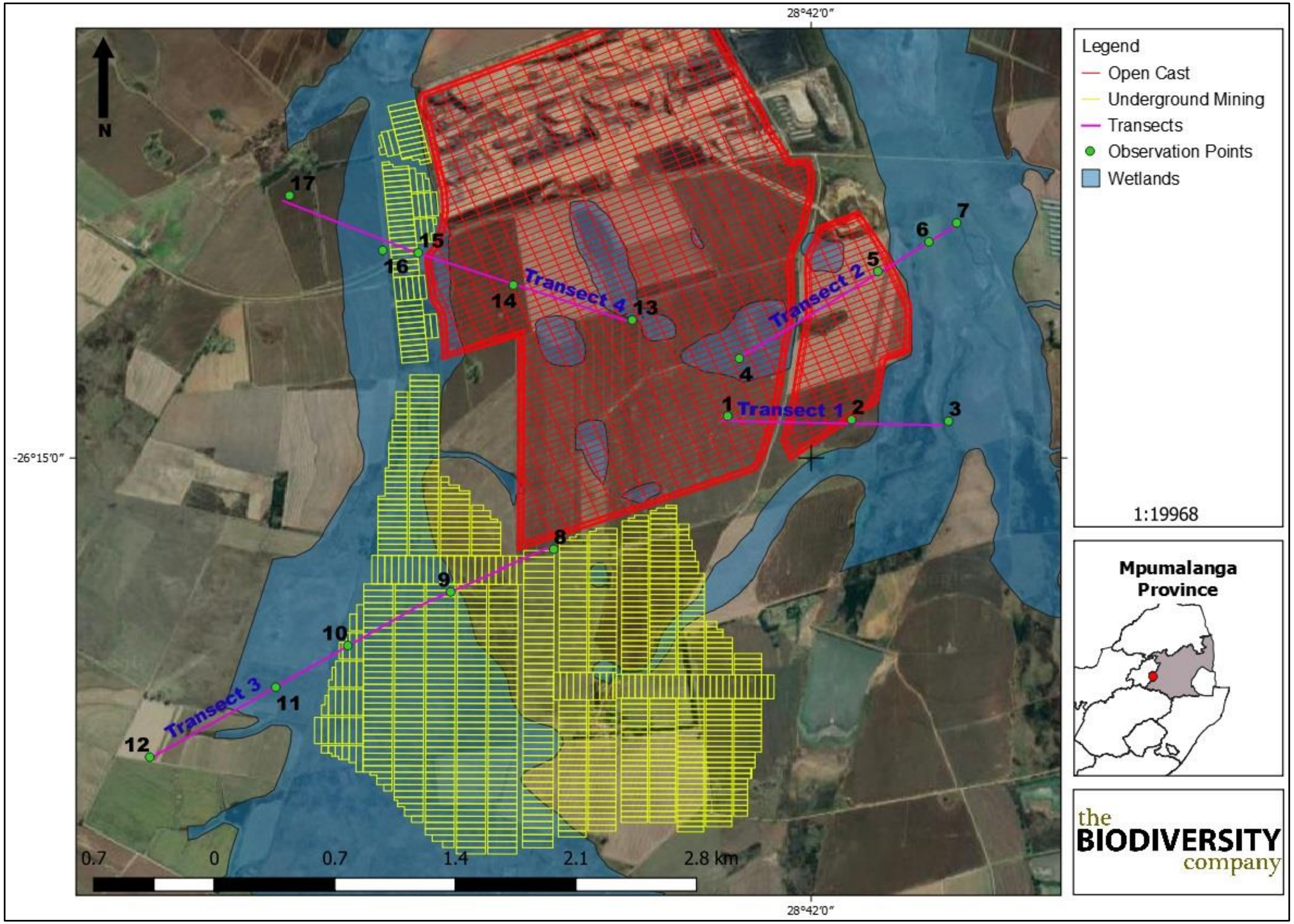

Figure 8: Transects and Sampling Sites

4.2.1 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., 2013).

Hydrological Soil Type	Description	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.	
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).	
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.	
Responsive (Shallow)	Shallow soils overlying relatively impermeable bedrock. Limited storage capacity results in the generation of overland flow after rain events.	
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.	

4.2.2 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.

4.2.3 *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 to 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.

4.3 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 9). 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.

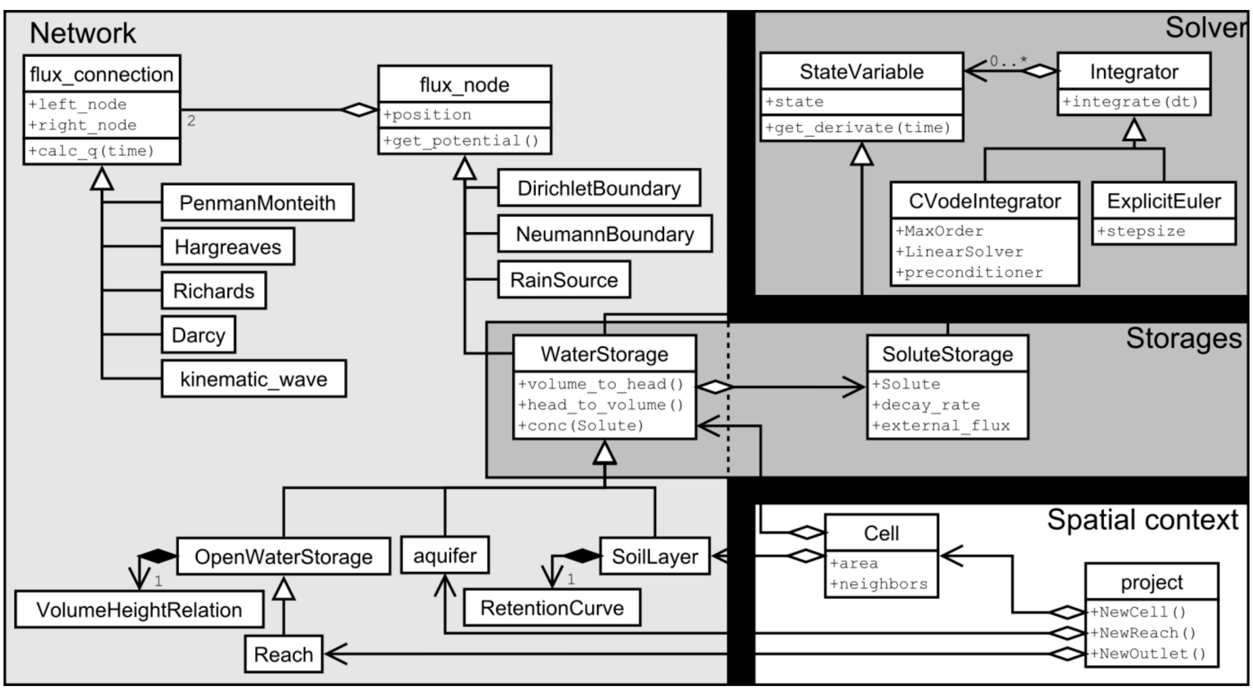

Figure 9: Simplified class representation of the Catchment Modelling Framework and its components (Kraft et al., 2011).

In this study three of the four transects (1,2 and 4 – see Figure 8) were configured in CMF and parameterised using measured data from the field and laboratory analysis (Figure 10). Transect

3 will be impacted by underground mining only and was not included in the hydropedological modelling. The topography (surface elevations) was obtained from Google Earth and included to the configuration of the transects. The Van Genuchten-Maulem hydraulic model was used in the simulation of water flow through the soils. Relevant Van Genuchten parameters were derived from measured hydraulic properties in combination with PedoTransfer Functions in Rosetta (2003).

The slopes were initially saturated by applying 100 mm daily rain on 10 consecutive days to the surface boundary. The slopes were then allowed to drain for 20 days under low evaporative demands where after 50 mm rain was applied. Water contents and fluxes were evaluated from the onset of rain free drainage (day 11) until drainage ceased following the 50 mm event (roughly day 50. 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 10b). The assumption was that there are *'no flow'* from the open-cast pits, the transects were therefore shortened to exclude the soils in/above the 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.

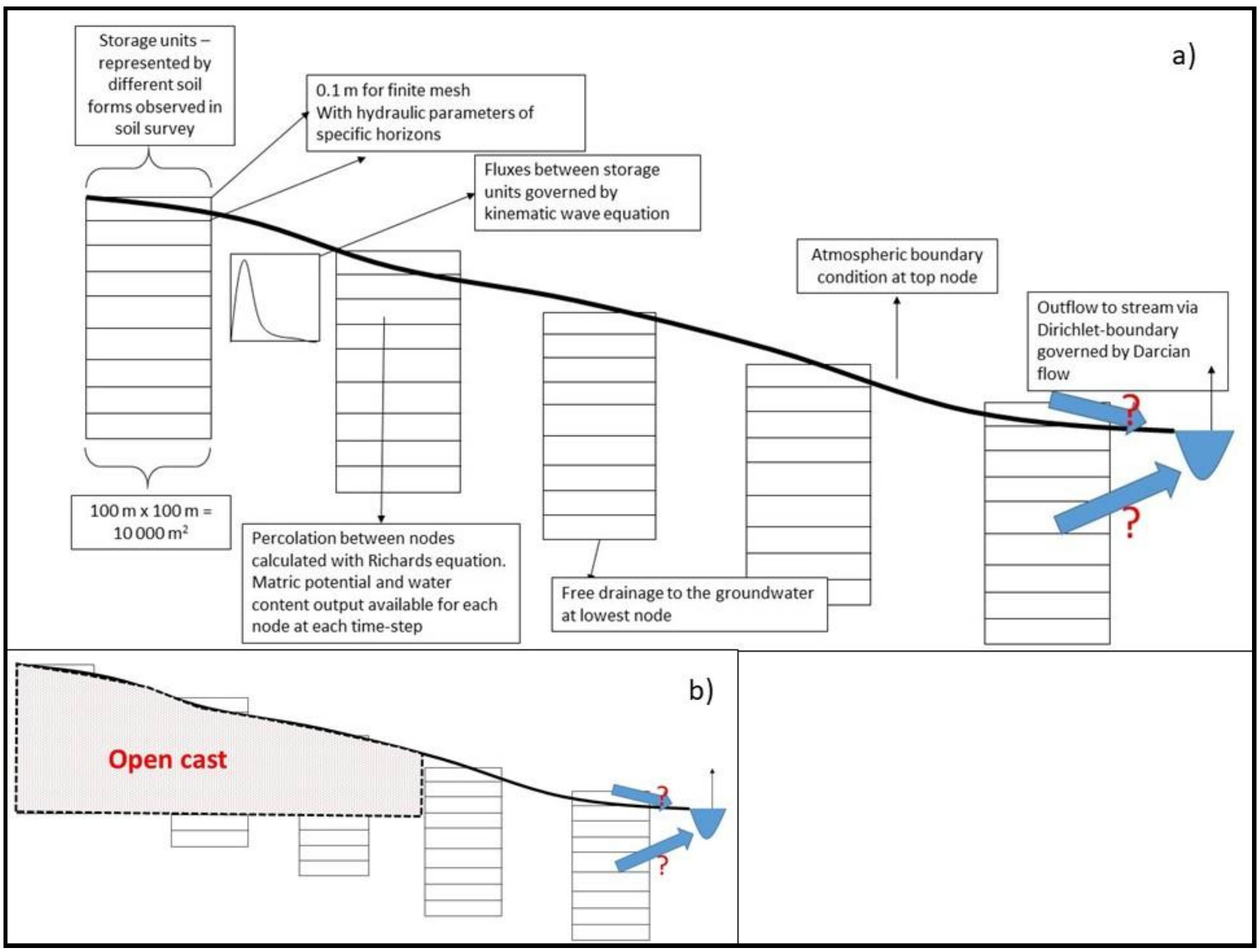

Figure 10: Modelling set-up under natural conditions used to quantify the impact of the proposed pit on surface and subsurface flows; a) natural conditions and b) after the proposed development (adapted from Van Tol et al., 2019).

5 Results and Discussions

5.1 Desktop Background Findings

5.1.1 Geology & Soils

The vegetation type occurring throughout the project area's geology and soil is characterised by red to yellow sandy soils of the Ba and Bb land type. The geology of this region includes sandstone and shale of the Madzaringwe Formations (Karoo Supergroup).

According to the land type database (Land Type Survey Staff, 1972 - 2006) the development falls within the Bb 3, the Ea 15 and the Ea 20 land types (see Figure 14). The Bb land type consists of plinthic catena. Upland duplex and margalitic soils are rare and dystrophic and/or mesotrophic red soils are not widespread. The Ea land type consists of one or more of the following soils: Vertic, Melanic, and red structured diagnostic horizons, of which these soils are all undifferentiated. Figure 11 illustrates the respective terrain units relevant to the Ea15 land type with the expected soils illustrated in Table 4.

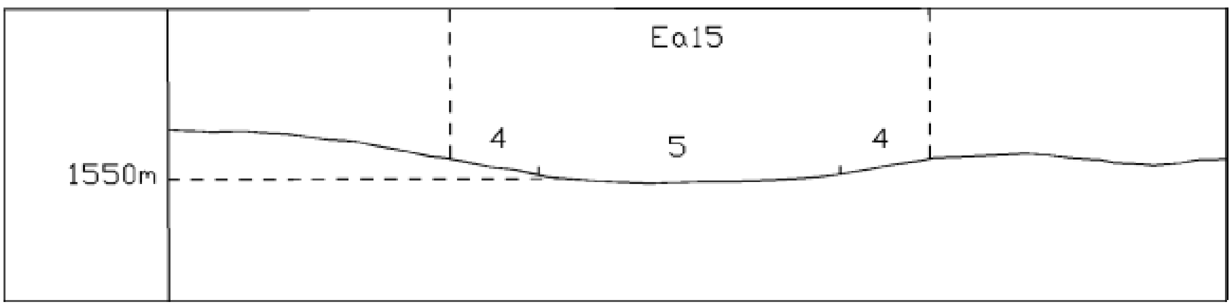

Figure 11: Illustration of land type Ea15's terrain units (Land Type Survey Staff, 1972 - 2006)

Table 4: Soils expected at the respective terrain units within the Ea15 land type (Land Type Survey Staff, 1972 - 2006)

Terrain Units			
4 (20%)		5 (80%)	
Soil	Percentage	Soil	Percentage
Rensburg	60	Rensburg	60
Arcadia	30	Inhoek	20
Bonheim	10	Willowbrook	10
		Stream Beds	10

Figure 11 illustrates the respective terrain units relevant to the Ea20 land type with the expected soils illustrated in Table 4.

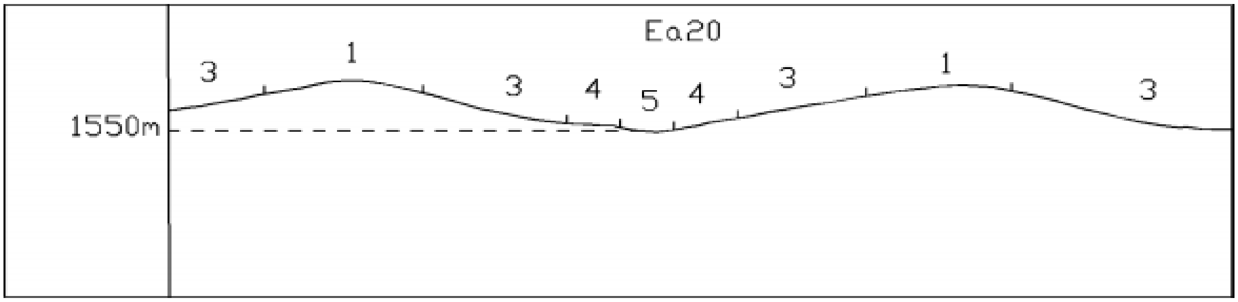

Figure 12: Illustration of land type Ea20's terrain units (Land Type Survey Staff, 1972 - 2006)

Table 5: Soils expected at the respective terrain units within the Ea20 land type (Land Type Survey Staff, 1972 - 2006)

Terrain Units							
1 (30%)		3 (60%)		4 (5%)		5 (5%)	
Soil	Percentage	Soil	Percentage	Soil	Percentage	Soil	Percentage
Arcadia	30	Arcadia	30	Arcadia	40	Willowbrook	80
Milkwood	15	Milkwood	10	Valsrivier	25	Stream beds	20
Swartland	15	Swartlands	10	Bonheim	10		
Glenrosa	15	Glenrosa	10	Swartland	5		
Avalon	10	Avalon	10	Milkwood	5		
Rensburg	10	Valsrivier	10	Willowbrook	5		
Rock	5	Westleigh	5	Estcourt	5		
		Estcourt	5	Sterkspruit	**5**		
		Sterkspruit	5				
		Rock	5				

Figure 11 illustrates the respective terrain units relevant to the Bb3 land type with the expected soils illustrated in Table 4.

