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Appendix F2:

Groundwater (Hydrogeological) Assessment

Dunbar Coal Mine Hydrogeology

EIS019/03-19/010

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Dunbar Coal Mine Hydrogeology

EIS019/03-19/010

Enviro Insight (Pty) Ltd

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1. Introduction

Alicanto Groundwater Solutions (Pty) Ltd ("AGS") was appointed by Mr Corne Niemandt of Enviro-Insight (Pty) Ltd ("the Client") to conduct a hydrogeological investigation for the proposed Dunbar Coal Mine ("the Site") located near to Hendrina, Mpumalanga Province.

The hydrogeological investigation will be used in the Site's environmental authorisation processes (i.e. Environmental Impact Assessment (EIA), Water Use License Application (WULA), etc.). The objective of the investigation was to characterise the baseline hydrogeological environment at the Site and the potential impact (if any) that the proposed Site activities would have on the receiving environment.

2. Scope of Work

A phased approach was followed for the project, where the results of each phase were discussed with the Client and amendments to the scope of work (if any) identified and approved before proceeding with the next phase.

The phases and their respective subtasks for the project were:

- Phase 1: Data Collection, Review and Analysis
    - Desktop Review; and
    - Hydrocensus Investigation.
- Phase 2: Field Investigation
    - Geophysical Survey;
    - Hydrogeological Borehole Installation; and
    - Aquifer Testing.
- Phase 3: Aquifer Characterisation and Impact Assessment
    - Geochemical Assessment;
    - Conceptual Model Development;
    - Numerical Modelling (Flow & Transport);
    - Groundwater Reserve Determination; and
    - Groundwater Impact Assessment.
- Phase 4: Reporting
    - Groundwater Management Plan Development; and
    - Technical Report Compilation.

The scope of work was based on the requirements for hydrogeological investigations for WULA's as per GNR 267 of March 2017 and the general requirements for a site-specific EIA.

3. Methodology

3.1. Phase 1: Data Collection, Review and Analysis

3.1.1. Desktop Review

A detailed desktop review was completed for the Site, during which all relevant data and information available in the public domain and provided by the Client for the Site was reviewed, analysed and collated into a central database.

The information reviewed included, but was not limited to, the following:

- 1:50’000 scale topographic maps 2629 BC, BA, AB and AD;
- 1:250’000 scale vector geological data (DWS, 2008);
- 1:500’000 scale hydrogeological map series 2526: Johannesburg (Barnard, 1999);
- Exploration borehole logs for the Site;
- 1 km resolution aerial geophysical data available for the region;
- National groundwater archive (NGA) boreholes datasets;
- Regional water quality datasets;
- GeoCoal Services, 2015. *An updated Geological Report on the Liviscan Coal Resources on Dunbar 189 IS*;
- Rison Consulting, 2008. *Geohydrological Investigation: Komati Ash Dam Extension*;
- Huisamen, A., 2017. *Quantification Methods and Management of Hydrogeochemistry in Decommissioned Collieries of the Mpumalanga Coalfields*; and
- GHT Consulting Scientists, 2009. *Komati Power Station Draft Hydrocensus Report*.

The data and information collected during the desktop review was used to compile a central project database to be used during proceeding phases of the project.

3.1.2. Hydrocensus Investigation

A Hydrocensus investigation was conducted within a 5-km radius of the Site and within the Site boundaries, during which a total of 22 boreholes were identified. A total of 9 boreholes were in use as either domestic or livestock water supply, with the remaining 13 boreholes being either monitoring boreholes or not in use. During the Hydrocensus the following information was collected at each of the groundwater features identified:

- Geographic coordinates;
- Water level (if applicable);
- Equipment installed (if applicable);
- General condition of the groundwater feature; and
- Abstraction rates and water use (if any).

A total of five (5) water quality samples were collected during the Hydrocensus investigation and submitted to a SANAS-accredited laboratory for analysis. The water samples were collected in accordance with the AGS sampling protocol, which is available on request.

The results of the hydrocensus investigation are discussed in Section 5.3, with the hydrocensus sheets presented in Appendix A and laboratory certificates for the hydrocensus investigation presented in Appendix B.

3.2. Phase 2: Field Investigation

3.2.1. Geophysical Survey

A total of twelve (12) geophysical traverses were completed at the Site using the electromagnetic (EM-34) method (8 traverses) and the magnetic method (4 traverses), as summarised in Table 3.1.

Both applied geophysical methods measured the natural properties of the underlying lithology, with borehole targets identified at anomalous areas within the profiles. The results and interpretation of the geophysical survey are discussed in Section 5.3.2 and the geophysical line graphs are presented in Appendix C.

Table 3.1: Geophysical Traverse Summary

Line No.	Start Coordinates (LO29, WGS84)	End Coordinates (LO29, WGS84)	Line Description	Geophysical Method	Length (m)
Line 1	X: 52414.75 Y: -2898136	X: 52283.70 Y: -2898385	Orientated NE to SW Background Borehole Siting	EM-34	280
Line 2	X: 51429.53 Y: -2896173	X: 51627.26 Y: -2895548	Orientated SSW to NNE Located between Opencast and River	EM-34	660
Line 2	X: 51433.21 Y: -2896178	X: 51587.74 Y: -2895708	Orientated SSW to NNE Located between Opencast and River	Magnetics	495
Line 3A	X: 51564.75 Y: -2895782	X: 51933.36 Y: -2895984	Orientated W to E Targeting mapped dolerite in Opencast	Magnetics	425
Line 3A	X: 51710.17 Y: -2895844	X: 51928.19 Y: -2895975	Orientated W to E Targeting mapped dolerite in Opencast	EM-34	260
Line 3B	X: 51908.63 Y: -2895992	X: 51855.71 Y: -2896225	Orientated N to S Targeting mapped dolerite in Opencast	EM-34	240
Line 4	X: 51872.66 Y: -2896213	X: 52407.81 Y: -2896462	Orientated W to E Targeting mapped dolerite in Opencast, near to Stockpile & PCD Area	EM-34	590
Line 5	X: 52587.37 Y: -2896534	X: 52741.91 Y: -2896218	Orientated S to N Targeting mapped dolerite in Opencast, near to Stockpile Area	EM-34	350
Line 5	X: 52742.73 Y: -2896214	X: 52591.06 Y: -2896536	Orientated N to S Targeting mapped dolerite in Opencast, near to Stockpile Area	Magnetics	355
Line 6	X: 52126.52 Y: -2895933	X: 52746.95 Y: -2896232	Orientated W to E Targeting mapped dolerite in Opencast	Magnetics	690
Line 8A	X: 51295.57 Y: -2895462	X: 51245.96 Y: -2895671	Orientated NE to SW Background Borehole Siting	EM-34	215
Line 8B	X: 51198.92 Y: -2895658	X: 51096.47 Y: -2895931	Orientated NE to SW Background Borehole Siting	EM-34	290
Total Distance (m)					**4850**

3.2.2. Hydrogeological Borehole Installation

A total of three (3) hydrogeological boreholes were installed at the Site based on the results of the geophysical investigation, as well as previous investigations, and installed at the site to act as aquifer characterisation boreholes. The boreholes were installed to depths of 33 to 66 m using conventional air percussion drilling methods to a final diameter of 200 mm and 165 mm diameter solid steel casing installed up to the end of the weathered zone (i.e. 13-18 m below ground level (bgl)).

Table 3.2 shows a summary of the boreholes installed at the Site, with the hydrogeological drilling results discussed in Section 5.3.3.

Table 3.2: Hydrogeological Borehole Installation Summary

X-Coordinate (LO29, WGS84)	Y-Coordinate (LO29, WGS84)	Borehole ID	Final Depth (m)	Casing Depth (m)	Water Strike Depth (m bgl)	Blow Yield (l/s)
51470.931	-2896094.975	DBR-01	66	12	12	1
52158.164	-2896332.464	DBR-02	65	18	25	0.2
52136.834	-2898259.772	DBR-03	30	18	15	<0.1

3.2.3. Aquifer Testing

Each of the newly installed borehole underwent constant rate aquifer testing, where water was removed from the borehole at a constant rate for periods between 25 and 195 minutes and the response in water level measured. Following the constant rate test the water level recovery was measured until the water level had recovered to 90% of the original water level. Table 3.3 shows a summary of the aquifer testing completed at the Site.

Following the recovery of the water level at the borehole a water quality sample was taken from each of the boreholes and submitted to a SANAS-accredited laboratory for analysis.

Table 3.3: Aquifer Test Summary

Borehole ID	Borehole Depth (m)	Collar Height (m)	Static Water Level (m bgl)	Pump Installation Depth (m)	Pumping Duration (min)	Final Drawdown (m)	Abstraction Rate (l/s)	Recovery Duration (min)	Recovery (%)
DBR-01	66	0.48	2.03	58	195	1.91	0.42	60	96%
DBR-02	65	0.15	2.77	58	78	54.69	0.34	150	84%
DBR-03	30	0.27	6.41	19	25	11.87	0.37	240	91%

The aquifer test results were interpreted using the Cooper-Jacob and Theis residual drawdown straight-line fitting methods to determine aquifer parameters such as transmissivity at the boreholes. The results of the aquifer testing are discussed in Section 5.3.4, with the water quality results discussed in Section 5.3.7. The aquifer testing data sheets and interpretation graphs are presented in Appendix D and Appendix E, respectively, with the laboratory certificates for the water quality results shown in Appendix F.

3.3. Phase 3: Aquifer Characterisation and Impact Assessment

3.3.1. Geochemical Assessment

Three (3) geological core samples were provided from exploration borehole DC01 (shown in Figure 5.12) and underwent several tests, as indicated in Table 3.4. The samples were representative of the waste rock, ore and discard material at the Site, summarised in Table 3.5, and the following was determined based on the test results:

- The geochemical nature of the materials (e.g. mineralogy, elemental composition, sulphur mineral species and the acidification and neutralisation potential for each waste type); and
- A first-order assessment of the potential water qualities that may emanate from the various waste materials (to be determined using kinetic testing).