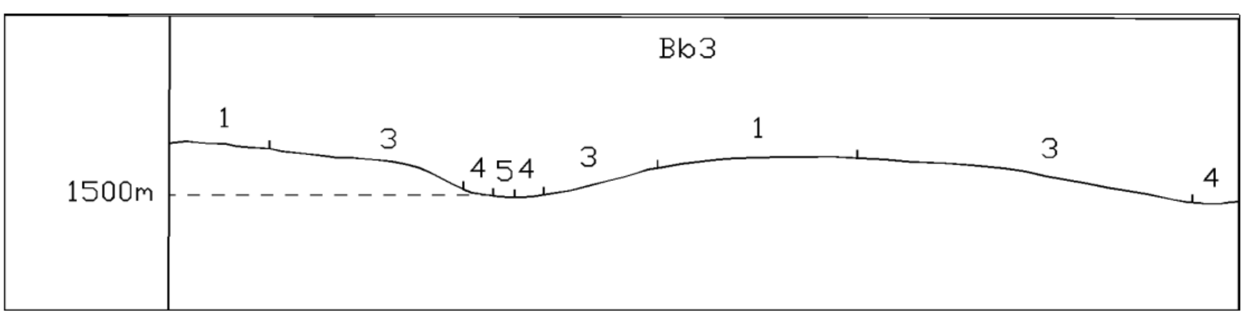

Figure 13: Illustration of land type Bb3's terrain units (Land Type Survey Staff, 1972 - 2006)

Table 6: Soils expected at the respective terrain units within the Bb3 land type (Land Type Survey Staff, 1972 - 2006)

Terrain Units							
1 (35%)		3 (55%)		4 (5%)		5 (5%)	
Soil	Percentage	Soil	Percentage	Soil	Percentage	Soil	Percentage
Hutton	40	Avalon	45	Longlands	20	Rensburg	
Avalon	25	Hutton	20	Valsrivier	20	Katspruit	
Pans	15	Mispah	10	Avalon	10	Willowbrook	
Glencoe	10	Glencoe	5	Hutton	10	Arcadia	
Westleigh	5	Westleigh	5	Westleigh	10		
Mispah	5	Valsrivier	5	Estcourt	10		
		Longlands	5	Kroonstad	10		
		Swartland	5	Arcadia	5		

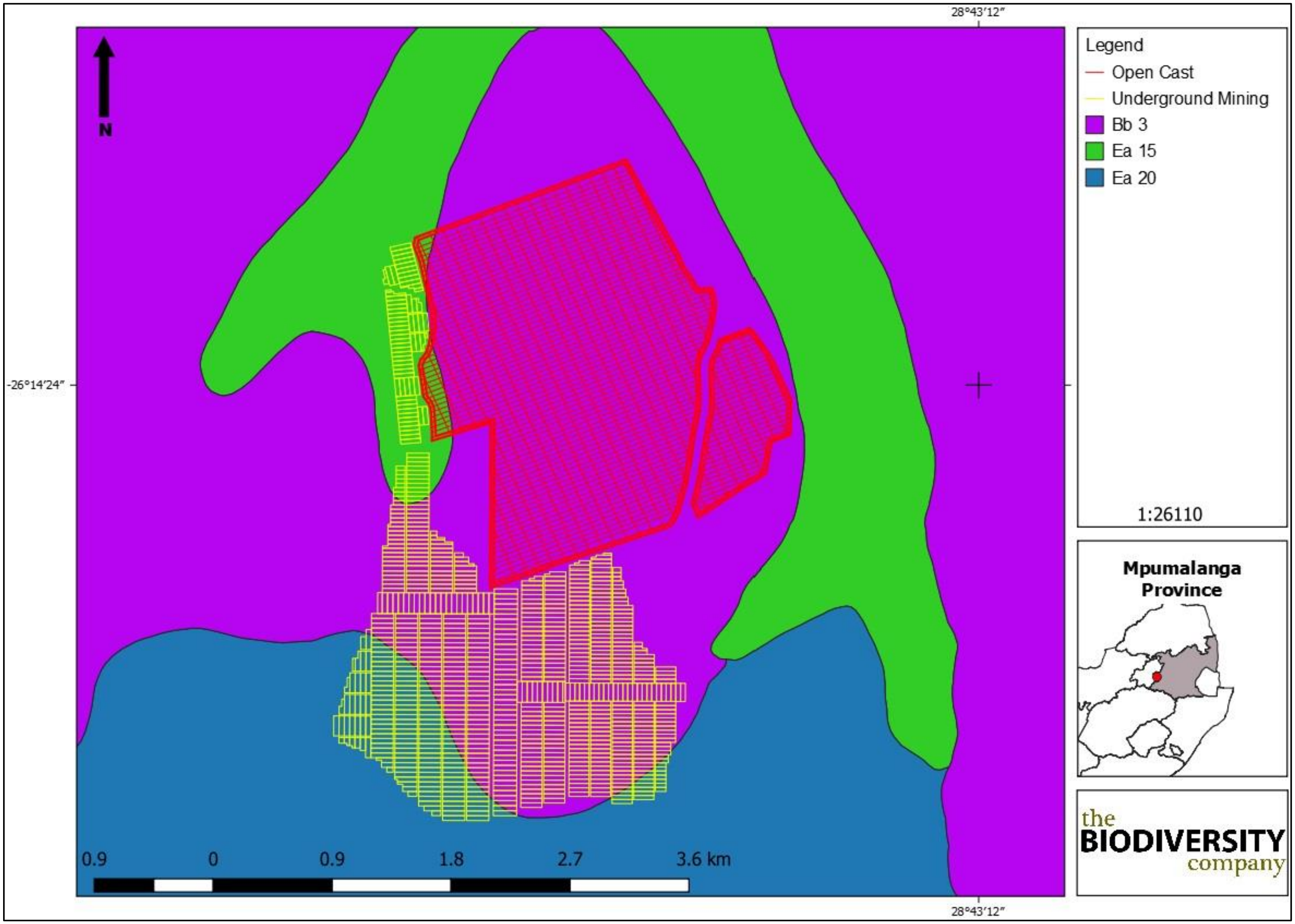

Figure 14: Land types present within the project area and its direct surroundings.

5.2 Hillslope Hydrology

The hydropedology survey was conducted in July 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 8.

5.2.1 Transect 1

The hydropedological behaviour of transect 1 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.

1. Observation 1 is located on the crest of the slope relevant to Transect 1 and has been classified as a Westleigh soil form, which consists of an orthic A-horizon on top of a soft plinthic B-horizon (see Figure 15). The dominance of soft plinthite in this soil profile reflects long periods of saturation, which increases oxidation/reduction processes, which results in the formation of plinthite. The soft plinthic B-horizon is located between the bedrock and topsoil, which suggests interflow between soil and bedrock. Precipitation infiltrates the soil profile rapidly and reaches the bedrock and Soft Plinthic layer, which is characterised by a much lower *Ks*, ultimately forcing water to be channelled along the bedrock towards the valley bottom. The profile for observation 1 is 260 cm deep, which limits *in-situ Ks* measurements. An *in-situ Ks* measurement was taken on the soft plinthic B-horizon approximately 80 cm above the bedrock. The *Ks* was determined to be extremely low at 3,08 mm/h.

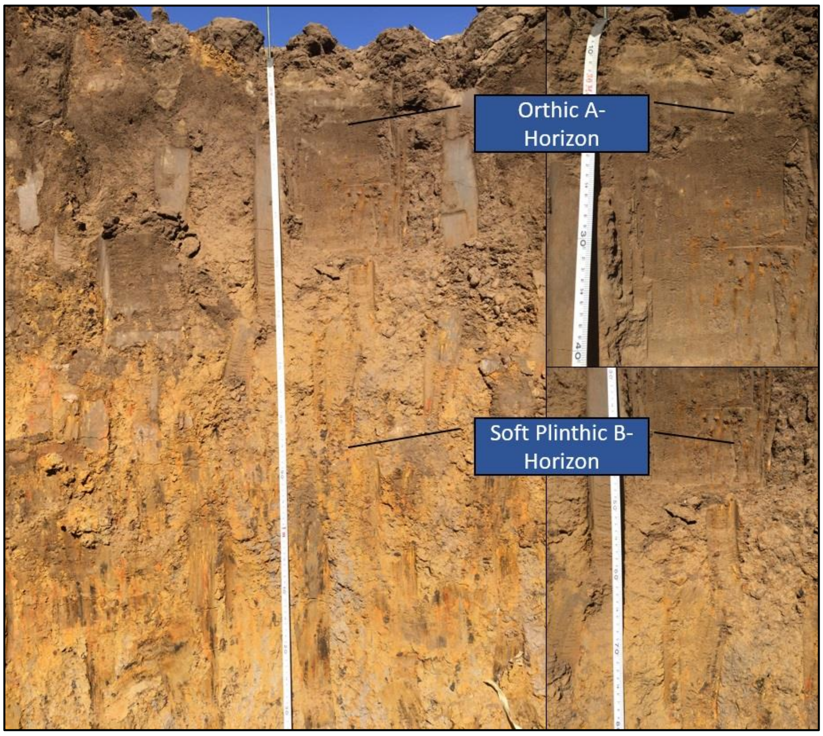

Figure 15: Interflow (soil/bedrock) (Westleigh) hydropedological soil type identified in observation 1, transect 1

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 Steendal soil form, which consists of a melanic A-horizon on top of a soft carbonate horizon (see Figure 16). The latter is characterised by a soft white matrix with scattered lime nodules which reacts to the application of HCl (see Figure 17). The Steendal soil form (in this case) isn't characterised by any signs of wetness (neither between the A- and B-horizon or between the soil and bedrock) or any indication of responsive soils. The *in-situ Ks* of the Sandstone layer beneath the Soft Carbonate layer has been measured at 6,72 mm/h at a depth of 1,3m. This soil form has therefore been classified as a Recharge soil form. Recharge through this soil will however be very slow and extraction via evapotranspiration is likely to dominate the hydrological behaviour. The accumulation/precipitation of lime in the B horizon of the profile is evidence that leaching/recharge is not dominant.

Figure 16: Recharge hydropedological soil type identified in observation 2, transect 1

Figure 17: Reaction of lime nodules to HCl

3. The valley bottom (toe position) of the hillslope is dominated by a responsive (saturated) hydropedological soil form known as a Willowbrook soil form. The Willowbrook soil form consists of a melanic A-horizon on top of a G-horizon (see Figure 18), which is indicative of prolonged periods of saturation. The dominant flow paths within this hydropedological soil form will be overland flow given the rapid saturation of the soil form with a lesser extent of the flow occurring through the profile and vertical movement into the underlaying bedrock.

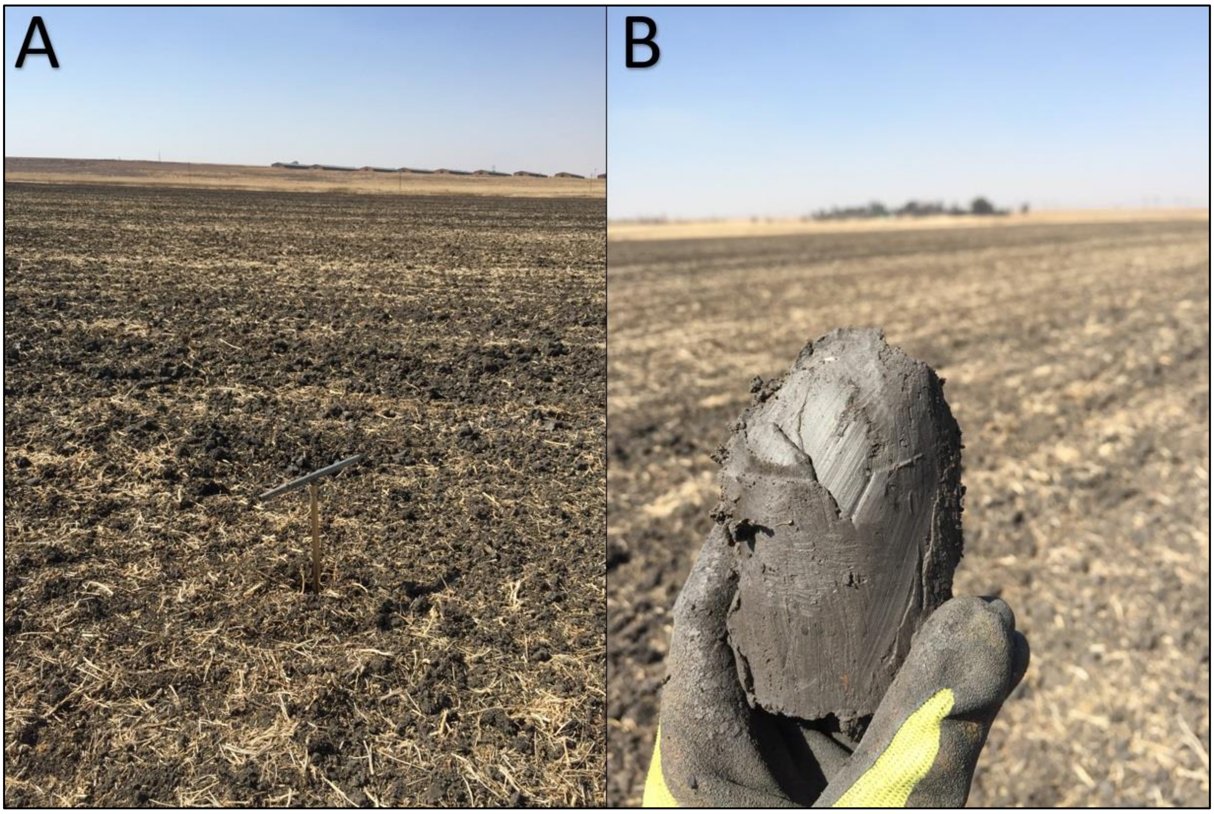

Figure 18: Willowbrook soil form. A: Auger observation within Willowbrook soil form. B: G-horizon.

Letters A to C in Figure 19 represents transitional zones from one hydropedological soil type to another and is described as follows:

- Transition A: Precipitation reaches the bedrock layer and is channelled via the soil/bedrock interface down slope. A fraction of the interflow is infiltrated into the bedrock with higher volumes channelled towards the next terrain unit/hydropedological soil form. Interflow is then infiltrated in the recharge soil form together with additional precipitation.

Transition B: The highest volume of water entering the recharge hydropedological soil form is infiltrated into the bedrock layer, after which the water seeps out through the bedrock at the toe of the slope, ultimately resulting in responsive (saturated) conditions.

- Transition C: Overland flow together with small fractions of interflow reaches the watercourse in the valley bottom. During high rainfall events, the soil form reaches saturation rapidly which allows for overland flow across the hydropedological soil form towards the watercourse.

It is evident from Figure 19 and Figure 20 that the proposed opencast mine will have a moderate to high effect on the hillslope hydrology of transect 1. The interflow (soil/bedrock) layer will be lost, ultimately cutting off all interflow and rendering precipitation into the remaining recharge zone as the only source of input.