Table 3.4: Geochemical Testing Overview

Test Procedure	No. of Samples	Expected Outcome	Method
Acid-Base Accounting (ABA)	3	To indicate the long-term potential for AMD/ARD	Modified Sobek (Lawrence & Wang, 1997 based on Sobek, EPA-600/2-78-054)
Sulphur Speciation	3	To indicate the amount of sulphides vs sulphates in the material	ASTM E195-11
Net-Acid Generating (NAG) Test	3	To indicate the net potential for AMD/ARD after oxidation with hydrogen peroxide	ASTM E195-11
X-Ray Diffraction	3	Minor to dominant minerals present in the rocks	-

Table 3.5: Geochemical Sample Summary

Sample ID	Sample Type	Borehole ID	Material
DBR Carb Shl	Core	DC-01	Carbonaceous Shale
INDB08/4L/2	Core	DC-01	Coal
DC-OVB	Core	DC-01	Overburden

The results of the geochemical assessment are discussed in Section 5.2 and laboratory certificates for the geochemical samples presented in Appendix G.

3.3.2. Conceptual Model Development

The results of the desktop review, geochemical investigation and site investigations were used to develop a comprehensive conceptual hydrogeological model for the site. The conceptual model aimed to describe the topographic, hydrological, geological and hydrogeological environments and quantify their interactions. The regional and site-specific data obtained per environment were consolidated into a central dataset where simplifications and concepts are applied for the system to be represented in the model environment (ASTM, 2010).

The conceptual model developed for the Site is presented in Section 6.

3.3.3. Numerical Modelling (Flow & Transport)

A numerical groundwater flow and contaminant transport model was constructed for the Site using Processing MODFLOW for Windows (PMWIN), which is a pre- and post-processing program for MODFLOW. MODFLOW is a widely used finite difference modelling code developed by the USGS and will be suitable for modelling the site and site conditions.

The objective of the numerical model was to simulate the planned future mining, as well as their impact on the hydrogeological environment. The methodology for the numerical modelling was adapted from the "Standard guide for application of a groundwater flow model to a site-specific problem" (ASTM, 2010) where the processes often overlap which allows for modelling to be an iterative process aimed at meeting the project objectives.

The following processes, in sequential order, were included within the numerical modelling task:

- Model Construction;
- Model Calibration;
- Sensitivity Analysis; and
- Predictive Modelling.

The numerical model is described in Section 8.

3.3.4. Groundwater Reserve Determination

A groundwater reserve determination was completed for the Site based on the Groundwater Resource Directed Measures (GRDM) methodology as per Dennis *et al.* (2012) and approved by the Department of Water and Sanitation (DWS).

The Groundwater Reserve for the Site is discussed in Section 7.

3.3.5. Groundwater Impact Assessment

The results of the hydrogeological investigations were used to complete a groundwater impact assessment for the Site. The impact assessment aimed to quantify the risks present at the Site, as well as mitigation and management measures that can be implemented to minimize the risks during the construction, operational and closure phases of the project life cycle.

The impacts on the receiving environment were quantified based on the magnitude (M), duration (D), scale (S) and probability of occurrence (P), following which mitigation measures were proposed and the risk re-evaluated to take mitigation and management measures into account.

The overall risk rating (R) is calculated using the equation: $R = (M + S + D) * P$, where the scale of the input parameters is shown in Table 3.6 and the risk categories are shown in Table 3.7.

Table 3.6: Risk Ranking Parameters

Magnitude:=M	***Duration:=D***
10: Very high/don't know	5: Permanent
8: High	4: Long-term (ceases with the operational life)
6: Moderate	3: Medium-term (5-15 years)
4: Low	2: Short-term (0-5 years)
2: Minor	1: Immediate
0: Not applicable/none/negligible	0: Not applicable/none/negligible
Scale:=S	***Probability:=P***
5: International	5: Definite/don't know
4: National	4: Highly probable
3: Regional	3: Medium probability
2: Local	2: Low probability
1: Site only	1: Improbable
0: Not applicable/none/negligible	0: Not applicable/none/negligible

Table 3.7: Risk Classification

Significance	***Environmental Significance Points***	***Colour Code***
Neutral	0	N
Low (negative)	<30	L
Medium (negative)	30 to 60	M
High (negative)	>60	H

The groundwater impact assessment for the Site is discussed in Section 9.

3.4. Phase 4: Reporting

3.4.1. Groundwater Management Plan Development

A groundwater management plan (GWMP) for the Site was developed using the results of the project tasks. The following was included in the GWMP:

- Descriptions of the water management philosophies for the site, which can be translated easily to company policies;
- Management strategies for groundwater;
- Performance objectives for the site, associated with management strategies and responsible persons/departments;
- A detailed analysis of the available management options and motivations for their implementation;
- A short, medium and long-term action plan for the GWMP's implementation at the site; and
- Control and monitoring measures to be implemented at the site.

The Site GWMP is presented in Section 10.

4. General Site Setting

4.1. Climate

The Site falls within the Highveld region of South Africa, with a dry winter season and wet, high intensity rainfall summer season (Nurizon, 2019). The majority of rainfall occurs between October and March, with a mean annual precipitation (MAP) of 620 mm and mean annual evaporation (MAE) of 1'972 mm as shown in Figure 4.1.

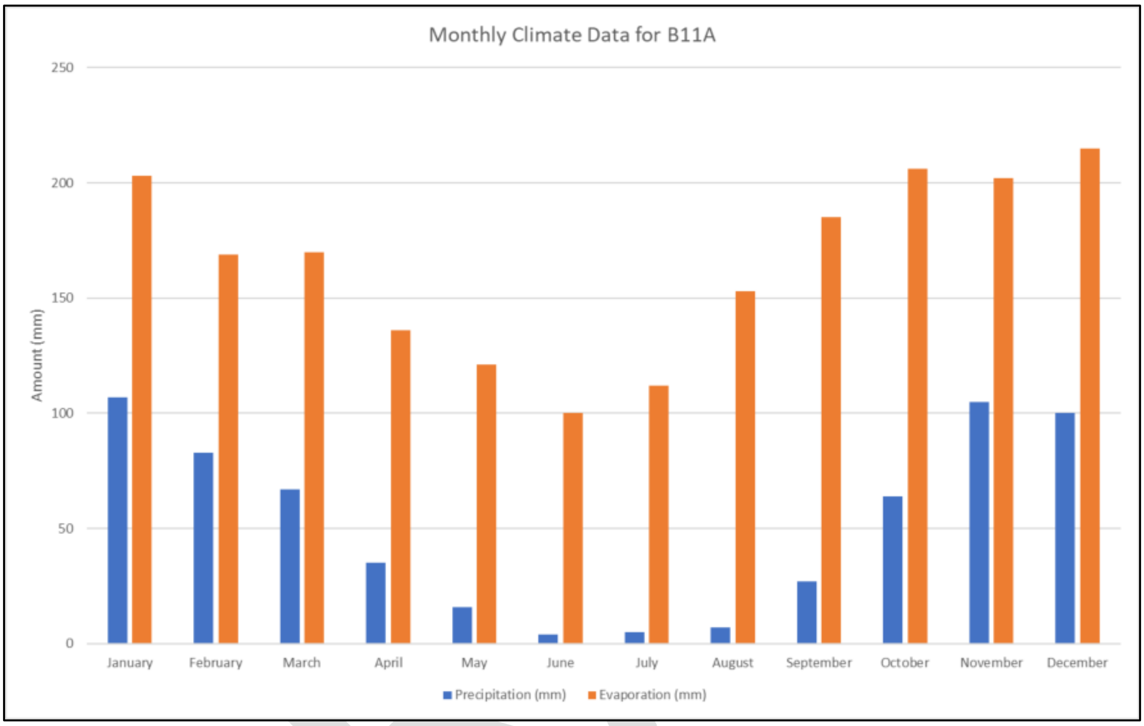

Figure 4.1: Monthly Rainfall and Evaporation Distribution (after Confluent Environmental, 2019)

4.2. Topographic Setting and Accessibility

The Site falls primarily within B11A with the western portion of the Site section falling within B11B (Figure 4.2). Site surface elevations range between 1'600 and 1'700 m amsl, sloping gently towards the perennial Leeuwfonteinspruit at the centre of the Site and various non-perennial channels and wetland/pan features situated across the Site region.

The Site is accessible via a maintained dirt track which is accessed from the tarred R35 regional road situated west of the Site.

Figure 4.2 shows the Site topographic setting and access roads.

4.3. Hydrological Setting

The perennial Leeuwfonteinspruit flows from north to south through the central region of the Site, fed by multiple non-perennial channels across the Site. The perennial Olifants River is situated ~5 km north west and south of the Site, with an unnamed perennial river situated ~5.5 km north east of the Site.

Numerous farm dams are present regionally, as well as non-perennial pans, perennial pans and wetland features, with the surface water features for the Site region presented in Figure 4.2.

4.4. Mining Activities

Coal will be extracted from the upper Seam 4 and bottom Seam 2 resources at two (2) opencast areas (i.e. Opencast 1 and Opencast 2) at the Site using conventional truck-and-shovel opencast mining methods, where the main activities during mining would be:

- Topsoil and Soft Overburden removal;
- Drilling, charging and blasting of hard overburden material;
- Loading and hauling; and
- Dumping.

The planned life of mine (LoM) for Opencast 1 is ten (10) years and five (5) years for Opencast 2, with an average production rate of 1.5 Mtpa and mining to depths of 60 m on average for both pit areas. According to Confluent Environmental (2019) the associated infrastructure at the Site during the operational phase of the LoM will include:

- Access and haul roads (incl. security and upgrades to existing roads);
- Contractor's laydown and work yard (incl. septic/chemical ablutions);
- Office Complex (incl. septic/chemical ablutions);
- Weighbridge, workshop and stores;
- Rail Siding (possible future expansion);
- Diesel storage facilities;
- Stockpiles (incl. topsoil, overburden, softs and run-of-mine);
- Crushing and screening facility;
- Pollution Control Dam (PCD); and
- Various storm water and surface water management berms, channels and trenches.