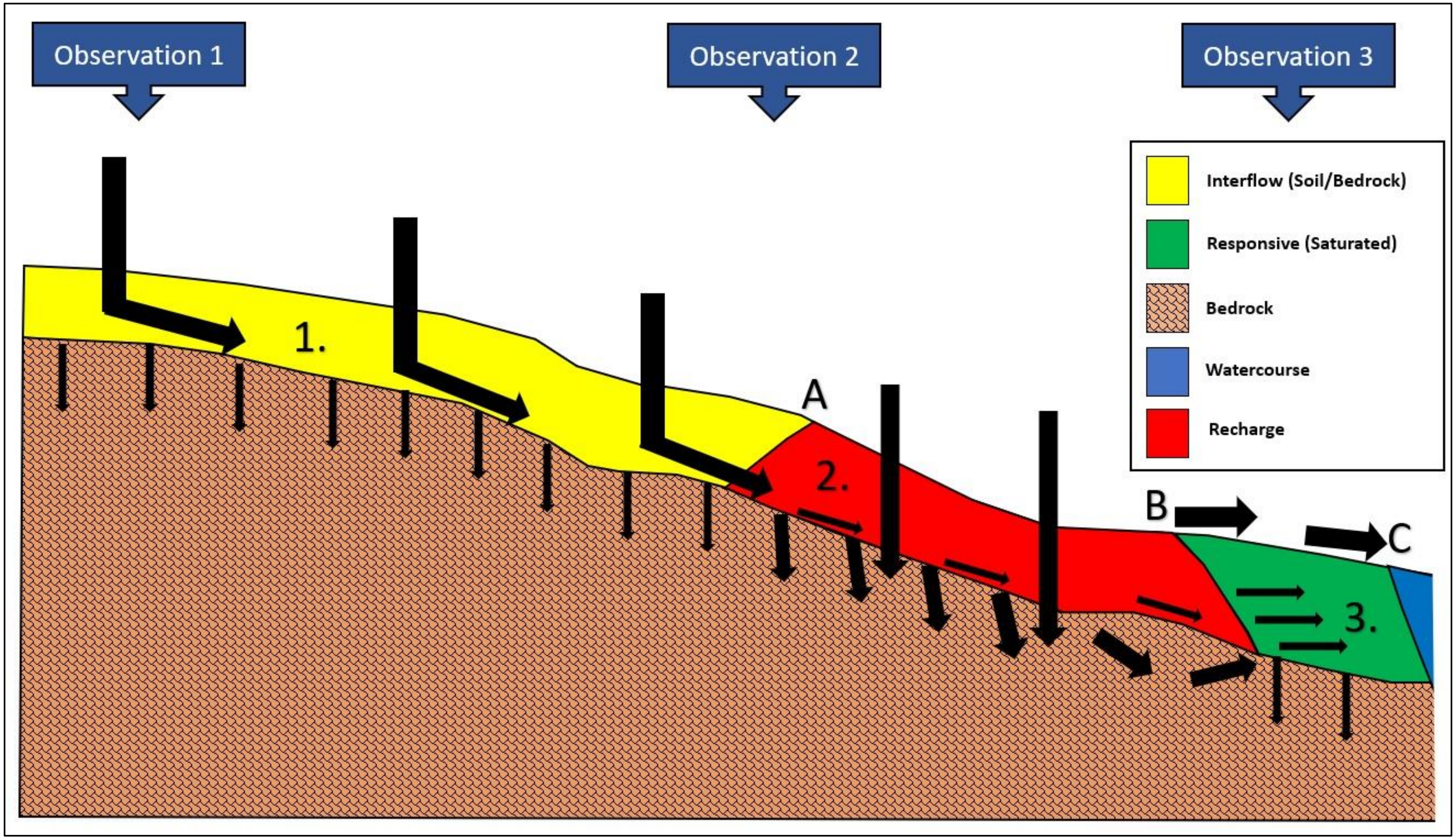

Figure 19: Conceptual hydropedological response model of transect 1 (in current state).

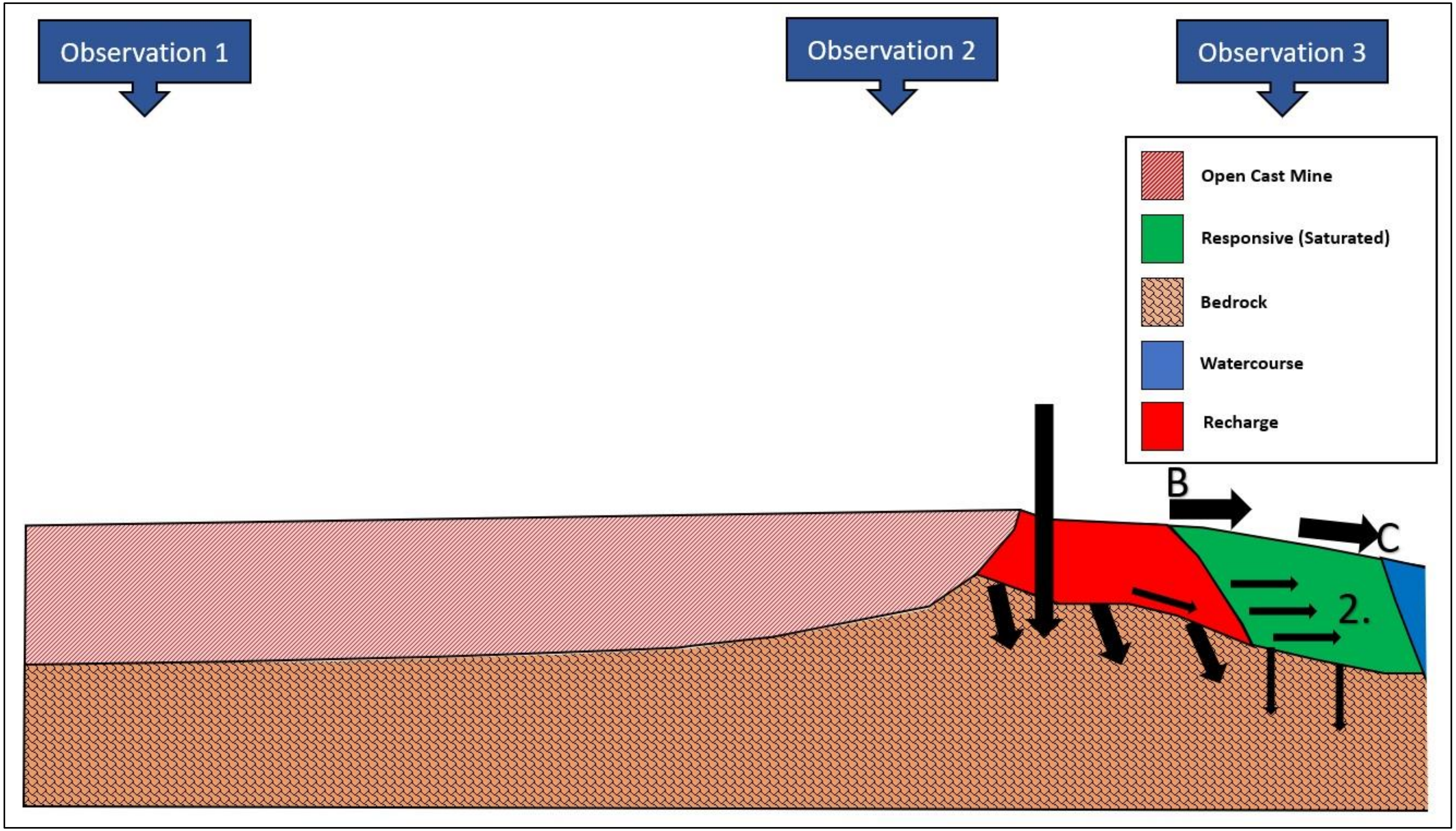

Figure 20: Conceptual hydropedological response model of transect 1 (in proposed state).

5.2.2 Transect 2

The hydropedological behaviour of transect 2 is illustrated in a conceptual hydrological response model (see Figure 23). The processes involved within this slope is described according to the number assigned to the relevant hydrological response.

1. Observation 4 and 5 is located from the crest to mid-slope of the hillslope relevant to Transect 2 and has been classified as a Westleigh soil form, which consists of an orthic A-horizon on top of a soft plinthic B-horizon (see Figure 15). The formation of the soft plinthic B-horizon and the dominant hydropedological flow paths is similar to that described for Transect 1.

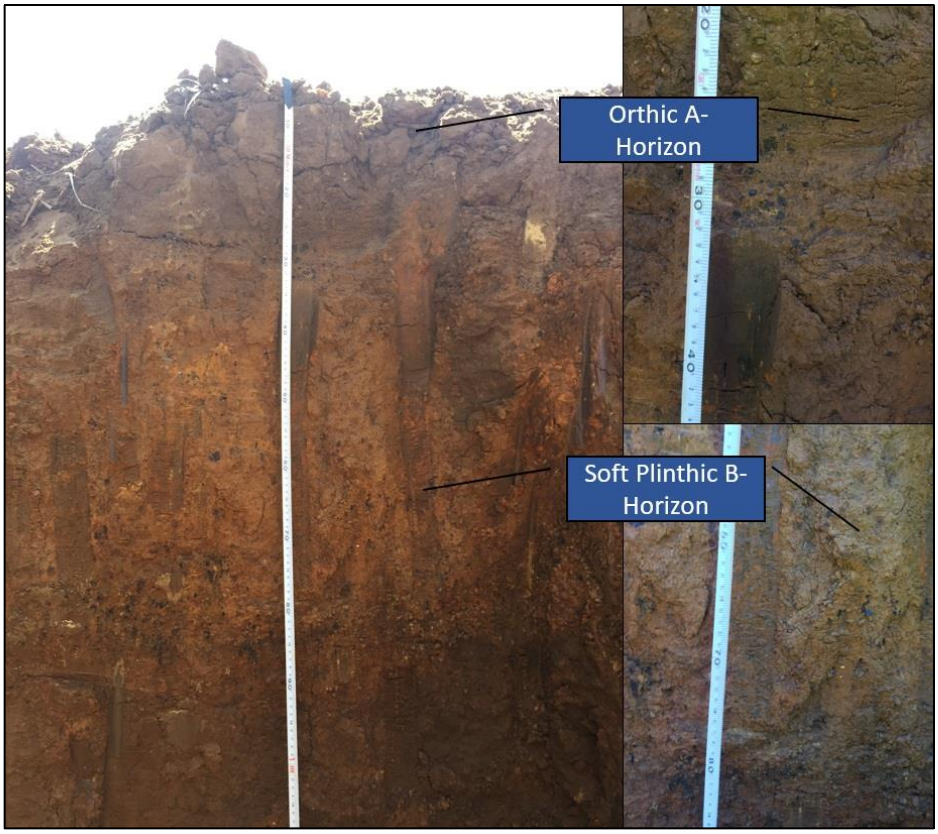

Figure 21: Interflow (soil/bedrock) hydropedological soil type identified in observation 4 and 5, transect 2

2. The valley bottom (toe position) of the hillslope (as in the case with Transect 1) is dominated by a responsive (saturated) hydropedological soil form known as a Willowbrook soil form. The Willowbrook soil form's dominant flow paths are similar to that of the Willowbrook soil form described in Transect 1.

The transition (Transition A) between the interflow (soil/bedrock) and the responsive (Saturated) hydropedological soil type is characterised by an influx of interflow channelled over the bedrock layer. Interflow slowly saturates the lower laying regions of the hillslope. Given the saturation of the toe of the hillslope, rapid saturation will occur during rainfall events, ultimately allowing for overland flow and minimal infiltration.

It is evident from Figure 22 and Figure 23 that the proposed opencast mine will have a moderate to high effect on the hillslope hydrology of transect 2. The interflow (soil/bedrock) layer will be lost, ultimately cutting off all interflow. Evapotranspiration will then be the dominant driver for the responsive hydropedological soil form, which will result in the loss of moisture. Given the loss of soil resources, overland flow will dominate, ultimately affecting the hillslope hydrology significantly.

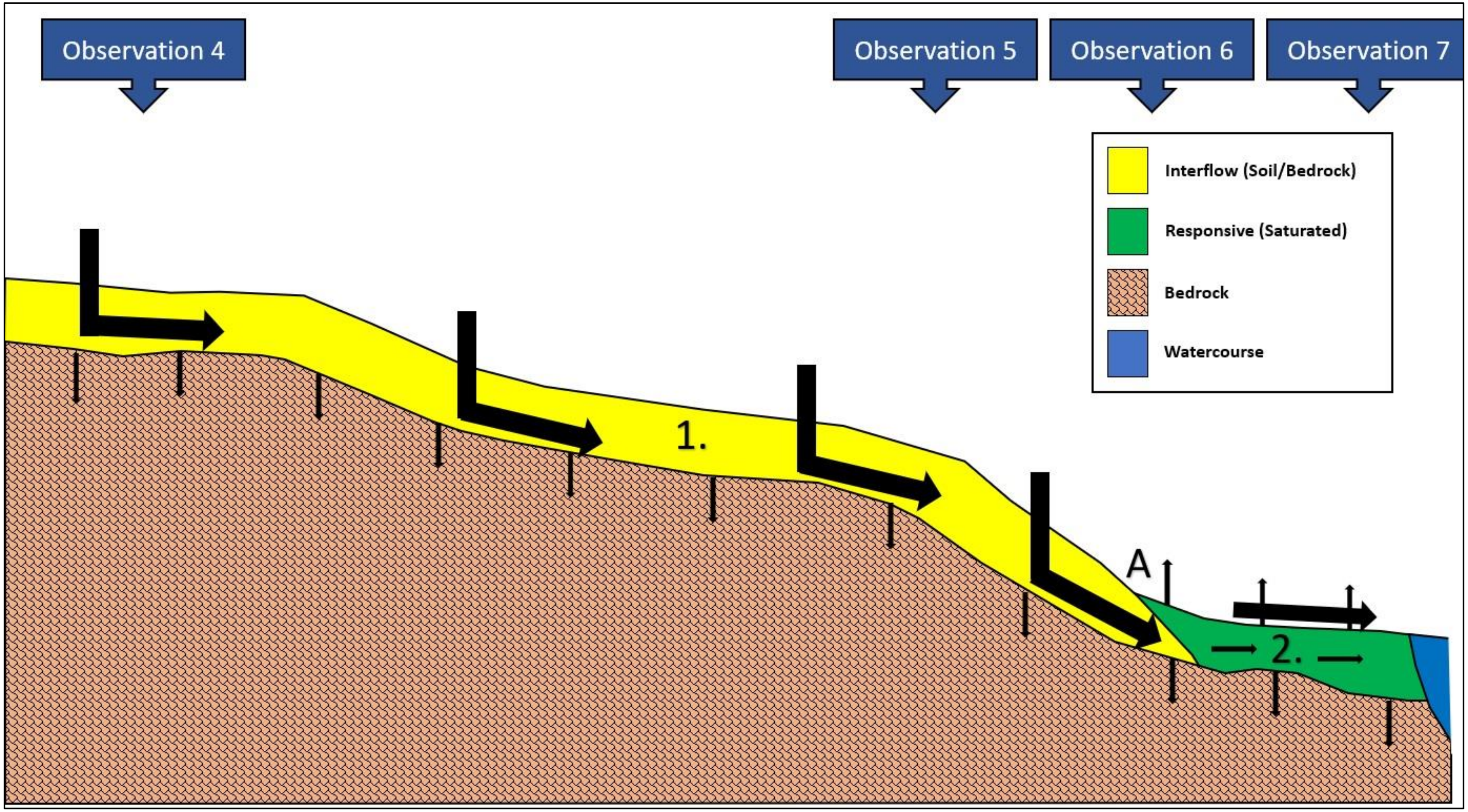

Figure 22: Conceptual hydropedological response model of transect 2 (in current state).