The proposed Site layout is shown in Figure 4.3.

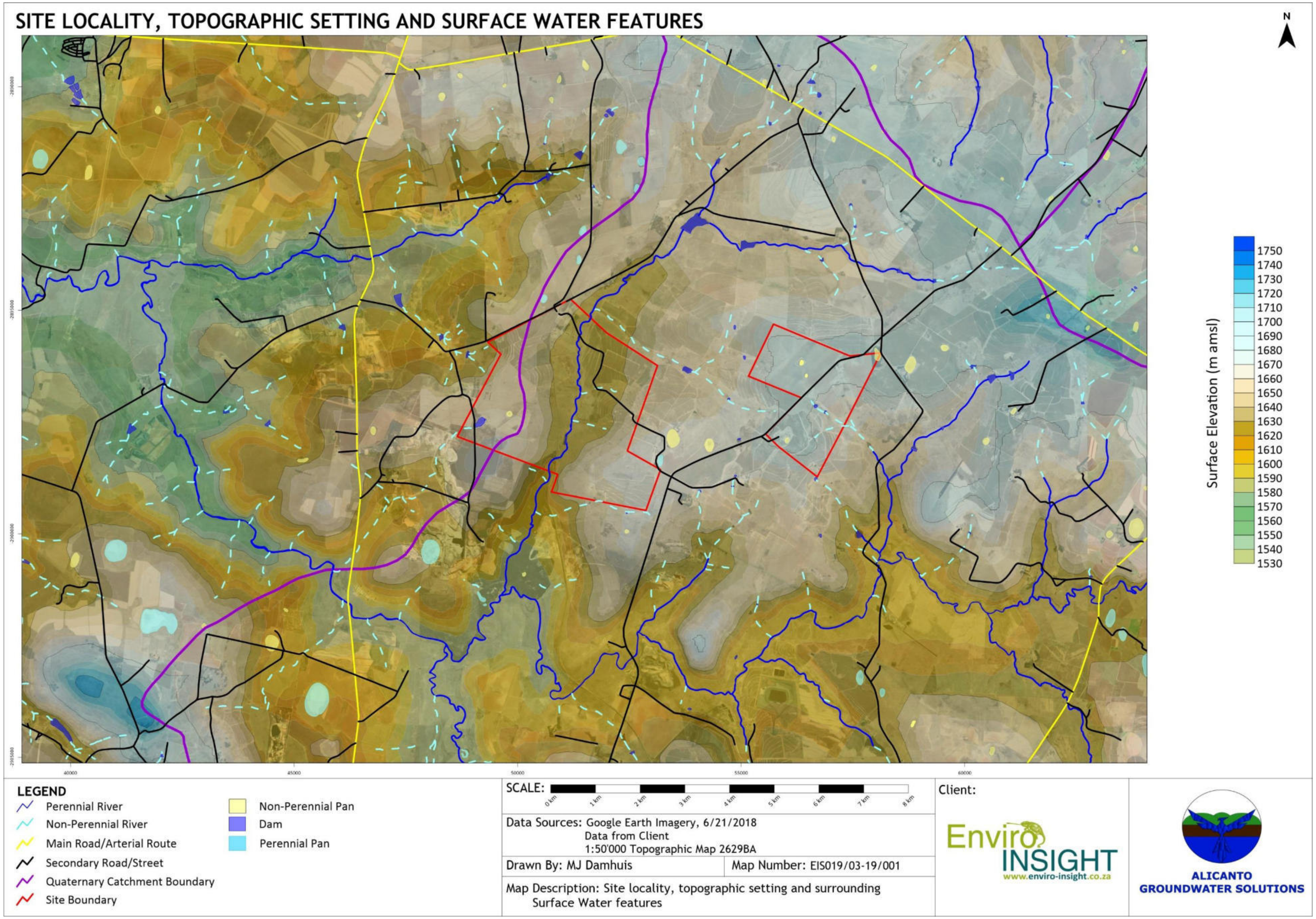

Figure 4.2: Site Locality, Topographic Setting and Surface Water

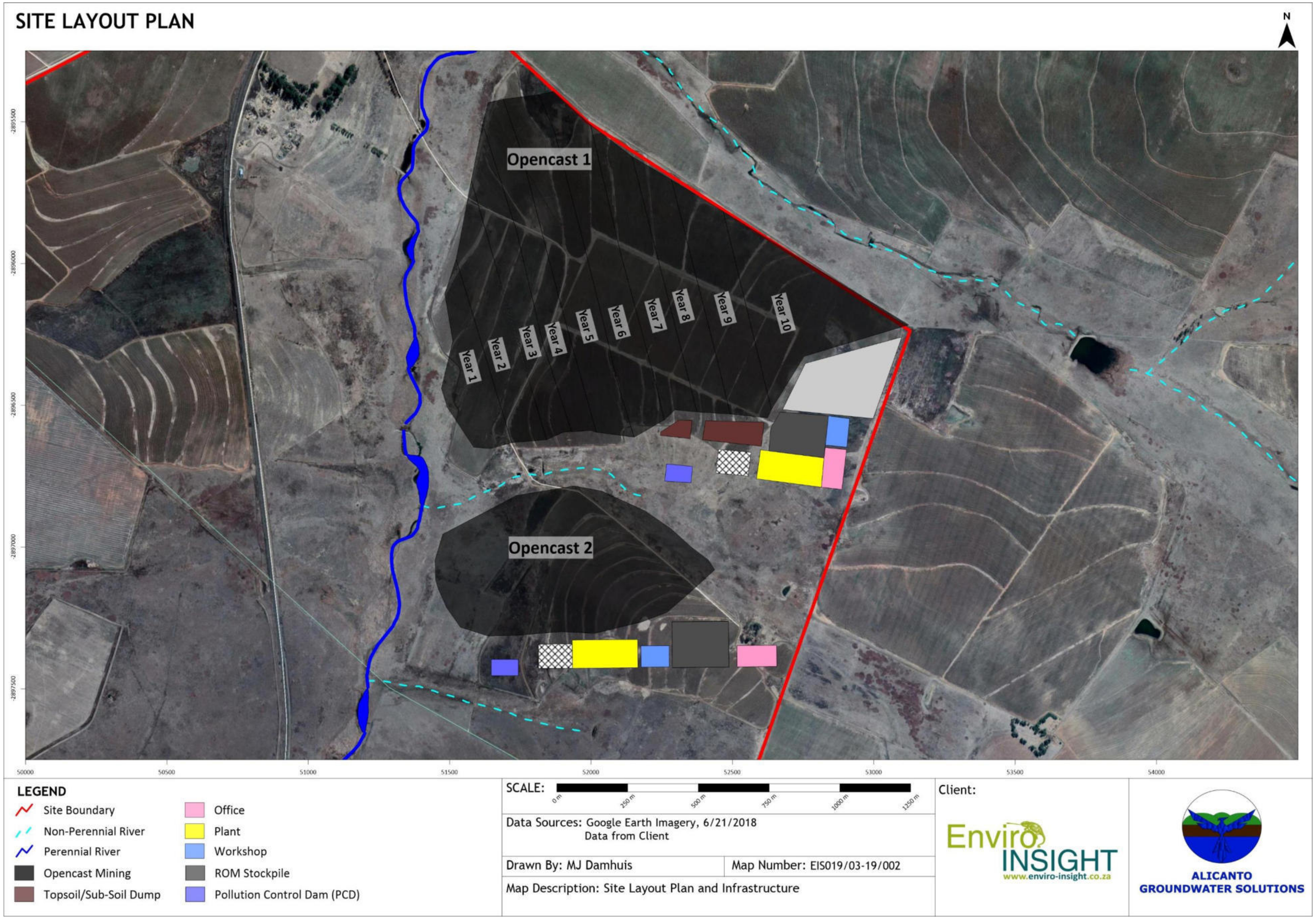

Figure 4.3: Site Layout Plan

5. Baseline Hydrogeological Environment

5.1. Geological Setting

5.1.1. Regional Geology

The Site is located on the boundary of the Highveld and Witbank coalfields of South Africa (InsaCoal, 2019) and is underlain predominantly by sandstone, shale and coal units of the Vryheid Formation (Ecca Group; Karoo Supergroup), with surface geological data (DWS, 2012) showing Rooiberg Group rhyolite and pyroclastic rocks dominating the southern extent of the Site. Surface outcrops of Karoo dolerite have been mapped to the east and west of the Site, with a diabase outcrop mapped west of the Site.

Typically, the Witbank coalfield has five (5) coal seams hosted within the Vryheid Formation, namely Seams 1 through 5 (from bottom to top), with a west to east section and general stratigraphy column for the Western Witbank Coalfield and Northern Highveld Coalfield (representative of the Site region) (after Venmyn-Deloitte, 2017) shown in Figure 5.1 and a regional geological map shown in Figure 5.4. The Site-specific geology is discussed in Section 5.1.2.