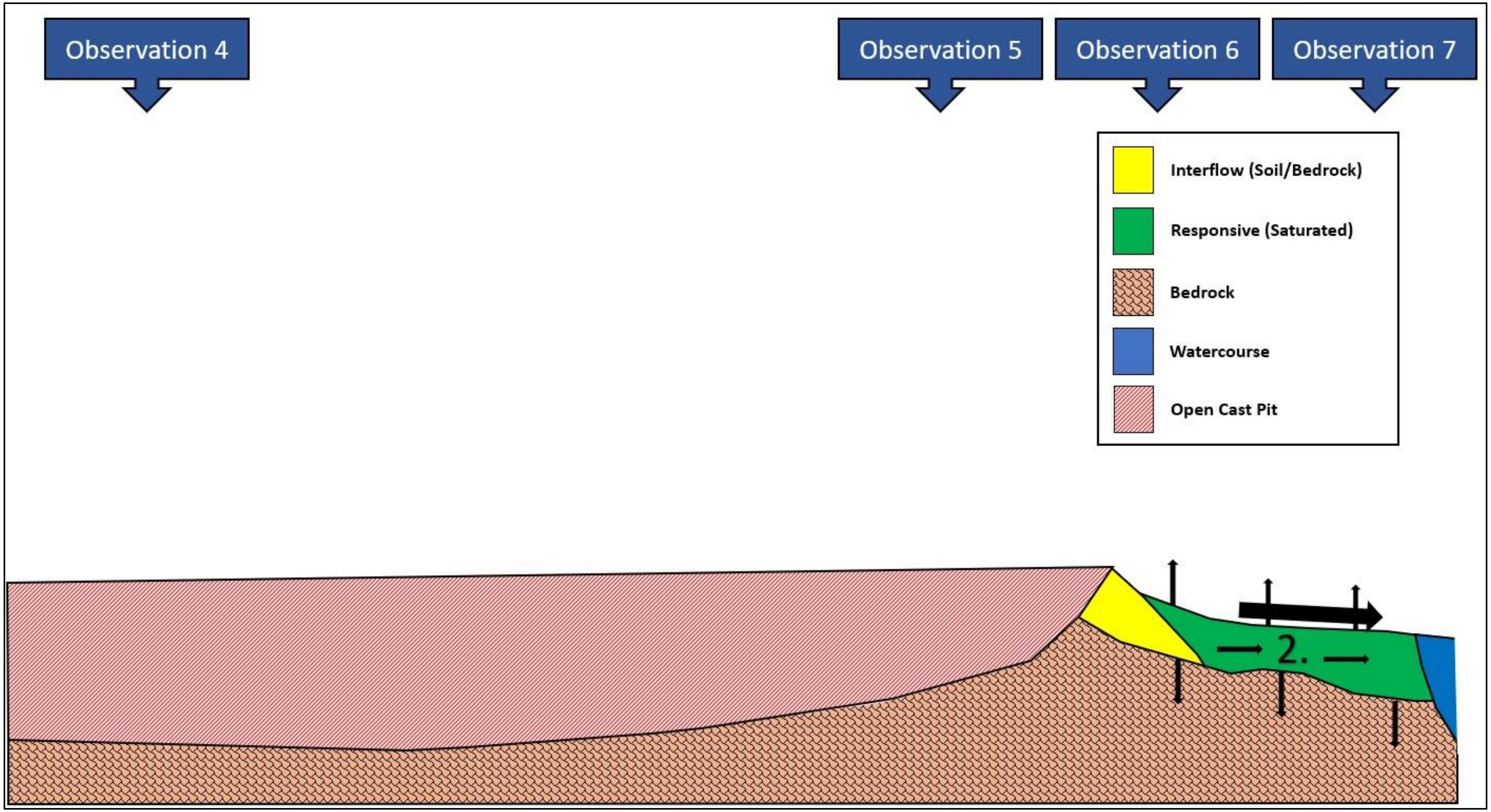

Figure 23: Conceptual hydropedological response model of transect 2 (in proposed state).

5.2.3 Transect 3

The hydropedological behaviour of transect 3 is illustrated in a conceptual hydrological response model (see Figure 27). The processes involved within this slope is described according to the number assigned to the relevant hydrological response.

1. Observation 8, 9 and 12 is located from the crest to the mid-slope of Transect 3. The soil form relevant to observation 8, 9 and 12has been classified as a Steendal soil form (see Figure 24 to Figure 26), which consists of a melanic A-horizon on top of a soft carbonate horizon (see Section 5.2.1 for descriptions of the soil form and its dominant flow paths. The *in-situ Ks* of the Sandstone layer beneath the soft carbonate layer has been assumed to be similar to that of Observation 1 at 6,72 mm/h. This soil form has therefore been classified as a Recharge soil form. Movement through this profile is however restricted given the presence of lime, which is indicative of stagnating water rather than movement.

Figure 24: Recharge hydropedological soil type identified in observation 8, transect 3

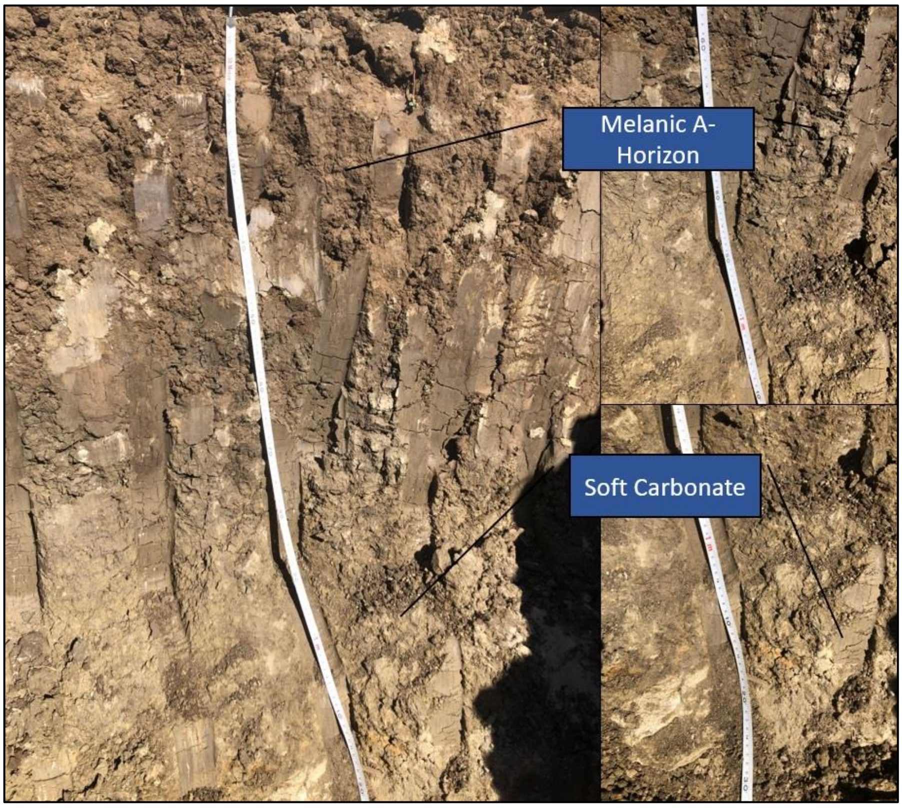

Figure 25: Recharge hydropedological soil type identified in observation 9, transect 3

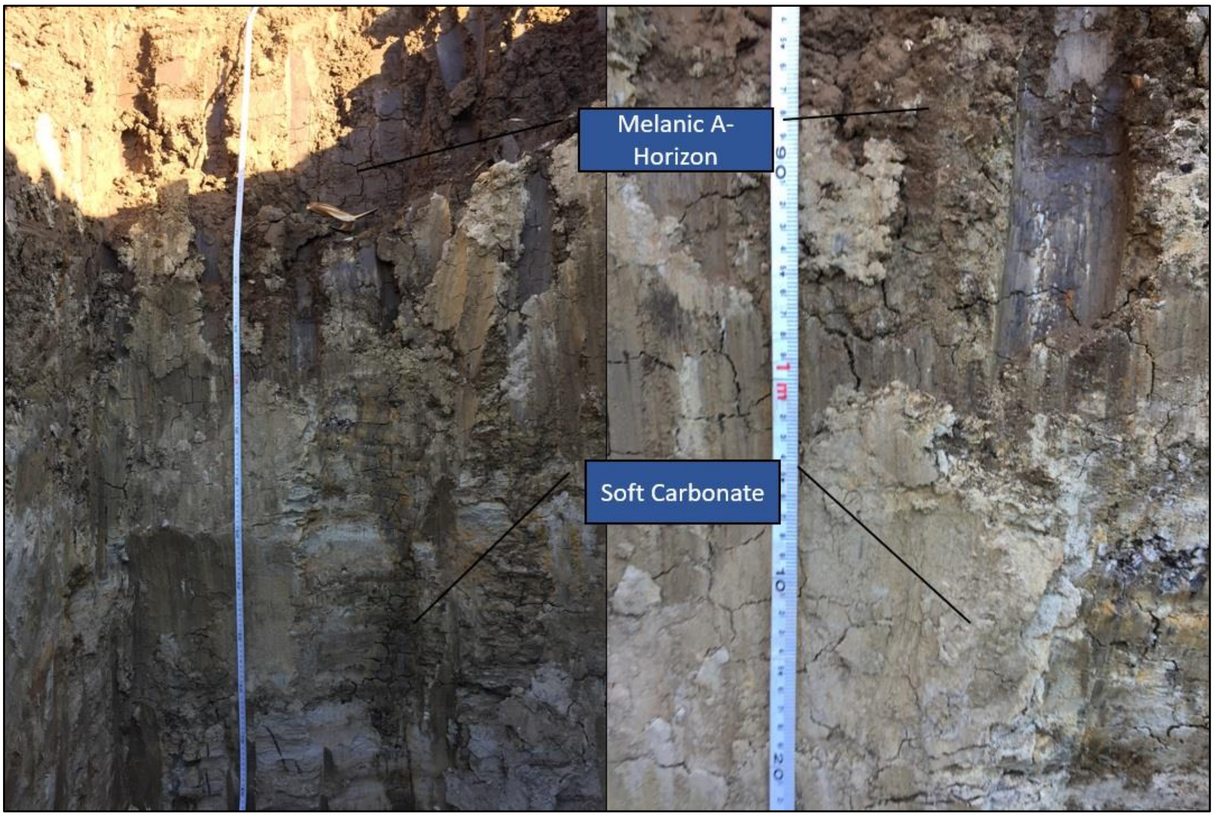

Figure 26: Recharge hydropedological soil type identified in observation 12, transect 3

2. The valley bottom (toe position) of the hillslope is dominated by a responsive (saturated) hydropedological soil form known as a Willowbrook soil form (Observation

10 and 11). The dominant flow paths within this hydropedological soil form will be overland flow given the level of saturation in this soil form.

Letters A to B in Figure 27 represents transitional zones from one hydropedological soil type to another and is described as follows:

- Transition A: The largest concentration of water entering the recharge hydropedological soil form is infiltrated into the bedrock layer, after which the water seeps out through the bedrock at the toe of the slope, ultimately resulting in responsive (saturated) conditions.
- Transition B: Overland flow together with small fractions of interflow reaches the watercourse in the valley bottom. During high rainfall events, the soil form reaches saturation rapidly which allows for overland flow across the hydropedological soil form towards the watercourse.

It is evident from Figure 27 and Figure 28 that the proposed opencast mine will have a low to moderate effect on the hillslope hydrology of transect 3. Only a small portion of the crest, which has been classified as a recharge soil form will be lost by means of opencast mining. The proposed underground mine will be 47 m at the shallowest section which limits any impacts towards the hillslope hydrology, rendering the expected impacts toward the hillslope hydrology as low.

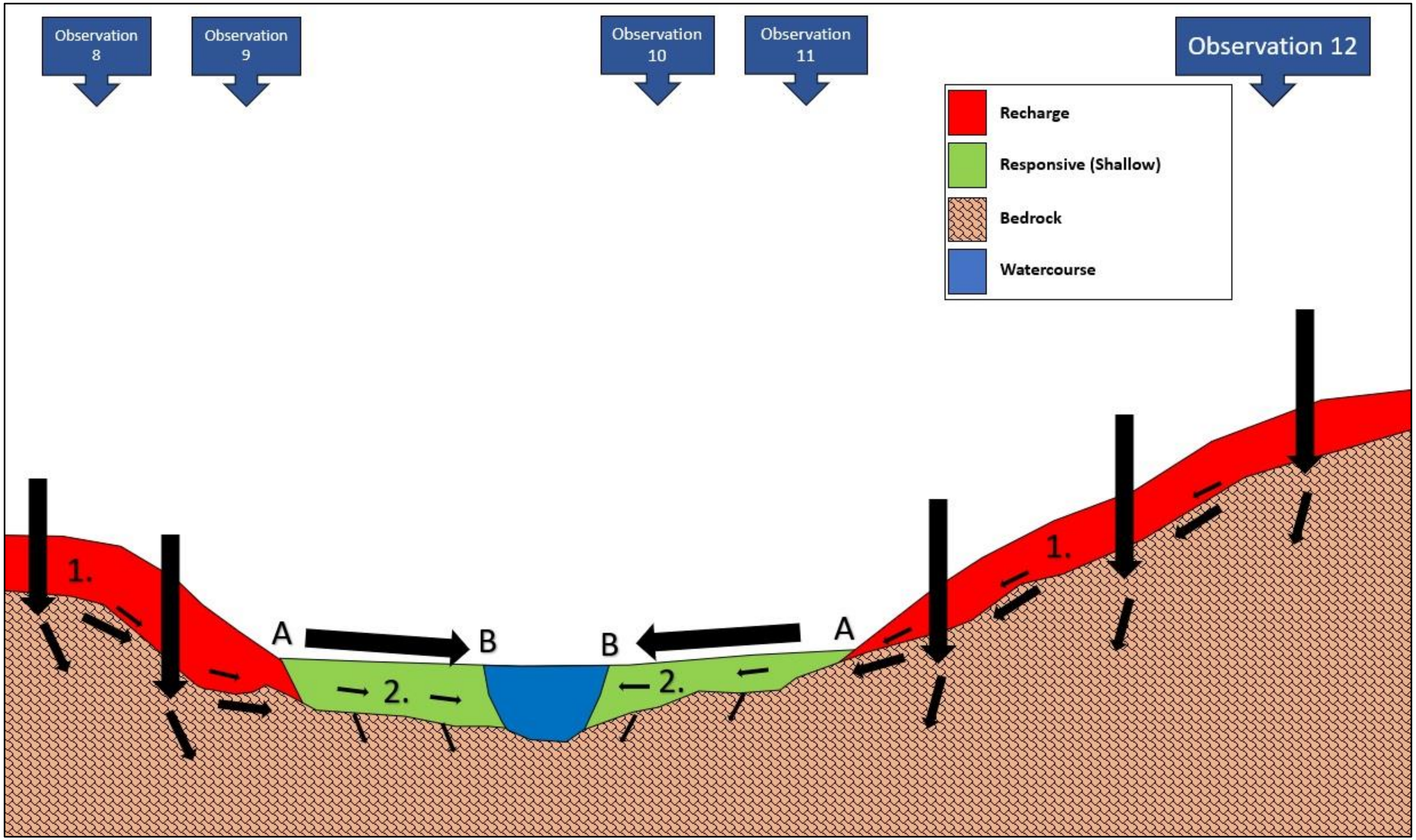

Figure 27: Conceptual hydropedological response model of transect 3 (in current state).