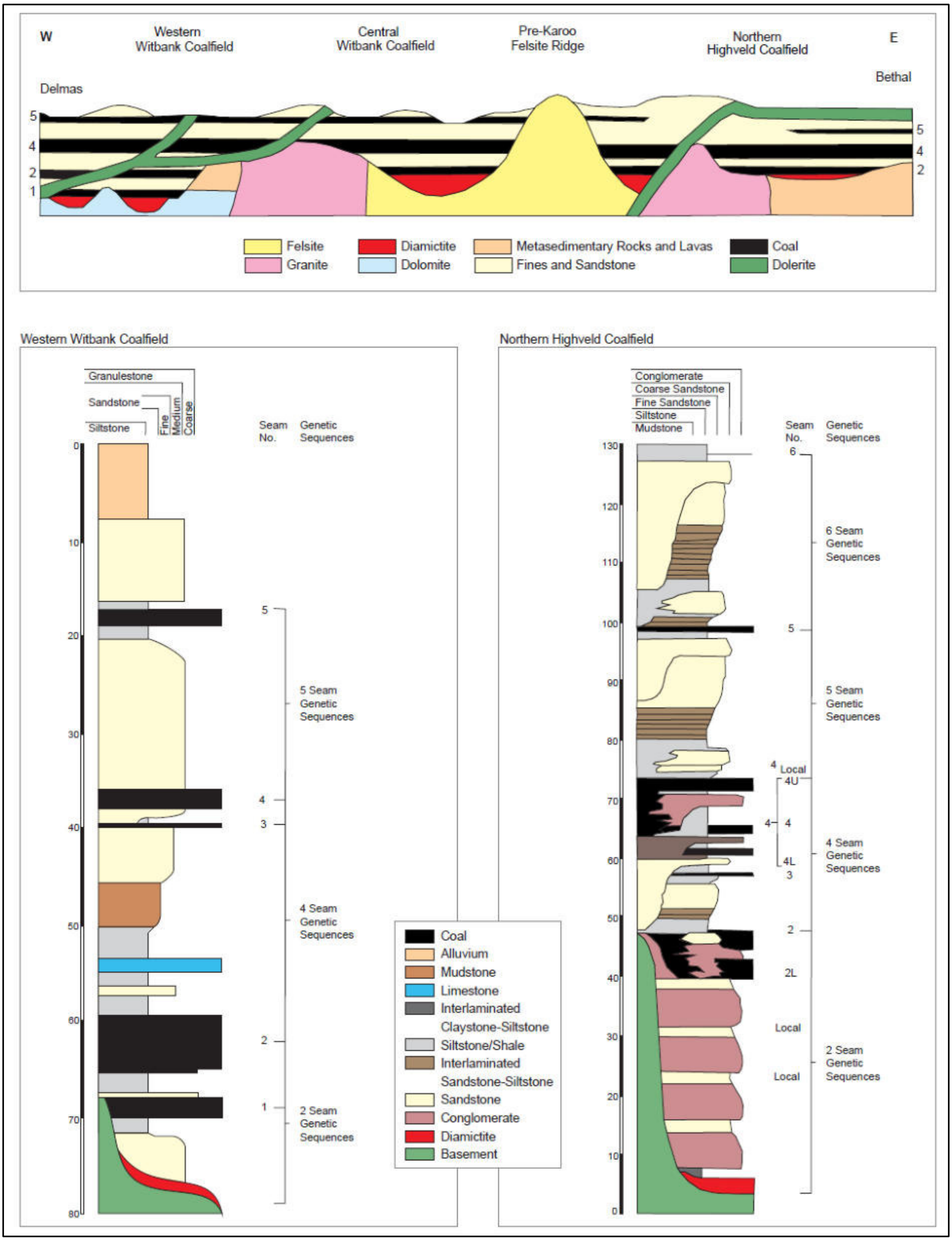

Figure 5.1: Regional Geological Section and General Stratigraphy (after Venmyn-Deloitte, 2017)

5.1.2. Site Geology

GeoCoal Services (2015) described the Site in terms of northern and southern sections, where the northern section showed typical seam and parting sequences for the Witbank coalfield and the southern section showed the Halfgewonnen sequence where the 5 and 4U seams were absent and seams 2 and 4 combined to form one thick seam. The Halgewonnen sequence is typical of the small, isolated coal islands found within the felsite of the Smithfield Ridge's northern margin (GeoCoal Services, 2015).

Figure 5.2 shows typical profiles for the northern and southern sections of the Site. Figure 5.3 shows the coal stratigraphy at the Site as presented in InsaCoal (2019), showing the coal seams to be dipping to the north.

Northern Section		
Average Thickness (m)	Profile	Lithology
0-27		Overburden
0.46		5 Seam
35		Interburden
<1.0		4U Seam
2.5		Interburden
3.76		4L Seam
15		Interburden
5.72		2 Seam
		Tillite
		Felsite

Southern Section		
Average Thickness (m)	Profile	Lithology
0-15		Overburden
<1.0		4U Seam
0.25		Parting
3.76		4L Seam
0.25		Parting
5.72		2 Seam
		Tillite
		Felsite

Figure 5.2: Typical Geological Profiles for Northern and Southern Site Sections (after GeoCoal Services, 2015)

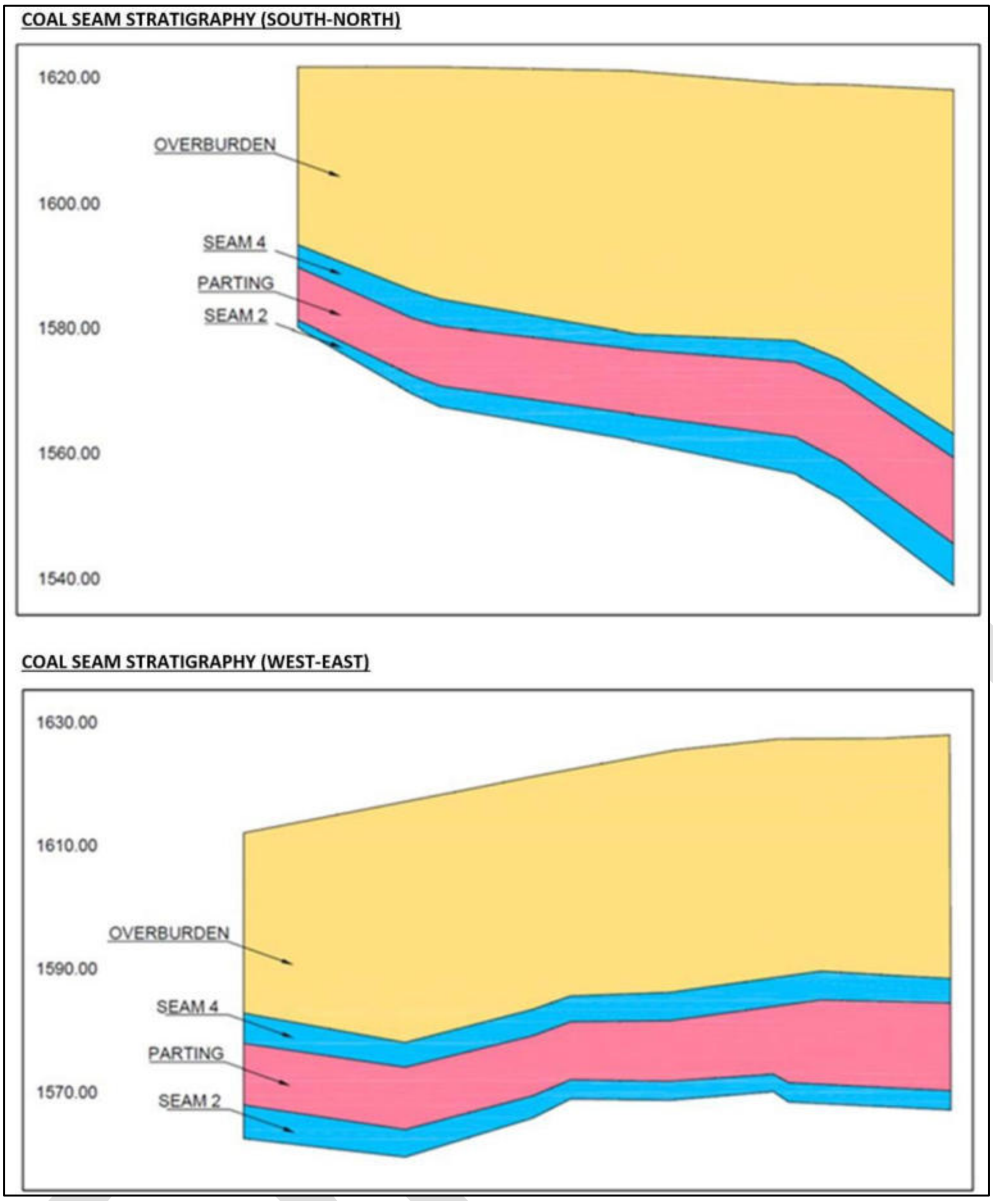

Figure 5.3: Coal Seam Stratigraphy (after InsaCoal, 2019)

5.1.3. Structural Geology

The Site is situated on a paleo-high, with felsite outcrops at the southern Site section, as well as numerous dolerite sills lying unconformably on the underlying felsite or Dwyka tillite (GeoCoal Services, 2015; InsaCoal, 2019). The dolerite sills are typically found below 2 Seam coal, but cross the seam locally (GeoCoal Services, 2015). Regional geological structures which trend north east-south west are situated ~10 and 15 km east and west of the Site, respectively.

Figure 5.4 shows the regional geological structures for the Site.

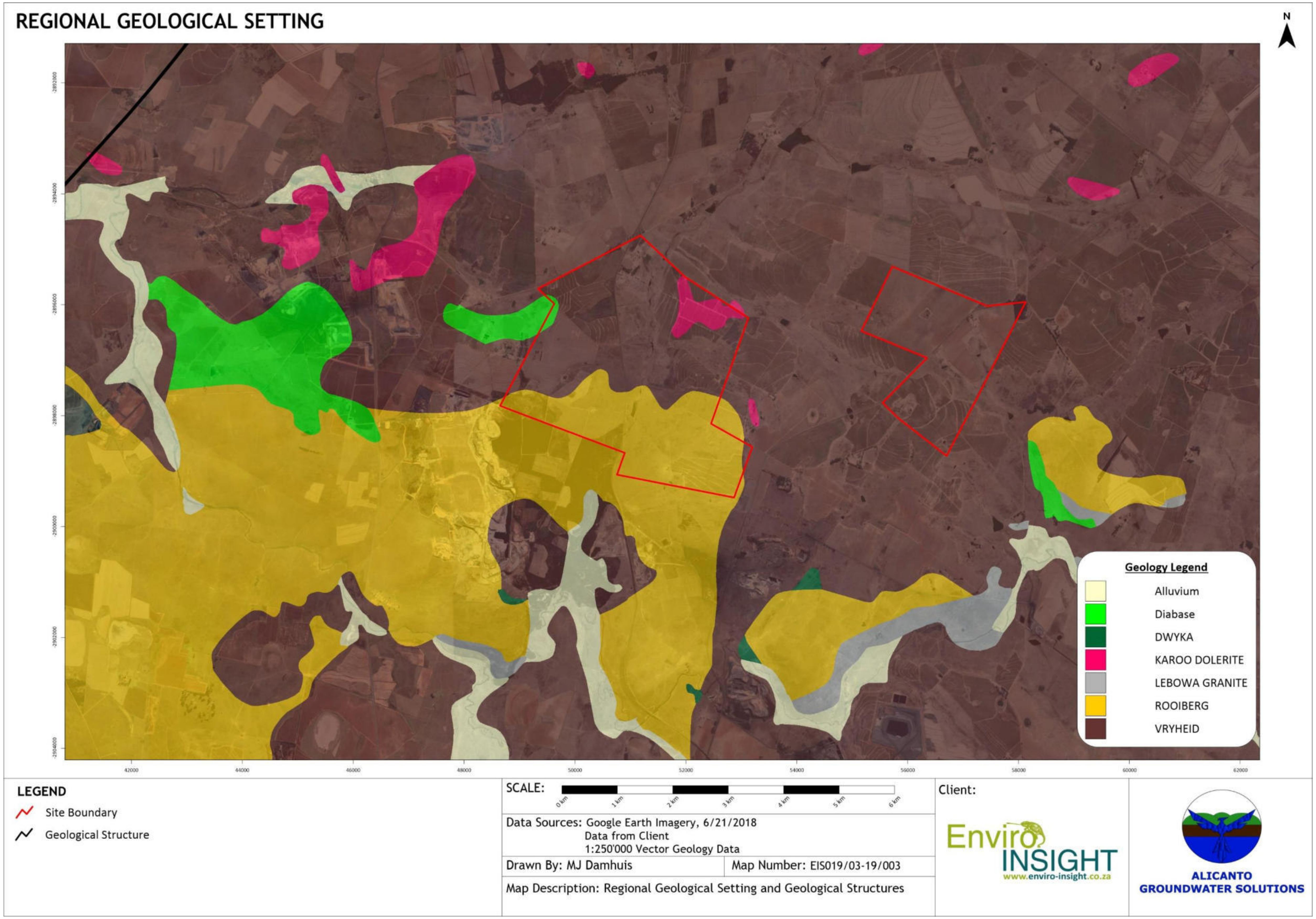

Figure 5.4: Regional Geological Setting

5.2. Geochemical Assessment

The geochemical samples taken at the Site were representative of overburden material (samples 'DRB Carb Shl' and 'DC-OVB'), as well as the 4 seam coal resource at the Site (sample 'INDB08/4L/2') and were subjected to numerous tests as described in Section 3.3.1.

5.2.1. Mineralogical Composition (XRD)

The mineralogical compositions of the samples were determined using XRD (Table 5.1), with the following observations made:

- Organic carbon (%C) was highest in the coal sample (INDB08/4L/2) (45.49 weight %), followed by carbonaceous shale (5.59 weight %). No organic carbon was present in the overburden sample;
- Pyrite was present in small amounts in the coal sample, with no pyrite noted in the carbonaceous shale or overburden samples;
- Quartz content increased from the coal sample to carbonaceous shale with the overburden sample showing the highest quartz value; and
- Dolomite was present in the coal sample, with calcite values in the overburden and coal samples being similar.

Table 5.1: Mineralogical Composition (XRD)

DC-OVB		DBR Carb Shl		INDB08/4L/2	
Mineral	Amount (weight %)	Mineral	Amount (weight %)	Mineral	Amount (weight %)
Quartz	76.25	Kaolinite	59.49	Organic C	45.49
Plagioclase	12.73	Quartz	29.78	Kaolinite	35.25
Sepiolite	4.17	Organic C	5.59	Quartz	12.81
Orthoclase	3.01	Muscovite	3.53	Dolomite	4.33
Muscovite	1.94	Dolomite	0.96	Calcite	1.3
Calcite	1.9	Rutile	0.64	Rutile	0.43
		Calcite	0	Pyrite	0.39
		Pyrite	0	Muscovite	0

5.2.2. Net-Acid Generation (NAG) Testing

The net acid generating test provides a direct assessment of the potential of a material to produce acid after a period of exposure to weathering and a strong oxidant and is completed by using hydrogen peroxide to oxidise sulphide minerals present in a sample. NAG testing is often used to refine the ABA test results for a site.

The screening method of Miller *et al*. (1997) is used to determine the acid generation potential of a sample, as shown in Table 5.2.

Table 5.2: NAG Test Screening Method (after 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	> 10	Negative
Rock Type Ib. Lower Capacity Acid Forming.	< 4	≤ 10	-
Uncertain, possibly Ib.	< 4	> 10	Positive
Uncertain	≥ 4	0	Negative (Reassess mineralogy) *
Rock Type IV. Non-acid Forming.	≥ 4	0	Positive

*If non- or low acid forming sulphides are dominant the Rock Type IV

Based on the Miller et al. (1997) screening criteria, all of the samples collected at the Site were rock type IV (non-acid forming), as shown in Table 5.3.

Table 5.3: NAG Test Results

Sample ID	NAG pH	NAG	NNP	Rock Type
DC-OVB	8.2	<0.01	7.98	Rock Type IV
DBR Carb Shl	6.5	0.2	1.8	Rock Type IV
INDB08/4L/2	7.0	<0.01	1.19	Rock Type IV

5.2.3. Acid-Base Accounting (ABA)

Acid-base accounting (ABA) is where the net potential of a rock to produce acidic drainage is assessed using a static test. ABA provides a first-order assessment of the potential drainage characteristics that could be expected from rock material (GCS, 2012). The component of ABA are as follows:

- **Acid Potential (AP)** is the theoretical amount of calcite that could be neutralized by the acid produced and is determined by multiplying the %S by 3.125. The units for AP are kg $CaCO_3$/t rock; and
- **Neutralization Potential (NP)** is the theoretical amount of calcite available to neutralize acidic drainage and is determined by treating the sample with a known excess of standardized sulphuric or hydrochloric acid to form a paste. The paste is then back-titrated with standardized sodium hydroxide to determine the amount of unconsumed acid. NP is expressed as kg $CaCO_3$/t rock.

The methods for screening of ABA results are summarised in Table 5.4.

Table 5.4: ABA Screening Methods

Term	Methodology	Criteria	
Net Neutralization Potential (NNP)	NNP = NP - AP	NNP < 0 kg CaCO3/t rock	Net acidic potential
		NNP > 0 kg CaCO3/t rock	Net neutralising potential
		-20 to 20 kg CaCO3/t rock	Grey Area' - NNP>20 kg CaCO3/t rock classified as Rock Type IV (No Potential for Acid Generation) - NNP<-20 kg CaCO3/t rock classified as Rock Type I (Likely Acid Generating)
Neutralisation Potential Ratio (NPR)/NP:AP Ratio (Price, 1997)	NP:AP	<1:1	Likely AMD generating
		1:1 to 2:1	Possibly AMD generating if NP is insufficiently reactive or depleted faster than sulphides
		2:1 to 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.
		>4:1	No further AMD testing required unless materials are to be used as a source of alkalinity.
Sulphide Sulphure (%S) (Soregaroli & Lawrence, 1998)	%S	<0.3%	Rock Type IV (No potential for acid generation)
		>0.3%	Rock Type I (Likely acid generating)

The carbonaceous shale and coal samples both showed potential for acid generation (Rock Type II), while the overburden sample showed no acid generation potential (Rock Type IV). The ABA test results are summarised in Table 5.5, with Figure 5.5 showing the sample NPR compared to paste pH and Figure 5.6 showing sample NPR versus Total %S.

Table 5.5: ABA Test Results

Sample ID	Paste pH	Total Sulphur (%) (LECO)	Acid Potential (AP) (kg/t)	Neutralization Potential (NP)	Nett Neutralization Potential (NNP)	Neutralising Potential Ratio (NPR) (NP : AP)	Rock Type
DBR Carb Shl	7.4	0.09	2.66	4.8	2.14	1.8	Rock Type II
INDB08/4L/2	7.6	1.25	39	46	7.54	1.19	Rock Type II
DC-OVB	8.4	0.06	1.9	15	13	7.98	Rock Type IV