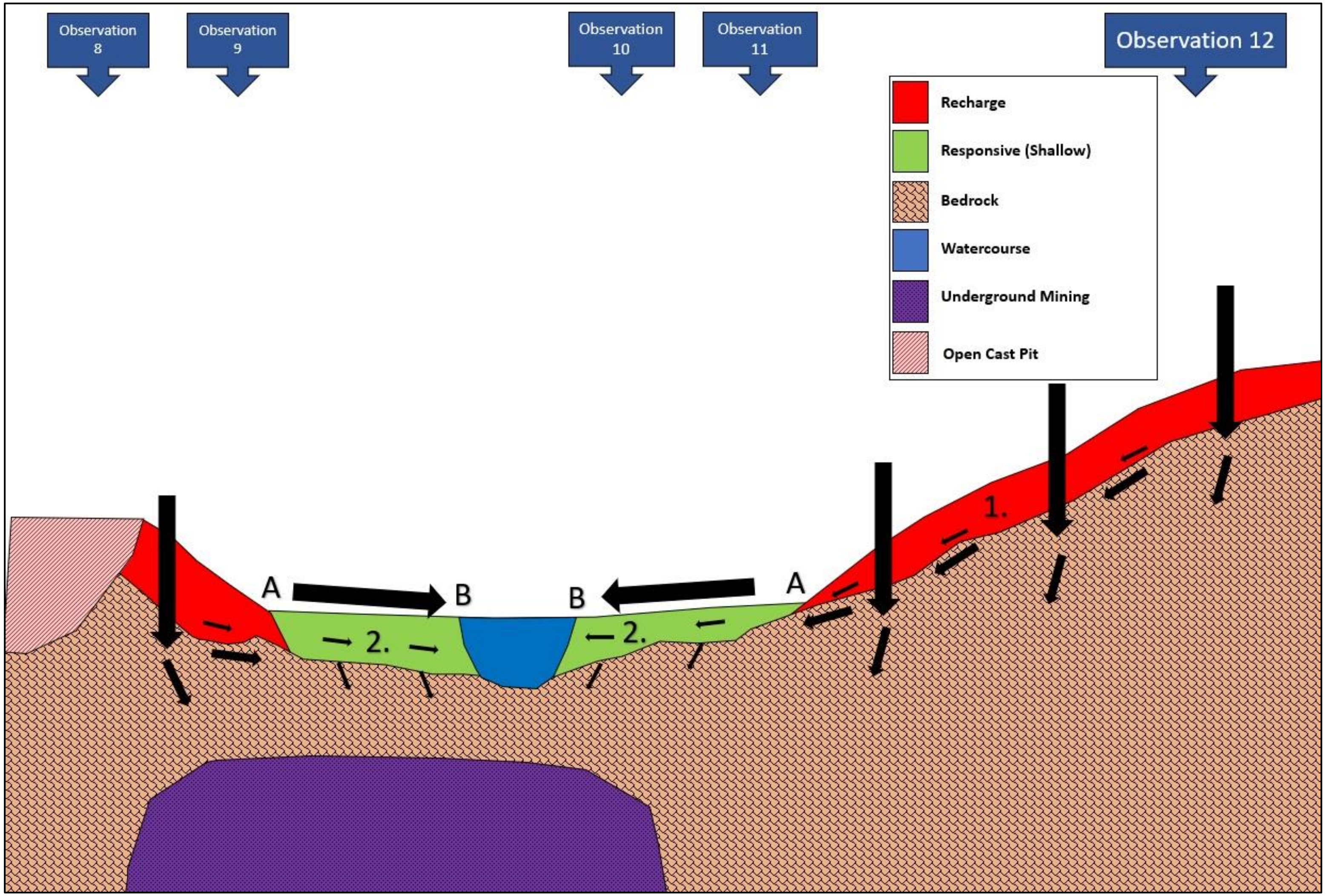

Figure 28: Conceptual hydropedological response model of transect 3 (in proposed state)

5.2.4 Transect 4

The hydropedological behaviour of transect 4 is illustrated in a conceptual hydrological response model (see Figure 32). The processes involved within this slope is described according to the number assigned to the relevant hydrological response.

1. Observations 13, 14, 16 and 17 have been classified as interflow (soil/bedrock) hydropedological soil types. Observation 13 has been determined to be a Westleigh soil form, which consists of an orthic A-horizon on top of a soft plinthic B-horizon. Together with the Westleigh soil form (orthic A-horizon on soft plinthic B-horizon) located at observation 14, 16 and 17, the Dresden soil form is dominated by plinthic conditions between soil and bedrock, which indicates interflow over the bedrock layer.

Figure 29: Interflow (soil/bedrock) (Westleigh) hydropedological soil type identified in observation 13, transect 4

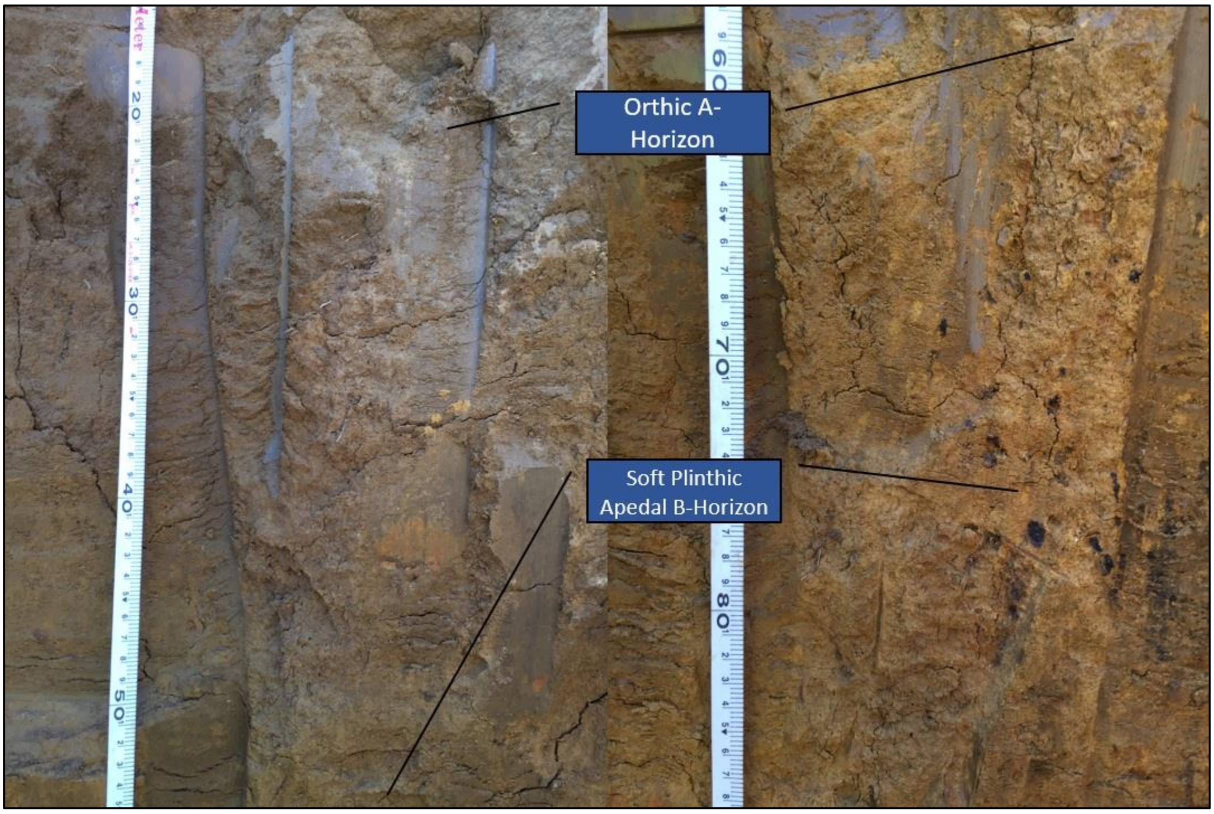

Figure 30: Interflow (soil/bedrock) (Westleigh) hydropedological soil type identified in observation 14, transect 4

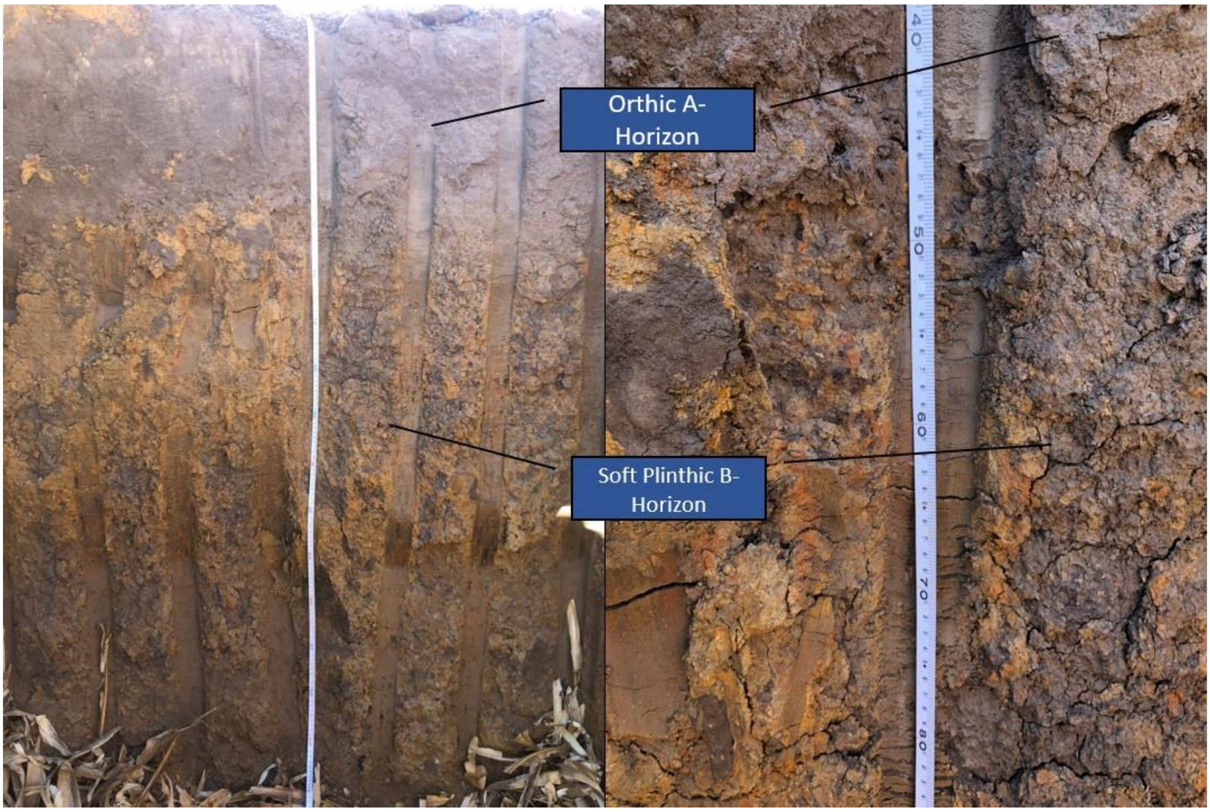

Figure 31: Interflow (soil/bedrock) (Westleigh) hydropedological soil type identified in observation 14, transect 4

2. A Glenrosa soil form with a high *in-situ Ks* of 65.14 mm/h is located at Observation 15. This soil form consists of an orthic A-horizon on top of a lithocutanic B-horizon. Given the signs of saturation (visible mottling), it has been assumed that an impermeable hard rock layer is located underneath the weathered pieces of rock present within the lithocutanic B-horizon which limits infiltration and promotes saturation.

The transition (Transition A) between the interflow (soil/bedrock) and the responsive (shallow) hydropedological soil type is characterised by an influx of interflow channelled over the bedrock layer. Interflow slowly saturates the lower laying regions of the hillslope. Given the saturation of the toe of the hillslope, rapid saturation will occur during rainfall events, ultimately allowing for overland flow and minimal infiltration.

It is evident from Figure 32 and Figure 33 that the proposed underground mine is the only component that will affect the hillslope hydrology. The proposed underground mine is 47 m at the shallowest, which emphasises the fact that little impacts are expected to the hillslope hydrology of Transect 4.

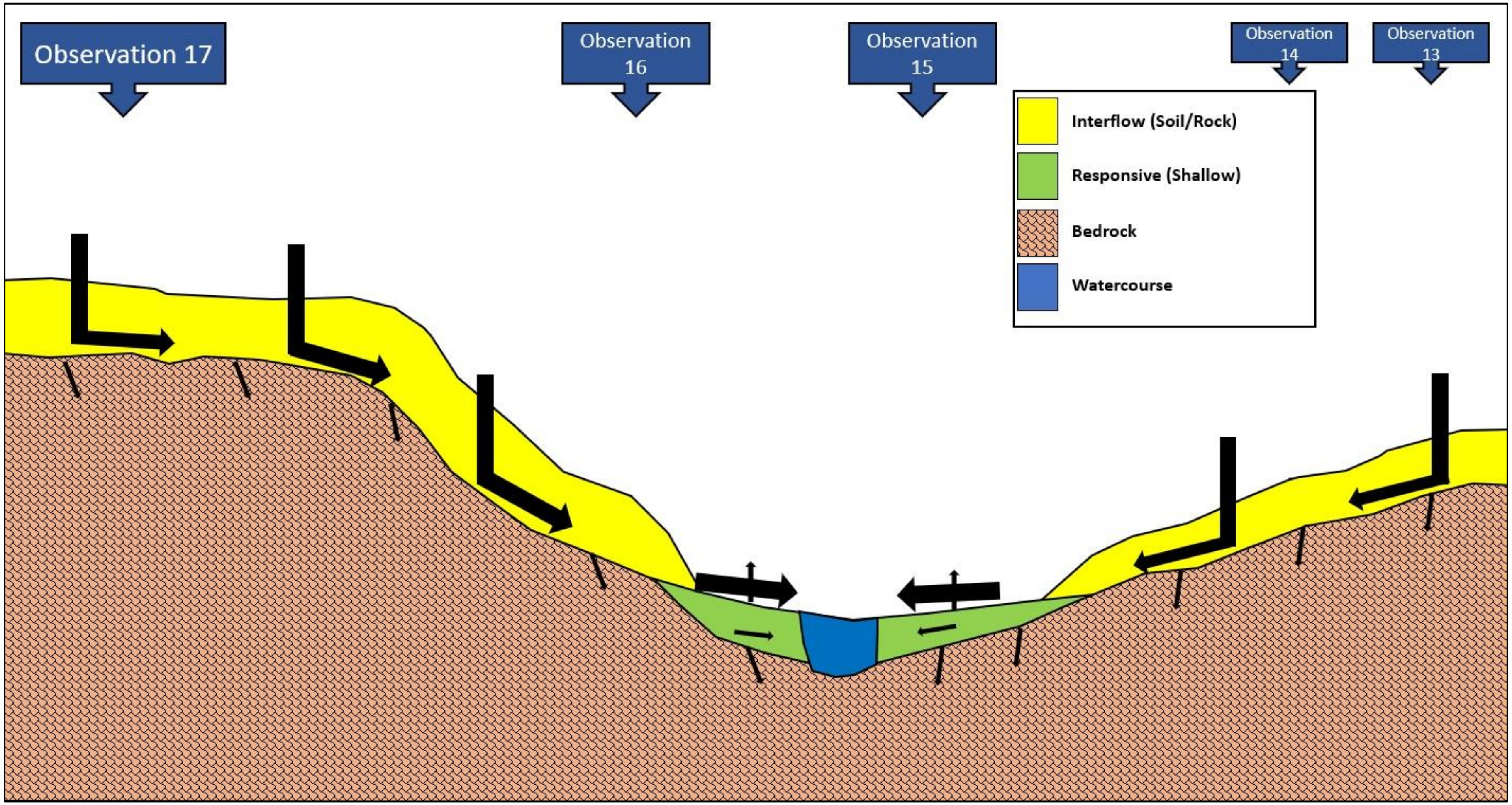

Figure 32: Conceptual hydropedological response model of transect 4 (in current state).