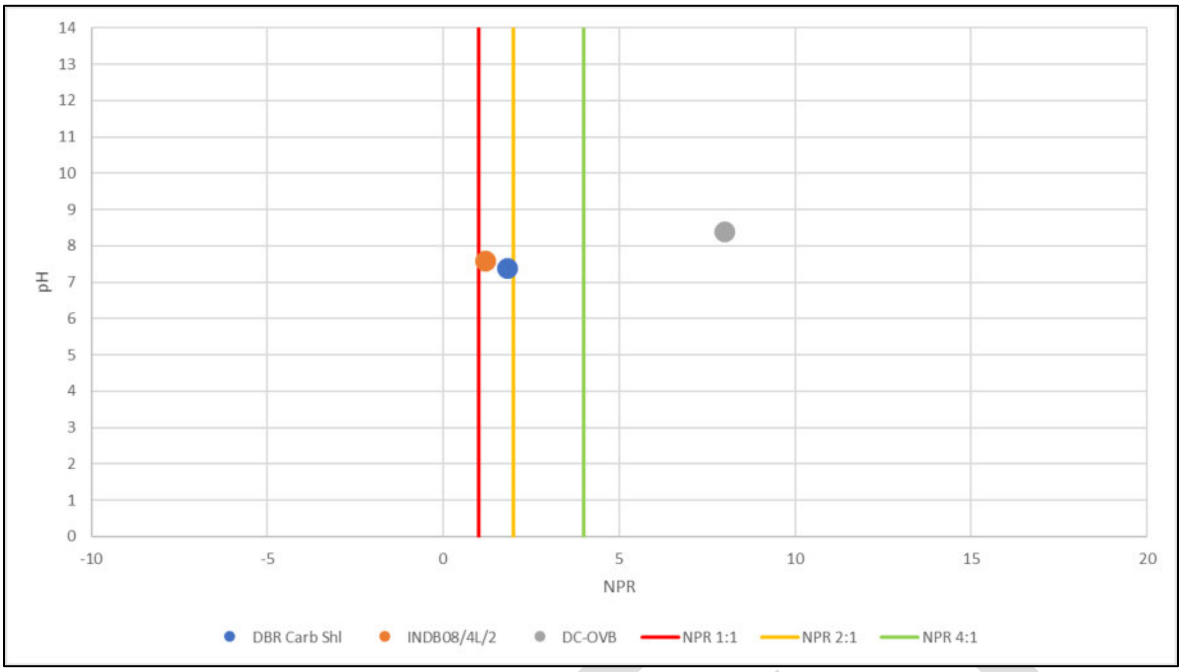

Figure 5.5: Sample NPR versus Paste pH

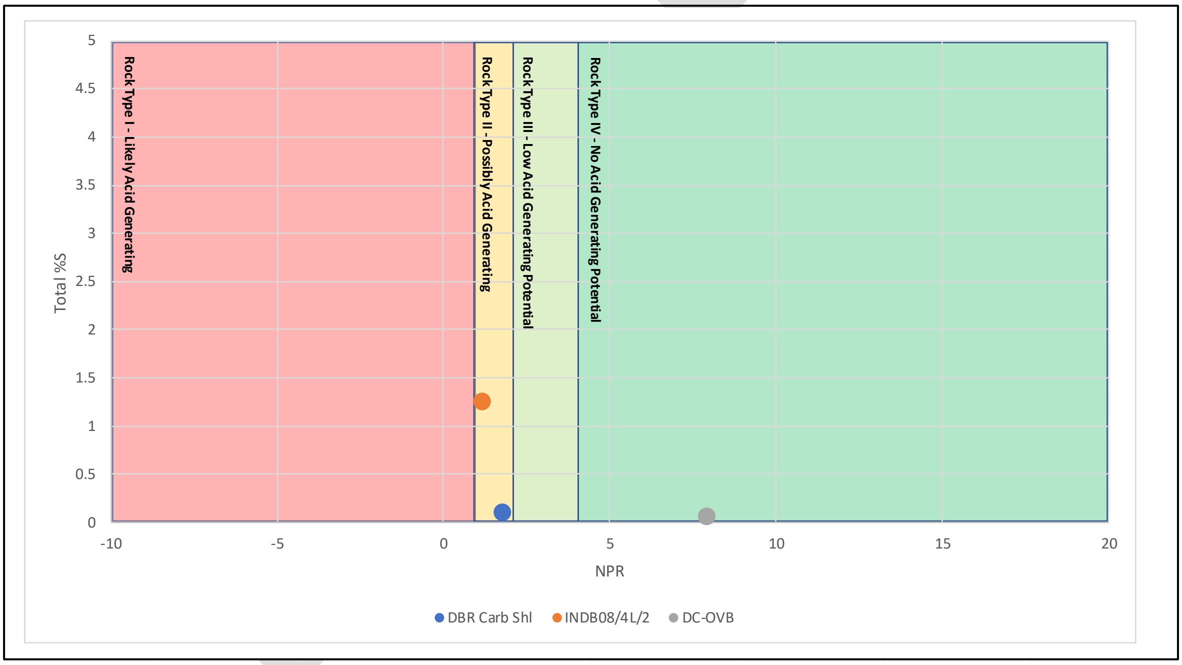

Figure 5.6: Sample NPR versus Total %S

5.2.4. Sulphur Speciation

Sulphur speciation of the samples showed the coal sample to have the highest percentage of sulphur as S and sulphide sulphur, with the overburden sample showing sulphur as S to be dominant while the carbonaceous shale sample showed sulphide sulphur as dominant. The sulphur speciation results are shown in Table 5.6.

Table 5.6: Sulphur Speciation Results

Sample ID	Total Sulphur (%) (ELTRA)	Sulphate Sulphur as S (%)	Sulphide Sulphur (%)
DBR Carb Shl	0.09	0.05	0.03
INDB08/4L/2	1.25	0.43	0.81
DC-OVB	0.06	0.01	0.05

5.2.5. Distilled Water Extraction

Each of the samples underwent distilled water extraction testing, where 1'000 ml of distilled water was added to 50 grams of sample material and the inorganic ions (Table 5.7) and selected metals (Table 5.8) present in the leachate product measured.

Table 5.7: Distilled Water Extraction Results: Inorganic Ions

Analyses	**DBR Carb Shl**		**INDB08/4L/2**		**DC-OVB**	
TCLP / Acid Rain / Distilled Water / H_2O_2	**Distilled Water**		**Distilled Water**		**Distilled Water**	
Dry Mass Used (g)	**50**		**50**		**50**	
Volume Used (mℓ)	**1000**		**1000**		**1000**	
pH Value at 25˚C	6.8		6.9		6.6	
Inorganic Anions	**mg/ℓ**	**mg/kg**	**mg/ℓ**	**mg/kg**	**mg/ℓ**	**mg/kg**
Total Dissolved Solids at 180 ˚C	50	1000	54	1080	56	1120
Chloride as Cl	<2	<40	<2	<40	<2	<40
Sulphate as SO4	<2	<40	6	120	2	40
Nitrate as N	<0.1	<2.0	<0.1	<2.0	<0.1	<2.0
Fluoride as F	<0.2	<4.0	<0.2	<4.0	<0.2	<4.0
Hexavalent Chromium as Cr6+	<0.010	<0.200	<0.010	<0.200	<0.010	<0.200

Table 5.8: Distilled Water Extraction Results: Selected Metals

Sample Id	Unit	DBR Carb Shl	INDB08/4L/2	DC-OVB
Silver as Ag	mg/l	BDL	BDL	BDL
Aluminium as Al	mg/l	0.435	0.145	0.307
Arsenic as As	mg/l	BDL	BDL	0.004
Boron as B	mg/l	BDL	BDL	BDL
Barium as Ba	mg/l	0.138	0.056	0.036
Beryllium as Be	mg/l	BDL	BDL	BDL
Bismuth as Bi	mg/l	BDL	BDL	BDL
Calcium as Ca	mg/l	4	6	3
Cadmium as Cd	mg/l	BDL	BDL	BDL
Cobalt as Co	mg/l	BDL	BDL	BDL
Chrome as Cr	mg/l	BDL	BDL	BDL
Copper as Cu	mg/l	BDL	BDL	BDL
Iron as Fe	mg/l	0.041	BDL	0.108
Mercury as Hg	mg/l	BDL	0.030	BDL
Potassium as K	mg/l	1.0	0.8	1.7
Lithium as Li	mg/l	BDL	BDL	BDL
Magnesium as Mg	mg/l	2	3	2
Manganese as Mn	mg/l	BDL	BDL	0.102
Molybdenum as Mo	mg/l	BDL	BDL	BDL
Sodium as Na	mg/l	1	BDL	1
Nickel as Ni	mg/l	BDL	BDL	BDL
Phosphorous as P	mg/l	BDL	BDL	BDL
Lead as Pb	mg/l	0.004	BDL	BDL
Antimony as Sb	mg/l	BDL	BDL	BDL
Selenium as Se	mg/l	BDL	BDL	BDL
Silica as Si	mg/l	1.3	0.6	1.5
Strontium as Sr	mg/l	0.334	0.376	0.161
Titanium as Ti	mg/l	BDL	BDL	BDL
Tellurium as Te	mg/l	BDL	BDL	BDL
Vanadium as V	mg/l	BDL	BDL	BDL
Zinc as Z	mg/l	0.323	BDL	BDL

Sulphate in the coal and carbonaceous samples were 6 mg/l (120 mg/kg) and 2 mg/l (40 mg/kg), respectively, with no sulphate generated in the overburden sample. None of the samples showed chlorine, fluoride or nitrate concentrations above the detection limit.

5.2.6. Acid Digestion Results

Acid digestion was done using 100 ml HNO_3:HF acid solution added to 0.25 grams of sample material, with the total fluoride and hexavalent chromium (Table 5.9) and selected metals (Table 5.10) in the resultant leachate reported.

Table 5.9: Acid Digestion Results: Totals

Analyses	DBR Carb Shl		INDB08/4L/2		DC-OVB	
Units	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg
Total Fluoride	---	410	---	267	---	262
Total Hexavalent Chromium as Cr6+	---	<5	---	<5	---	<5

Table 5.10: Acid Digestion Results: Selected Metals

Sample Id	DBR Carb Shl	INDB08/4L/2	DC-OVB
Silver as Ag	BDL	BDL	BDL
Aluminium as Al	227	83	118
Arsenic as As	0.006	0.015	0.001
Boron as B	BDL	0.128	BDL
Barium as Ba	0.891	0.953	1.89
Berylium as Be	BDL	BDL	BDL
Bismuth as Bi	BDL	BDL	BDL
Calcium as Ca	3	37	19
Cadmium as Cd	0.001	BDL	BDL
Cobalt as Co	0.030	BDL	BDL
Chrome as Cr	0.564	0.194	0.487
Copper as Cu	0.055	0.019	BDL
Iron as Fe	16	20	22
Mercury as Hg	BDL	0.001	BDL
Potassium as K	15.6	3.1	66
Lithium as Li	BDL	0.030	BDL
Magnesium as Mg	5	5	7
Manganese as Mn	0.173	0.292	0.416
Molybdenum as Mo	BDL	BDL	BDL
Sodium as Na	BDL	BDL	22
Nickel as Ni	0.068	0.028	BDL
Phosphorous as P	0.922	2.36	0.447
Lead as Pb	0.073	0.066	0.058
Antimony as Sb	BDL	BDL	BDL
Selenium as Se	BDL	BDL	BDL
Silica as Si	545	251	849
Strontium as Sr	0.577	0.974	0.462
Titanium as Ti	15	11	5.02
Tellurium as Te	BDL	BDL	BDL
Vanadium as V	0.185	0.061	BDL
Zinc as Z	0.253	0.040	0.073

5.2.7. Kinetic Leach Testing (after Mokoena, 2012)

Mokoena (2012) completed kinetic and static leach testing on selected samples collected from the Site region, with the samples being representative of overburden and coal material found in the region. Based on the results of testing, Mokoena (2012) concluded that most of the sample material would generate acid mine drainage with limited buffer capacity present at the Site region.

Contaminants of concern for the Site were sulphate (SO_4), aluminium, manganese and iron, with the cumulative concentrations after twenty (20) weeks of testing by Mokoena (2012) for similar sample material to that found at the Site shown in Table 5.11. Sulphate values ranged between ~150 and 1'850 mg/l and an average of ~670 mg/l. Aluminium, manganese and iron values were generally 0 mg/l, with non-zero value samples showing an average of 5.10 mg/l, 1.06 mg/l and 98.28 mg/l, respectively.

Table 5.11: Selected Ion Values after 20 Weeks (after Mokoena, 2012)

Sample ID	Cumulative Values of Selected Major Ions after 20 weeks			
	Sulphate as SO4 (mg/l)	Aluminium as Al (mg/l)	Manganese as Mn (mg/l)	Iron as Fe (mg/l)
KS1-2	158.50	-	-	-
KS1-3	638.80	-	-	638.80
KS2-4	318.80	-	-	-
KS3-5	220.30	-	-	-
KS3-6	748.30	-	-	-
G1-2	638.80	62.40	7.50	638.80
G2-3	1 850.40	4.00	1.50	-
G3-3	979.80	-	4.80	-
G4-1	1 672.00	-	-	-
G5-6	481.70	-	-	-
G6-3	453.90	-	-	-
G7-2	169.70	-	-	-
G10-5	357.30	-	-	-

5.3. Hydrogeological Setting

5.3.1. General Hydrogeology

According to the 1:500'000 hydrogeological map series 2526: Johannesburg (Barnard, 1999) the Site is underlain by intergranular and fractured aquifers, with borehole yields within the Karoo sediments at the northern Site section ranging between 0.1 and 0.5 l/s and boreholes yields in the southern Site section felsite units varying between 0.5 and 2 l/s. Regional borehole data was obtained from the National Groundwater Archive (NGA) (DWS, 2019a) and previous hydrogeological investigations within the region (GHT, 2009; Jones & Wagener, 2013).

The average borehole depth within the Site region was 45 m, with water strikes typically encountered between 15 and 30 m, as shown in Figure 5.7, with a secondary water strike zone between 60 and 70 m. The average recorded blow yield within the Site region was 0.7 l/s, ranging between <0.1 l/s and 3 l/s (up to 7.5 l/s locally at structure zones).

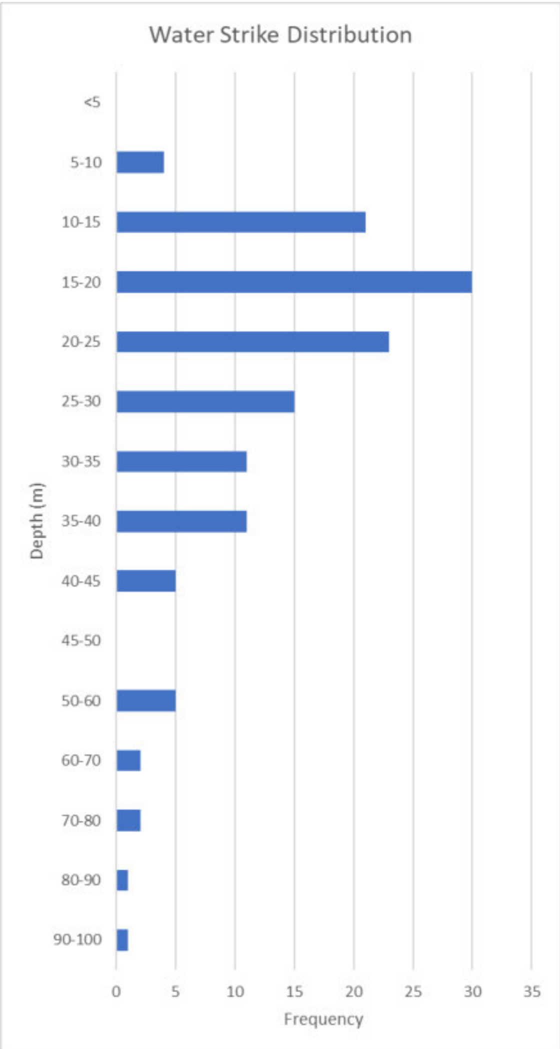

Figure 5.7: Regional Water Strike Distribution

According to Hodgson & Krantz (1998) three distinct hydrogeological units are present within the Karoo coalfields, namely:

- An upper, weathered hydrogeological unit;
- A fractured, Ecca sediments hydrogeological unit; and
- A deeper, fractured basement hydrogeological unit.

The upper, weathered hydrogeological unit is typically found between 5 and 12 m depths, with the dominant recharge mechanism being infiltration of rainwater (1-5% of MAP) and secondary interactions with surface water bodies, locally. The movement of groundwater in the upper weathered unit is controlled by the lower permeability shale or dolerite layers and typically mimics surface topography.

The fractured Ecca hydrogeological unit is found at depths ranging between 15 and 50 m (refer to Figure 5.7) with water strike intersections decreasing with depth. The matrix of the Ecca geology is well-cemented, thus lowering groundwater potential in the matrix and leading to almost all economic water strikes being associated with secondary geological features such as faults, fracture zones and intrusive contact zones (e.g. contact zones at dolerite sills or dykes).

The basement hydrogeological unit is generally regarded as insignificant due to its low yielding nature, great depth (>100 m) and limited recharge potential due to the overlying Dwyka tillite or felsite units.

5.3.2. Geophysical Survey

A total of twelve (12) geophysical lines were completed using a combination of electromagnetics (EM-34) (8 lines) and magnetics (4 lines) geophysical methods, with a total of 4'850 m of survey completed. The geophysical lines and the targets identified are shown in Figure 5.8 and discussed in detail below, with the resultant geophysical line graphs shown in Appendix C.

Line 1 was completed using the EM-34 method to a length of 280 m, orientated NE-SW as a background borehole south of the mining area. A potential drilling target was site at 180 m where the horizontal dipole (HD) and vertical dipole (VD) intersected, suggesting a fractured zone.

Line 2 was completed to a length of 660 m using EM-34 and 495 m using magnetics, orientated SSW-NNE between the mining operations and the river at the Site. Targets were identified at 154 m and 253 m on the magnetic line, indicating the edge of the dolerite intrusion, with a target at 235 m on the EM-34 line which correlated with the magnetic target at 154 m and indicated a potential fracture zone at the limit of the dolerite intrusion.

Line 3A was orientated W-E and targeted the potential dolerite intrusion at the opencast using the EM-34 (260 m) and magnetic (425 m) methods. A target was identified at 191 m on the magnetics line, corresponding to a change in HD at 58 m on the EM-34 line, suggesting a potential horizontal contact zone between the dolerite intrusion and country rock.

Line 3B was completed to a length of 240 m using the EM-34 method, orientated N-S and targeting the potential dolerite intrusion at the opencast. No targets were identified.

Line 4 targeted the potential dolerite intrusion at opencast 1 near to the proposed stockpile and PCD areas and was completed to a length of 590 m using the EM-34 method. A potential vertical contact zone was identified at 100 m.

Line 5 was orientated N-S and targeted the potential dolerite intrusion at the opencast near to the proposed stockpile area using the EM-34 (350 m) and magnetic (355 m) methods. Two targets were identified at 60 m and 80 m on the EM-34 line, potentially representative of a fractured zone and horizontal contact zone, respectively, with a secondary target identified at 150 m on the magnetic line.

Line 6 targeted the potential dolerite intrusion at the opencast using the magnetic method and was completed to a length of 690 m in a W-E orientation. No targets were identified.

Line 8A aimed to identify potential background borehole targets at the Site using the EM-34 method, with the line completed to a length of 215 m orientated NE-SW. Due to interference from nearby overhead powerlines the line was shifted ~50 north and completed as **Line 8B** to a length of 290 m along the same orientation. Potential fracture zones were identified at 33 m on Line 8A and at 132 m along Line 8B.

Table 5.12 shows a summary of the geophysical targets identified at the Site.