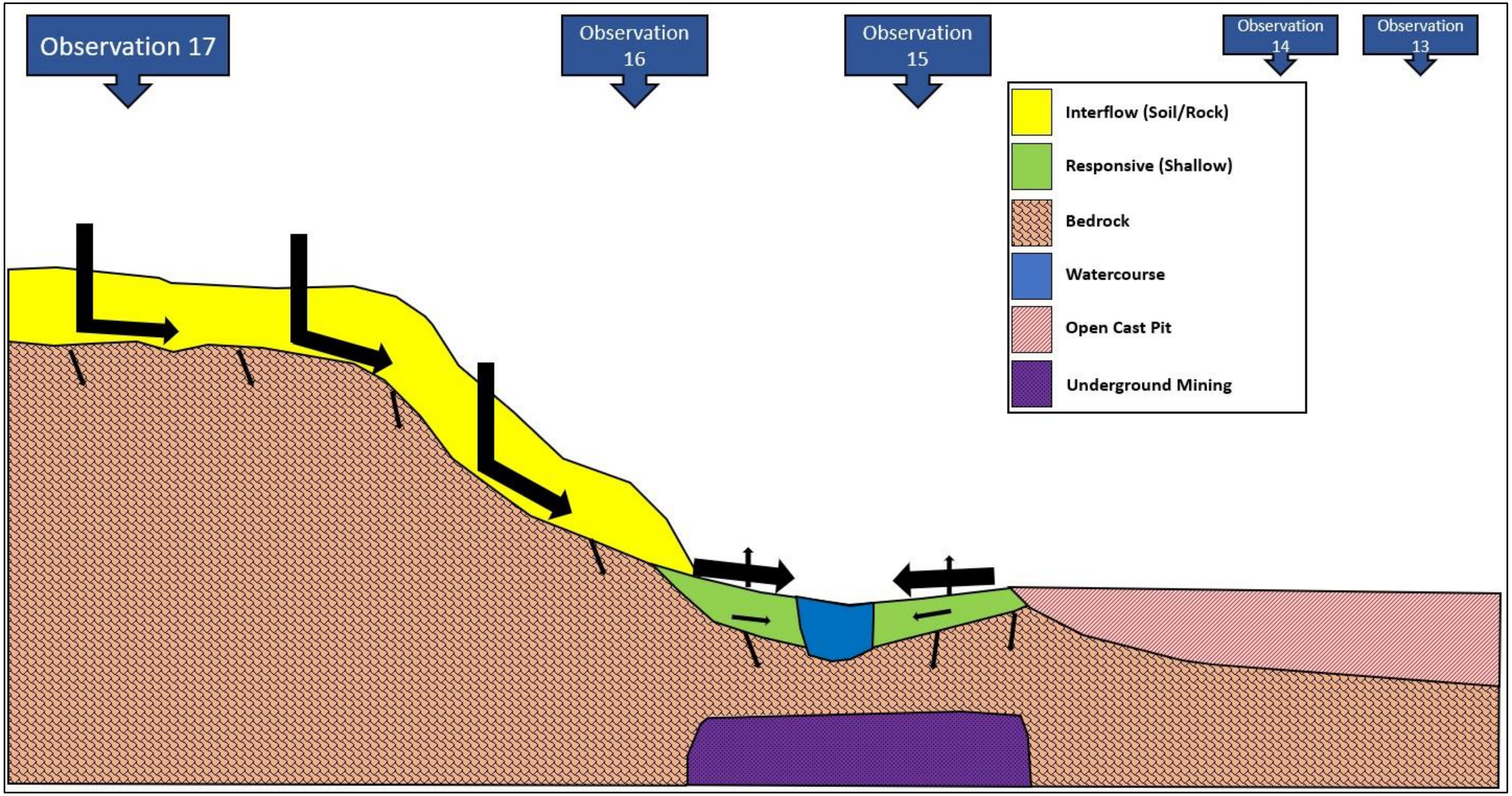

Figure 33: Conceptual hydropedological response model of transect 4 (in proposed state)

5.3 Laboratory Results

The hydraulic parameters from *in-situ* and laboratory measurements of the dominant horizons are presented in (Table 7) with the van Genuchten parameters estimated in Rosetta presented in Table 8.

Table 7: Selected hydraulic properties for representative horizons

	Obs	Soil form	Horizons	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Db ($g.cm^{-3}$)	DUL ($mm.mm^{-1}$)	Ks ($mm.h^{-1}$)
Transect 1	1	We	ot	40	57.6	15.4	28.0	1.41	0.19	54.43
			sp	260	42.4	19.8	39.0	1.46	0.32	9.45
	2	St	ml	60	45.7	15.2	39.8	1.22	0.34	37.50
			sc	120	41.9	17.4	42.2	1.17	0.47	7.51
	3	Wb	ml	130	45.7	15.2	39.8	1.22	0.34	37.50
			gh	200	36.8	17.8	45.8	1.32	0.30	9.45
Transect 2	4	We	ot	20	57.6	15.4	28.0	1.41	0.19	54.43
			sp	160	42.4	19.8	39.0	1.46	0.32	9.45
	5	We	ot	20	57.6	15.4	28.0	1.41	0.19	54.43
			sp	230	42.4	19.8	39.0	1.46	0.32	9.45
	6	Wb	ml	160	45.7	15.2	39.8	1.22	0.34	37.50
			gh	210	36.8	17.8	45.8	1.32	0.30	9.45
	7	Wb	ml	130	45.7	15.2	39.8	1.22	0.34	37.50
			gh	190	36.8	17.8	45.8	1.32	0.30	9.45
Transect 3	8	St	ml	70	45.7	15.2	39.8	1.22	0.34	37.50
			sc	280	41.9	17.4	42.2	1.17	0.47	7.51
	9	St	ml	70	45.7	15.2	39.8	1.22	0.34	37.50
			sc	300	41.9	17.4	42.2	1.17	0.47	7.51
Transect 4	13	Dr	ot	40	57.6	15.4	28.0	1.41	0.19	54.43
			hp/sp	150	42.4	19.8	39.0	1.46	0.32	9.45
	14	We	ot	50	57.6	15.4	28.0	1.41	0.19	54.43
			sp	230	42.4	19.8	39.0	1.46	0.32	9.45
	15	Gs	ot	40	57.6	15.4	28.0	1.41	0.19	54.43
			li	40+	41.9	17.4	42.2	1.17	0.47	7.51
	16	We	ot	60	57.6	15.4	28.0	1.41	0.19	54.43
			sp	290	42.4	19.8	39.0	1.46	0.32	9.45

Table 8: Van Genucthen parameters for representative horizons

	Obs	Soil form	Horizons	Depth (cm)	Θr	Θr	α	n	λ
Transect 1	1	We	ot	40	0.0782	0.4288	0.00326	1.7305	0.5
			sp	260	0.0799	0.4346	0.00201	1.268	0.5
	2	St	ml	60	0.0837	0.5112	0.00233	1.2795	0.5
			sc	120	0.0954	0.5426	0.00092	1.294	0.5
	3	Wb	ml	130	0.0837	0.5112	0.00233	1.2795	0.5
			gh	200	0.0931	0.4767	0.00256	1.3536	0.5
Transect 2	4	We	ot	20	0.0782	0.4288	0.00326	1.7305	0.5
			sp	160	0.0799	0.4346	0.00201	1.268	0.5
	5	We	ot	20	0.0782	0.4288	0.00326	1.7305	0.5
			sp	230	0.0799	0.4346	0.00201	1.268	0.5
	6	Wb	ml	160	0.0837	0.5112	0.00233	1.2795	0.5
			gh	210	0.0931	0.4767	0.00256	1.3536	0.5
	7	Wb	ml	130	0.0837	0.5112	0.00233	1.2795	0.5
			gh	190	0.0931	0.4767	0.00256	1.3536	0.5
Transect 3	8	St	ml	70	0.0837	0.5112	0.00233	1.2795	0.5
			sc	280	0.0954	0.5426	0.00092	1.294	0.5
	9	St	ml	70	0.0837	0.5112	0.00233	1.2795	0.5
			sc	300	0.0954	0.5426	0.00092	1.294	0.5
Transect 4	13	Dr	ot	40	0.0782	0.4288	0.00326	1.7305	0.5
			hp/sp	150	0.0799	0.4346	0.00201	1.268	0.5
	14	We	ot	50	0.0782	0.4288	0.00326	1.7305	0.5
			sp	230	0.0799	0.4346	0.00201	1.268	0.5
	15	Gs	ot	40	0.0782	0.4288	0.00326	1.7305	0.5
			li	40+	0.0954	0.5426	0.00092	1.294	0.5
	16	We	ot	60	0.0782	0.4288	0.00326	1.7305	0.5
			sp	290	0.0799	0.4346	0.00201	1.268	0.5

5.4 Modelling Results

The soil distribution patterns between the various transects are relatively similar, especially in terms of the hydraulic properties (Table 7 and Table 8). The simulated outflows presented in Figure 34, Figure 36 and Figure 38 are comparable with only small differences in the magnitudes and shapes of the outflow curves. The same applies to the simulated water contents presented in Figure 35, Figure 37 and Figure 39. The impact of the development on the various transects are therefore discussed together.

Following the large rain events on the first ten days of the simulation (see methodology section), valley bottom soils under both the 'natural' and 'developed' state are fully saturated (Figure 35, Figure 37 and Figure 39). These soils are releasing water laterally to the stream at maximum rates and not differences between 'natural' and 'developed' state outflows (Figure 34, Figure 36 and Figure 38). After approximately 10 days of rain-free drainage (day 21) small differences between the 'natural' and 'developed' states become apparent. This is due to more continuous drainage from the longer natural slope than the 'developed' slope. The soils under the latter will also dry out faster than under the natural state due to the same reason.

The difference between the 'natural' and 'developed' state become more pronounced with the addition of 50 mm of rain to relatively dry profiles. Here lateral and overland flow from the longer undeveloped 'natural' slope will ensure that soils wet up more and quicker than the 'developed' valley bottom soil (Figure 34, Figure 36 and Figure 38). Discharge from the natural slopes are therefore more and lasts considerably longer than under the 'developed state (Figure 34, Figure 36 and Figure 38).

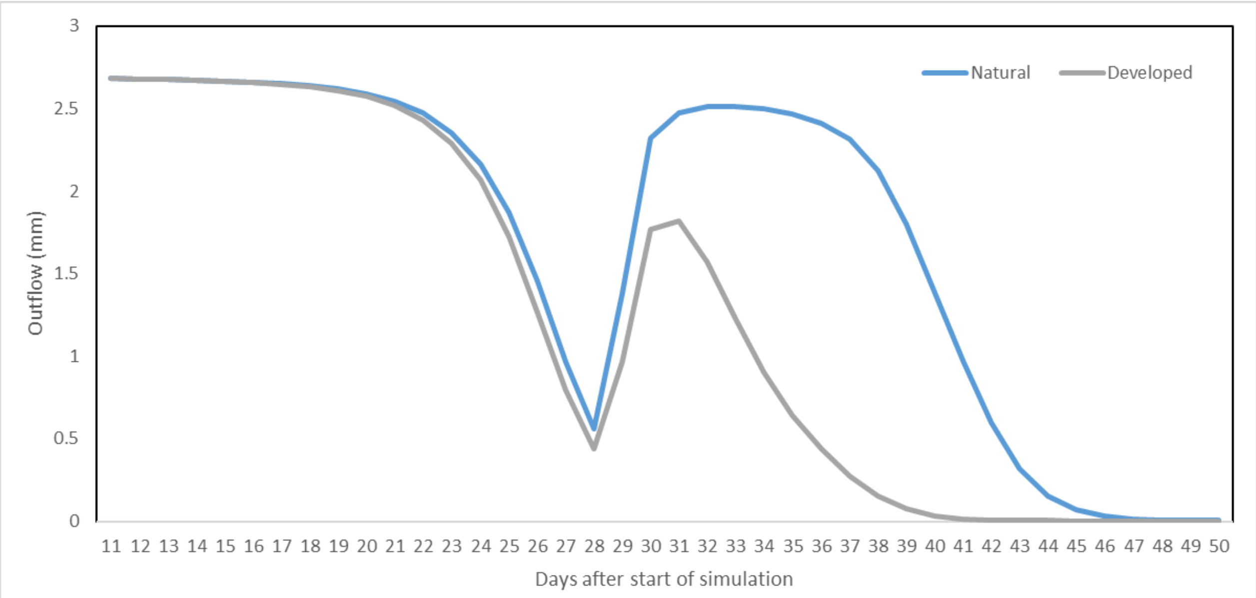

Figure 34: Simulated outflow (mm) from transect 1 during natural and developed conditions.

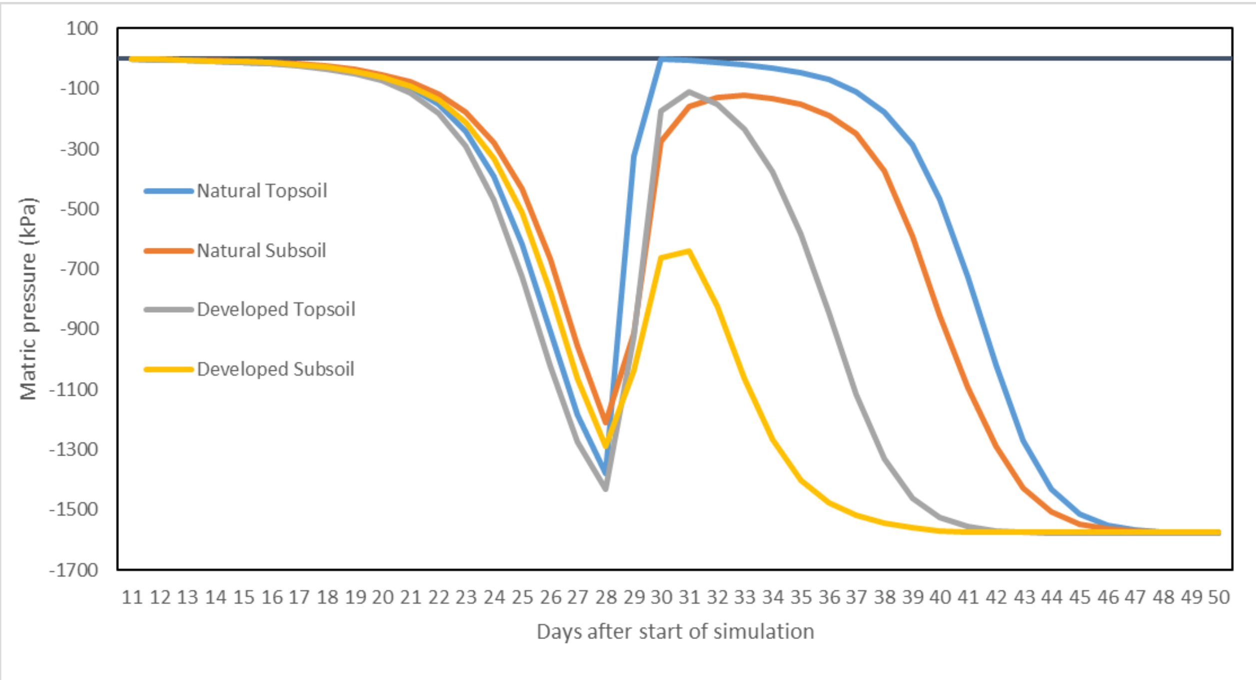

Figure 35: Simulated matric pressure (kPa) of different horizons of the wetland soil (valley bottom landscape unit) in transect 1 under natural and developed conditions.

The smaller contribution area associated with the proposed development ('developed' in Figure 34, Figure 36 and Figure 38) resulted in a 67% reduction in outflow when compared to the natural conditions. (**Note: this value should be considered a maximum reduction in outflow and not an average).**

Under drier conditions, the lateral flows in these landscapes would be limited. The relatively low hydraulic conductivities and low relief of the landscapes suggest that lateral flows are not a major contributor to streamflow.

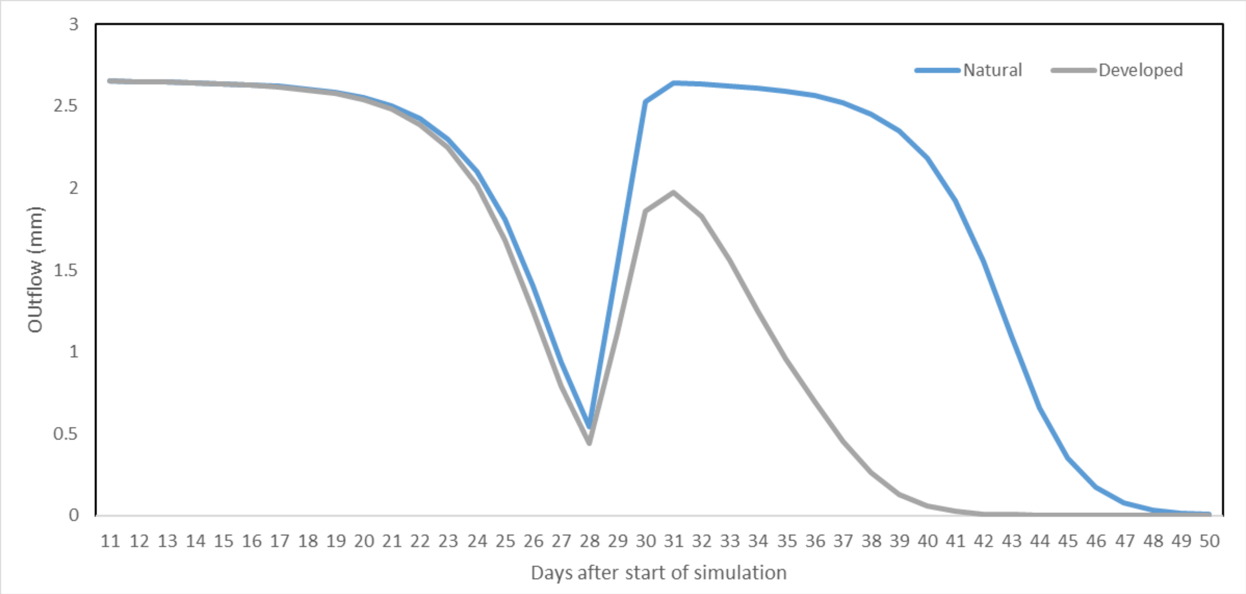

Figure 36: Simulated outflow (mm) from transect 2 during natural and developed conditions.

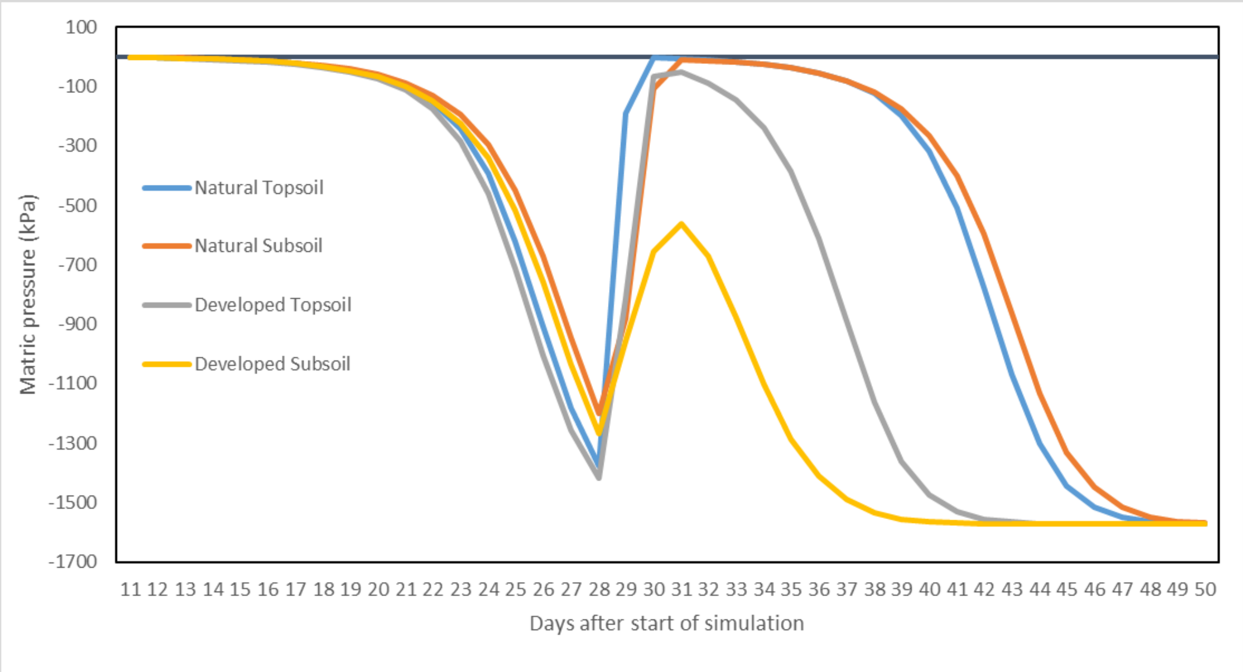

Figure 37: Simulated matric pressure (kPa) of different horizons of the wetland soil (valley bottom landscape unit) in transect 2 under natural and developed conditions.

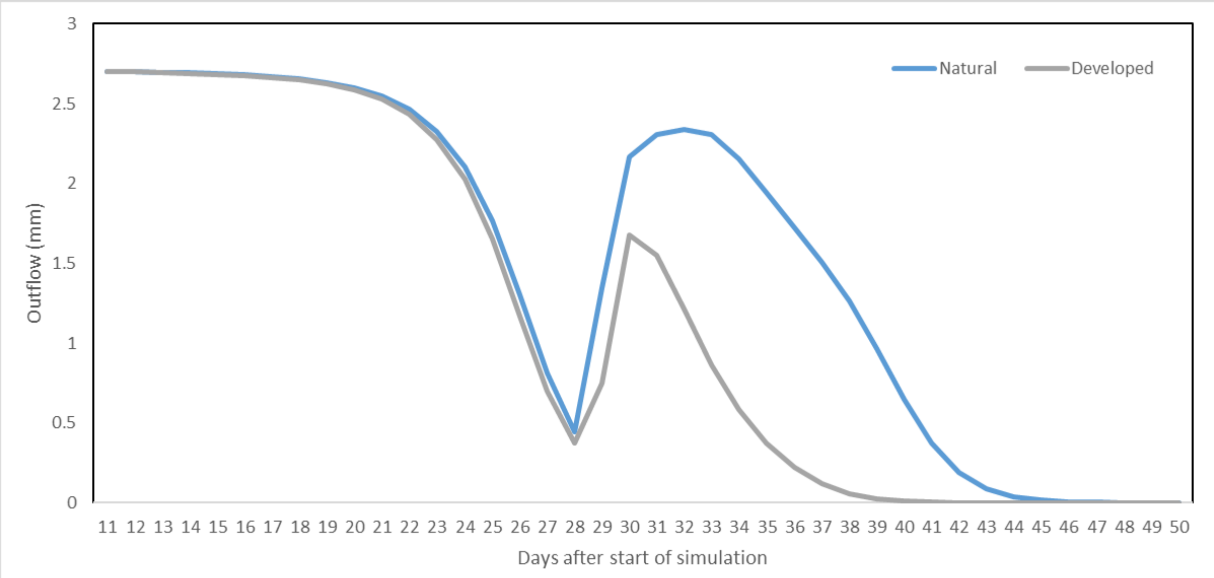

Figure 38: Simulated outflow (mm) from transect 4 during natural and developed conditions.

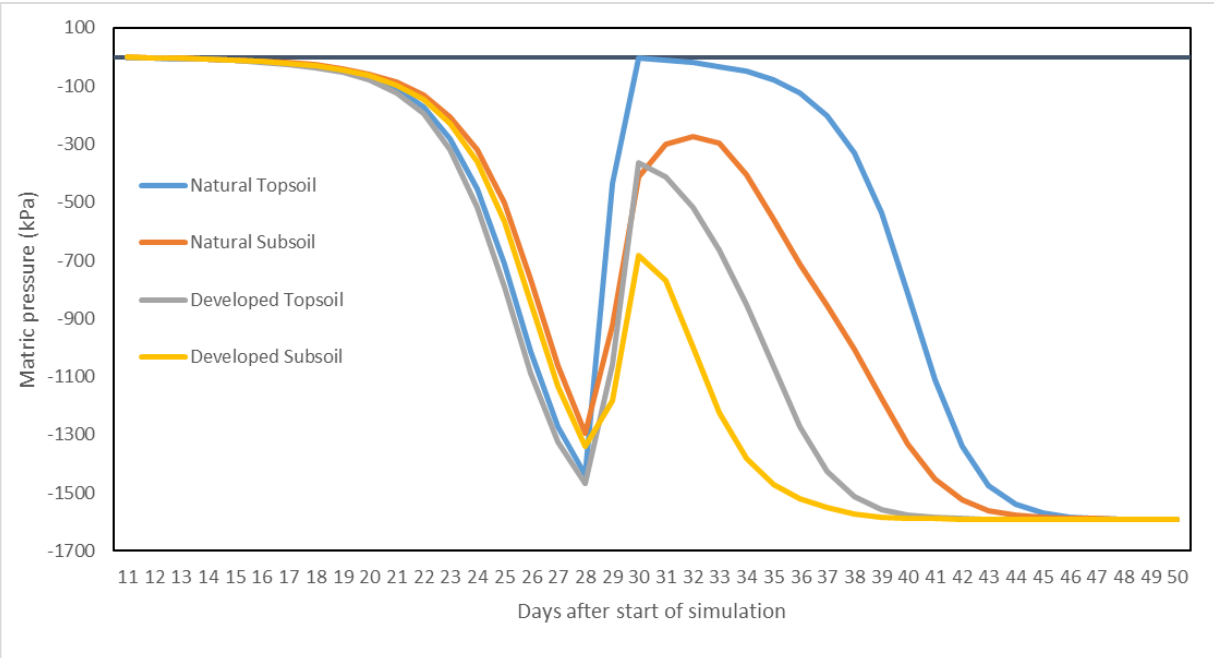

Figure 39: Simulated matric pressure (kPa) of different horizons of the wetland soil (valley bottom landscape unit) in transect 4 under natural and developed conditions.

6 Impact Assessment

The following potential impacts were considered on the hillslope wetland hydrology based on the construction, operational, decommissioning and closure phases of the proposed opencast mining and underground mining activities.

6.1 Construction Phase

During the construction phase, soil stripping, construction of haul roads and blasting takes place. This phase will be completed within a few months, which emphasises the short duration of the construction phase.

6.1.1 Proposed Opencast Mine

The environmental risk associated with the proposed opencast pit has been calculated to be low before and after mitigation. The prioritisation factor however has been scored high due to public responses for mining in the area, cumulative impacts from mining in the area as well as the degree of irreplaceable losses which has increased the final significance to moderate.

Table 9: Significance ratings for the relevant phase and alternative

Impact Name	**Loss of Sub-Surface Flows**				
Alternative	**Proposed Opencast Mine**				
Phase	**Construction**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	3
Extent of Impact	3	3	Reversibility of Impact	3	3
Duration of Impact	2	2	Probability	2	2
Environmental Risk (Pre-mitigation)					-5,50
Mitigation Measures					
See Section 7- Recommendations					
Environmental Risk (Post-mitigation)					-5,50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					3
Issue has received an intense meaningful and justifiable public response					
Cumulative Impacts					3
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is highly probable/definite that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					3
The impact may result in the irreplaceable loss of resources of high value (services and/or functions).					
Prioritisation Factor					2,00
Final Significance					-11,00

6.1.2 Underground Mining

The environmental risk associated with the proposed underground mine has been calculated to be low before and after mitigation, given the fact that no mitigation will be required. The prioritisation factor however has been scored moderately high due to public responses for mining in the area and cumulative impacts from mining in the area which has increased the final significance to moderate.

Table 10: Significance ratings for the relevant phase and alternative

Impact Name	Loss of Sub-Surface Flows				
Alternative	Proposed Underground Mine				
Phase	Construction				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	3	3
Extent of Impact	3	3	Reversibility of Impact	3	3
Duration of Impact	2	2	Probability	1	1
Environmental Risk (Pre-mitigation)					-2,75
Mitigation Measures					
See Section 7- Recommendations					
Environmental Risk (Post-mitigation)					-2,75
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					3
Issue has received an intense meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1,50
Final Significance					-4,13

6.2 Operational Phase

During the operational phase, coal will be extracted together with overburden material. This phase will be completed within a few years (life of mine), which emphasises the long duration of the operational phase.

6.2.1 Proposed Opencast Mine

The environmental risk associated with the proposed opencast pit has been calculated to be high before mitigation and is expected to drop to moderate after the implementation of mitigation measures aimed at reintroducing water intercepted by the opencast pit back into the relevant watercourses. The prioritisation factor however has been scored high due to public responses for mining in the area, cumulative impacts from mining in the area as well as the degree of irreplaceable losses which has increased the final significance to high.

Table 11: Significance ratings for the relevant phase and alternative

Impact Name	Loss of Sub-Surface Flows				
Alternative	Proposed Opencast Mine				
Phase	Operational				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**

Nature of Impact	-1	-1	Magnitude of Impact	5	4
Extent of Impact	4	4	Reversibility of Impact	4	3
Duration of Impact	4	4	Probability	3	3
Environmental Risk (Pre-mitigation)					-12,75
Mitigation Measures					
See Section 7- Recommendations					
Environmental Risk (Post-mitigation)					-11,25
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					3
Issue has received an intense meaningful and justifiable public response					
Cumulative Impacts					3
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is highly probable/definite that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					3
The impact may result in the irreplaceable loss of resources of high value (services and/or functions).					
Prioritisation Factor					2,00
Final Significance					-22,50

6.2.2 Underground Mining

The environmental risk associated with the proposed underground mine has been calculated to be low before and after mitigation, given the fact that no mitigation will be required. The prioritisation factor however has been scored moderately high due to public responses for mining in the area and cumulative impacts from mining in the area which has increased the final significance to moderate.

Table 12: Significance ratings for the relevant phase and alternative

Impact Name	**Loss of Sub-Surface Flows**				
Alternative	**Proposed Underground Mine**				
Phase	**Operational**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	2
Extent of Impact	3	3	Reversibility of Impact	3	3
Duration of Impact	4	4	Probability	1	1
Environmental Risk (Pre-mitigation)					-3,00
Mitigation Measures					
See Section 7- Recommendations					
Environmental Risk (Post-mitigation)					-3,00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					3
Issue has received an intense meaningful and justifiable public response					

Cumulative Impacts	2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.	
Degree of potential irreplaceable loss of resources	1
The impact is unlikely to result in irreplaceable loss of resources.	
Prioritisation Factor	1,50
Final Significance	-4,50

6.3 Decommissioning Phase

During the decommissioning phase, backfilling of the opencast area will take place, haul roads will be removed (ripped and rehabilitated) and any infrastructure will be removed. This phase will be completed within a few months, which emphasises the short duration of the operational phase.

6.3.1 Proposed Opencast Mine

The environmental risk associated with the proposed opencast pit has been calculated to be low before and after mitigation. The prioritisation factor however has been scored high due to public responses for mining in the area, cumulative impacts from mining in the area as well as the degree of irreplaceable losses which has increased the final significance to moderate.

Table 13: Significance ratings for the relevant phase and alternative

Impact Name	**Loss of Sub-Surface Flows**				
Alternative	**Proposed Opencast Mine**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	5	5
Extent of Impact	4	4	Reversibility of Impact	4	4
Duration of Impact	2	2	Probability	2	2
Environmental Risk (Pre-mitigation)					-7,50
Mitigation Measures					
See Section 7- Recommendations					
Environmental Risk (Post-mitigation)					-7,50
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					3
Issue has received an intense meaningful and justifiable public response					
Cumulative Impacts					3
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is highly probable/definite that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					3
The impact may result in the irreplaceable loss of resources of high value (services and/or functions).					
Prioritisation Factor					2,00
Final Significance					-15,00

6.3.2 Underground Mining

The environmental risk associated with the proposed underground mine has been calculated to be low before and after mitigation, given the fact that no mitigation will be required. Even though the prioritisation factor however has been scored moderately high due to public responses for mining in the area and cumulative impacts from mining in the area, the final significance still remains low.

Table 14: Significance ratings for the relevant phase and alternative

Impact Name	**Loss of Sub-Surface Flows**				
Alternative	**Proposed Underground Mine**				
Phase	**Decommissioning**				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	2
Extent of Impact	2	2	Reversibility of Impact	2	2
Duration of Impact	2	2	Probability	1	1
Environmental Risk (Pre-mitigation)					-2,00
Mitigation Measures					
See Section 7- Recommendations					
Environmental Risk (Post-mitigation)					-2,00
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					3
Issue has received an intense meaningful and justifiable public response					
Cumulative Impacts					2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					1
The impact is unlikely to result in irreplaceable loss of resources.					
Prioritisation Factor					1,50
Final Significance					-3,00

6.4 Closure Phase

During the closure phase, rehabilitation and monitoring will take place to amend all degraded areas. This phase will be completed within a few years, which emphasises the short duration of the operational phase. It is worth noting that the vadose zone's detailed properties will never be rehabilitated back to its natural state given significant degradation of soil resources as well as the underlaying bedrock.

6.4.1 Proposed Opencast Mine

The environmental risk associated with the proposed opencast pit has been calculated to be moderate before and after mitigation with a final significance scored high.

Table 15: Significance ratings for the relevant phase and alternative

Impact Name	Loss of Sub-Surface Flows				
Alternative	Proposed Opencast Mine				
Phase	Closure Phase				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	5	5
Extent of Impact	4	4	Reversibility of Impact	5	5
Duration of Impact	5	5	Probability	3	3
Environmental Risk (Pre-mitigation)					-14,25
Mitigation Measures					
See Section 7- Recommendations					
Environmental Risk (Post-mitigation)					-14,25
Degree of confidence in impact prediction:					High
Impact Prioritisation					
Public Response					3
Issue has received an intense meaningful and justifiable public response					
Cumulative Impacts					3
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is highly probable/definite that the impact will result in spatial and temporal cumulative change.					
Degree of potential irreplaceable loss of resources					3
The impact may result in the irreplaceable loss of resources of high value (services and/or functions).					
Prioritisation Factor					2,00
Final Significance					-28,50

6.4.2 Underground Mining

The environmental risk associated with the proposed underground mine has been calculated to be low before and after mitigation, given the fact that no mitigation will be required. Even though the prioritisation factor however has been scored moderately high due to public responses for mining in the area and cumulative impacts from mining in the area, the final significance still remains low.

Table 16: Significance ratings for the relevant phase and alternative

Impact Name	Loss of Sub-Surface Flows				
Alternative	Proposed Underground Mine				
Phase	Closure Phase				
Environmental Risk					
Attribute	**Pre-mitigation**	**Post-mitigation**	**Attribute**	**Pre-mitigation**	**Post-mitigation**
Nature of Impact	-1	-1	Magnitude of Impact	2	2
Extent of Impact	2	2	Reversibility of Impact	2	2
Duration of Impact	2	2	Probability	1	1
Environmental Risk (Pre-mitigation)					-2,00

Mitigation Measures	
See Section 7- Recommendations	
Environmental Risk (Post-mitigation)	-2,00
Degree of confidence in impact prediction:	High
Impact Prioritisation	
Public Response	3
Issue has received an intense meaningful and justifiable public response	
Cumulative Impacts	2
Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal cumulative change.	
Degree of potential irreplaceable loss of resources	1
The impact is unlikely to result in irreplaceable loss of resources.	
Prioritisation Factor	1,50
Final Significance	-3,00

To summarise, the final significance scores for opencast mining during the operational and closure phase has been scored a moderate environmental risk score with an increase to a high final significance score given the public response score, cumulative impacts and the irreplaceable loss factor. As for the construction and decommissioning phase of the opencast mining activities, a low environmental risk is expected which is expected to increase to a moderate final significance score. The low to moderate probability scores are attributed to the fact that a high (maximum 67%) loss of interflow is expected during extreme rainfall events (during the 1:10 or 1:25-year flooding events) with very little to no loss expected during an average rainfall year.

As for the underground mining works, the final significance during all phases have been determined to be low, which indicates that no fatal flaws have been detected for the proposed underground mining activities.

According to the mitigation hierarchy (DEA, 2013), prevention of impacts is first prize, followed by minimising significance ratings via relevant mitigation measures and recommendations. The third step (given that avoidance and a decrease of significance could not be met) will be to rehabilitate any degraded areas which will include a detailed rehabilitation plan focussed on the closure phase. In cases where the specialist deem rehabilitation insufficient, an offset of sensitive receptors will be recommended.

Underground mining activities are expected avoid any impacts to the vadose zone and does therefore not require any further mitigation measures except for a blasting and geochemical/groundwater assessment to determine the impacts to groundwater aquifers that feed the adjacent watercourses. Therefore, no fatal flaws have been identified for these activities. As for the opencast mining activities, high and moderate final significance ratings have been calculated with no chance of a decrease via mitigation measures and relevant recommendations. Rehabilitation has also been deemed insufficient given the fact that soil stripped and stockpiled will be degraded to such an extent that all physical properties will be altered significantly (i.e. porosity, *Ks* etc). Additionally, the underlaying bedrock which is the main driver of vadose zone properties in such a landscape will be destroyed and removed ultimately indicating a permanent loss of some of the hillslope features. An offset will therefore be required which emphasises on the watercourses. In this case, the source and pathway will be lost, ultimately leaving only the receptor (the watercourses). The wetland offset strategy must incorporate the findings from this hydropedological assessment.

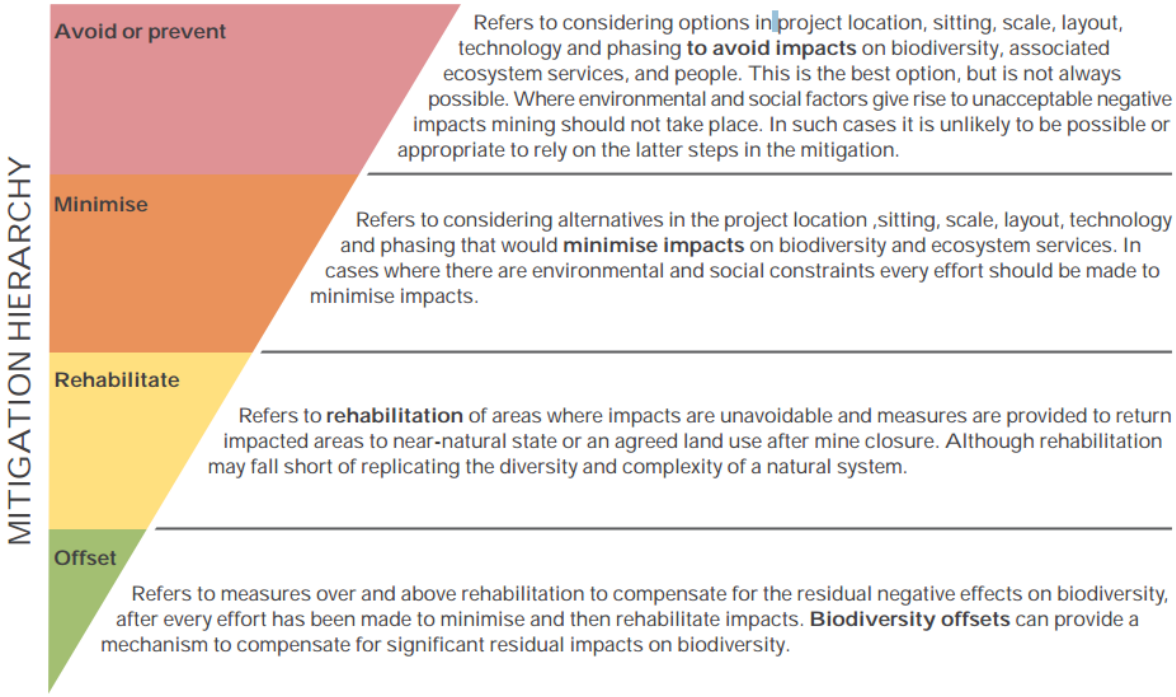

Figure 40: The mitigation hierarchy as described by the DEA (2013)

7 Recommendations

The following mitigations have been made to avoid various threats to sensitive receptors;

- A blasting assessment has been recommended to determine the possibilities of cracks forming in the upper bedrock layer during blasting;
- A groundwater assessment/geochemical assessment has been recommended to determine the loss of flow from groundwater aquifers to the watercourse;
- It is recommended that a detailed stormwater management system be incorporated for the proposed opencast mining area that channels precipitation and any other surface water accumulated within the pit towards a lined stormwater attenuation pond. The water from the attenuation pond must be pumped to a pollution control facility, after which the remediated water must be pumped back to a second attenuation pond in close proximity to the watercourse to feed the respective watercourse in a diffuse manner. It is vital that both watercourses (east and west) be fed with equal amounts of remediated water given the fact that the watershed which plays a fundamental role in diverting precipitation to both watercourses will be lost. See Figure 42 for a map illustrating a conceptual location of the proposed second attenuation pond. It is recommended that the second attenuation pond be fitted with a weir structure that diffusely spreads outflow into the wetland (as has been conceptually illustrated in Figure 41); and

- A wetland offset strategy is recommended given the fact that the responsive hydropedological forms are the only sections of the hillslopes that will remain intact, with the rest of the hillslopes (recharge and interflow hydropedological forms) being removed during the proposed activities. This strategy has been considered as a last resort according to the mitigation hierarchy due to the irrelevance of “avoidance”, “decreasing impacts” and “rehabilitation”.

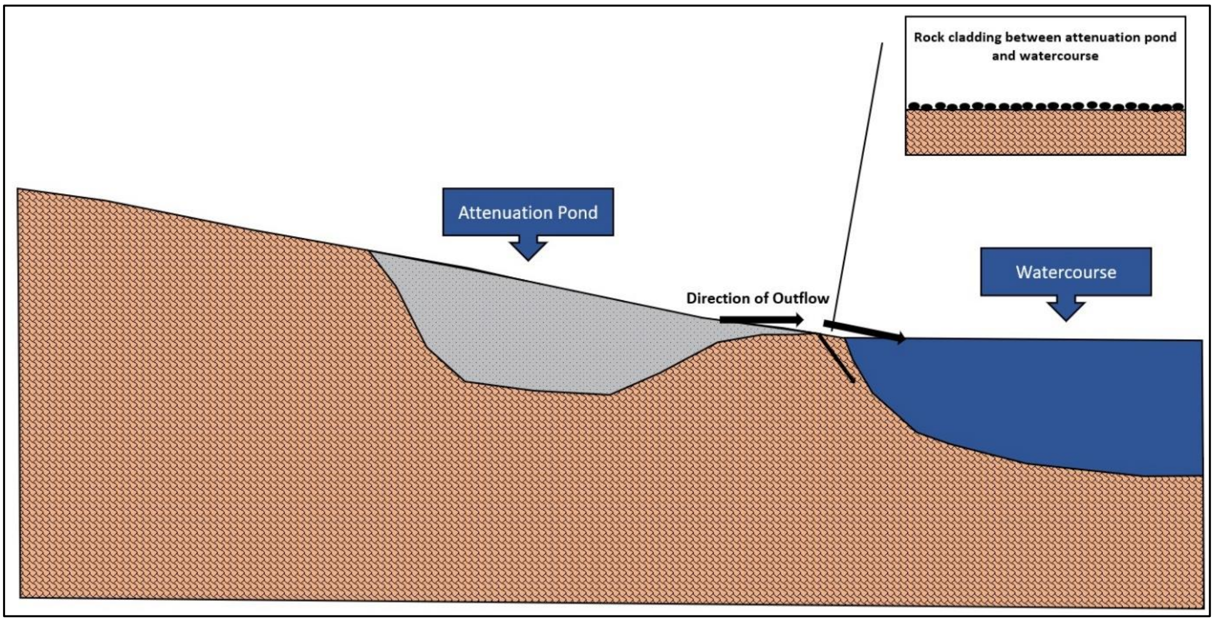

Figure 41: Conceptual layout of recommended attenuation pond

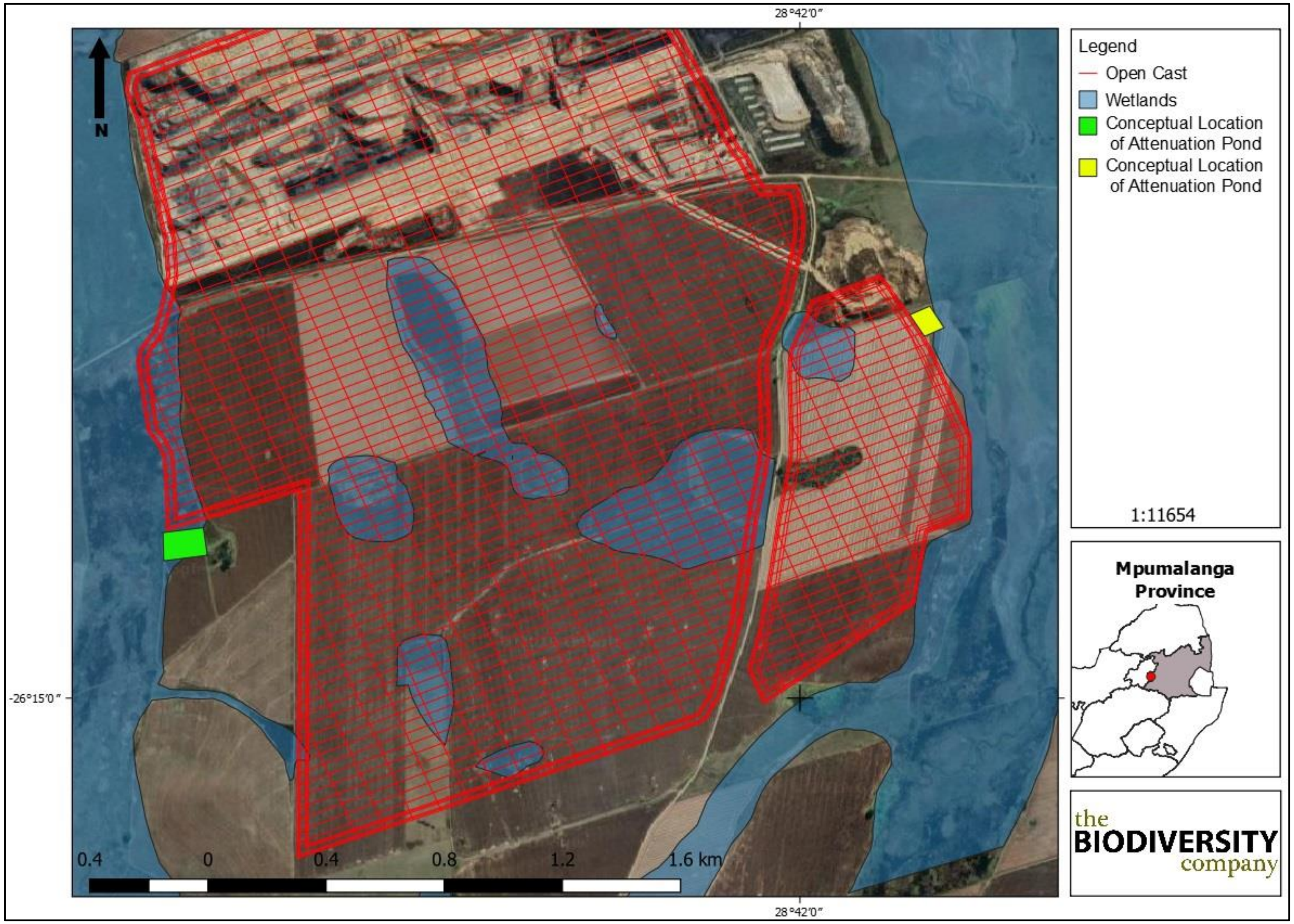

Figure 42: Conceptual locations of attenuation ponds

8 Conclusions

This report represents findings from a hydropedological survey of four transects to assess the potential impact of opencast and underground 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. In general, the measurements and simulations are in agreement with the conceptual understanding based on morphological interpretations. The depth of the planned underground mining activities and impermeability of the bedrock suggest that this activity will not have any significant impact on vadose zone processes.

The hydropedological modelling focussed on three of the four transects (only those impacted by open-cast mining). Simulations focussed on the contribution of lateral flows through the transects following a very wet period to illustrate the **maximum** impact of the development on lateral outflows. Under these conditions the development could result in up to 67% reduction in lateral contributions to flow. The difference in the lateral contributions is large due to the difference in water regimes of the soils in the valley bottom. Under natural conditions these soils will be fed by a larger contribution area than under ‘developed’ conditions and will consequently remain wetter for longer and also ‘wet-up’ quicker following rain events. This will result in more lateral drainage from the natural than the ‘developed’ state.

Under normal (drier) conditions, the low hydraulic conductivity of the soils together with the low relief of the landscape, suggest that lateral flows through the soils are limited. This is supported by the precipitation of lime in Steendal soils on mid slope positions (limited leaching or lateral flows).

To summarise, a significant loss of interflow is expected during extreme rainfall events (1:10 or 1:25-year flooding events) with very little to no loss of interflow expected during an average rainfall year. This phenomenon has attributed to a low to moderate probability score, which has ultimately ensured a lower final significance score.

Given the limited impacts towards sub-surface flows during an average rainfall year and the presence of stagnant hydropedological types, it is the specialist’s opinion that the proposed activities may proceed under the condition that all recommendations made within this report be adhered to.

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