Table 5.12: Geophysical Target Summary

Target ID	Geophysical Traverse	Geophysical Method	X-Coordinate (LO29, WGS84)	Y-Coordinate (LO29, WGS84)
L1_180m	Line 1	EM-34	52333.58	-2898297
L2_154m	Line 2	Magnetic	51479.15	-2896026
L2_225m	Line 2	EM-34	51498.35	-2895959
L2_253m	Line 2	Magnetic	51509.72	-2895930
L3A_191m	Line 3A	Magnetic	51739.05	-2895861
L3A_58m	Line 3A	EM-34	51758.24	-2895873
L4_100m	Line 4	EM-34	51966.58	-2896251
L5_150m	Line 5	EM-34	52653.68	-2896398
L5_60m	Line 5	EM-34	52613.88	-2896480
L5_80m	Line 5	Magnetic	52708.35	-2896287
L8A_33m	Line 8A	EM-34	51286.9	-2895494
L8B_132	Line 8B	EM-34	51150.1	-2895782

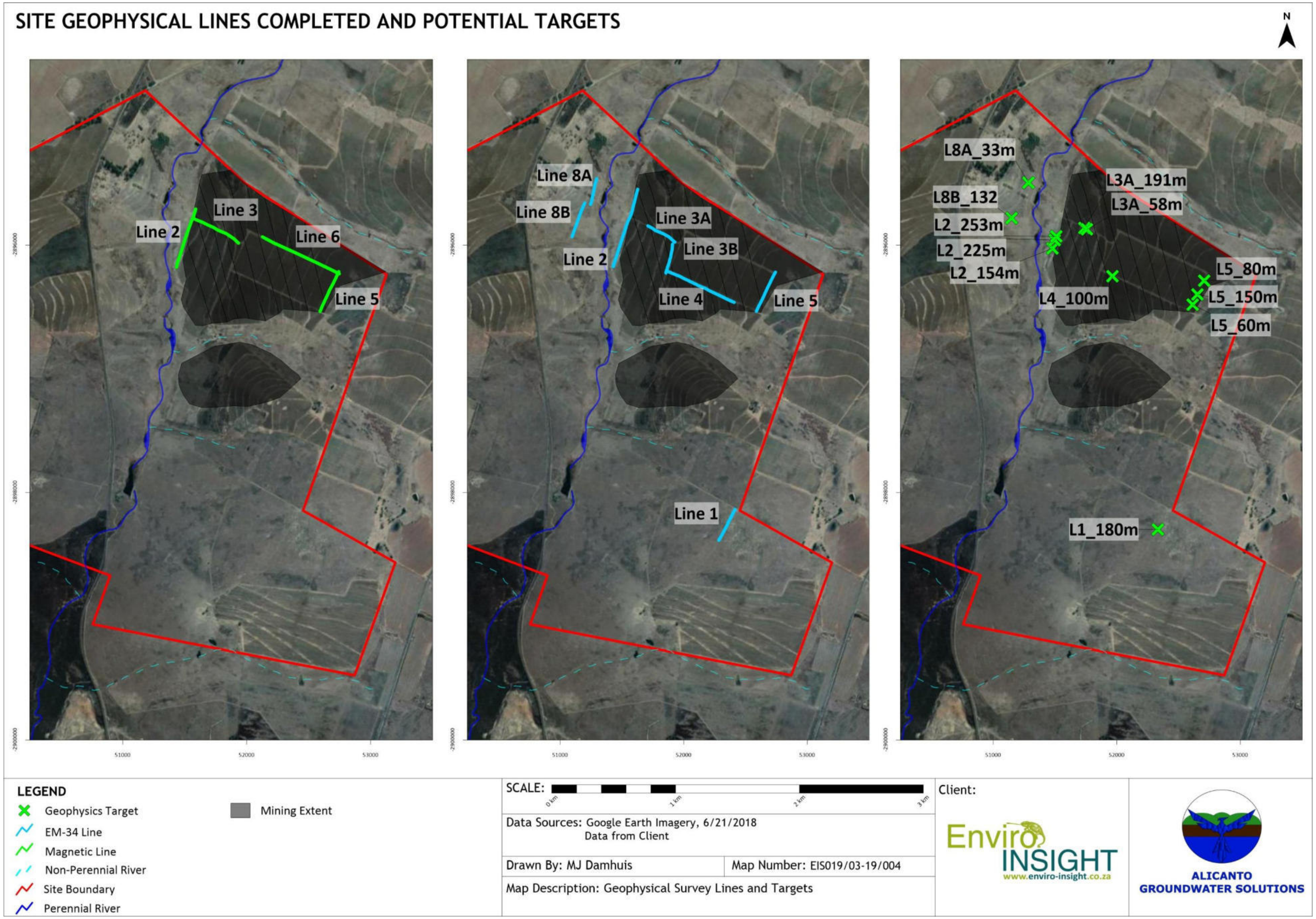

Figure 5.8: Geophysical Survey Lines and Targets

5.3.3. Site Hydrogeology

5.3.3.a. Hydrocensus Investigation

A Hydrocensus investigation was conducted within a 5-km radius of the Site and within the Site boundaries, during which a total of 22 boreholes were identified. A total of 9 boreholes were in use as either domestic or livestock water supply, with the remaining 13 boreholes being either monitoring boreholes or not in use.

The average borehole depth was ~28 m, ranging between 8 and 53 m, with the borehole abstraction rates (based on communications with users) ranging between ~100 and 1'000 litres per day. Nine (9) water level measurements were obtained during the hydrocensus and five (5) water quality samples were taken and submitted to a SANAS-accredited laboratory for analysis, as discussed further in Sections 5.3.6 and 5.3.7, respectively.

Table 5.13 shows a summary of the hydrocensus investigation, with Figure 5.12 showing the hydrocensus borehole localities.

5.3.3.b. Hydrogeological Borehole Drilling Results

Three (3) hydrogeological boreholes were installed at the Site based on the geophysical survey results, acting as dedicated aquifer characterisation boreholes for the Site. The boreholes are shown in Figure 5.12 and were installed to final depths between 30 and 66 m to a final diameter of 200 mm (8") with steel stabiliser casing installed to below the weathered zone at depths of 12-18 m.

Borehole **DBR-01** was installed to a final depth of 66 m and was sited based on geophysical target L2_154 m. Transported red-brown to brown soil was intersected to 6 m, with highly weathered dolerite chips present from 2 m onwards. Dolerite was intersected between 6 and 10 m, followed by a burned contact zone to 11 m. Mudstone (11-12 m) and coarse-grained sandstone (12-24 m) were underlain by carbonaceous shale (24-34 m), with a water strike intersected at 24 m at the contact zone between the sandstone and shale units (blow yield 1 l/s). Following the carbonaceous shale was highly weathered sandstone (34-42 m), coal (42-45 m), carbonaceous shale (45-55 m), coal (55-62 m) and mixed grey mudstone and Dwyka tillite up to final depth. The water strike intersected at 24 m was the only water strike recorded during drilling and the final borehole yield was 1 l/s with the static water level at the borehole measured as 2.03 m bgl. Figure 5.9 shows the borehole log for DBR-01.

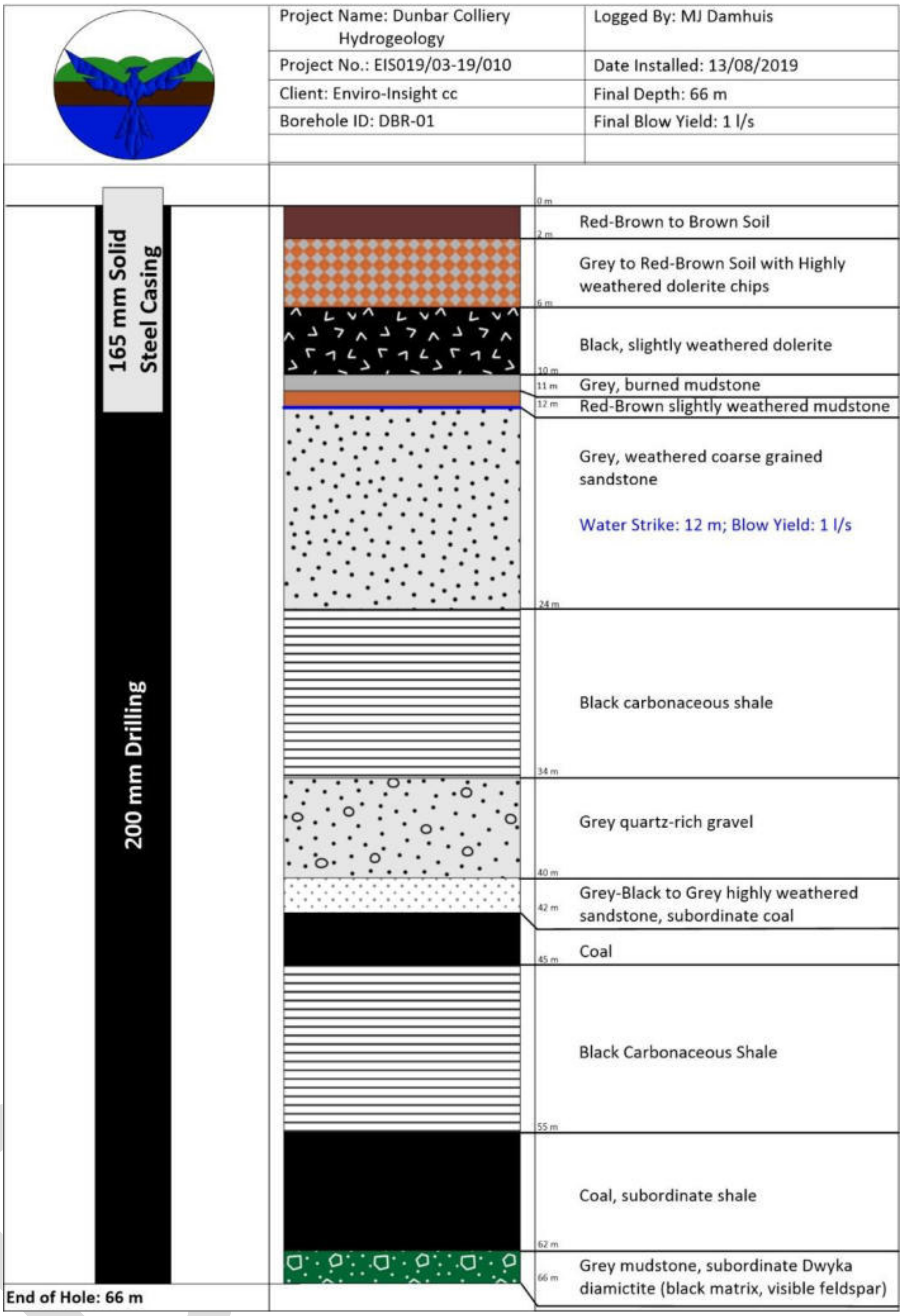

Figure 5.9: Hydrogeological Borehole Log: DBR-01

Borehole **DBR-02** was installed to a final depth of 65 m and was sited based on its location being central to opencast 1. Transported red-brown to brown soil was intersected to 4 m, with light brown, gravelly soil present at 2-3 m and iron nodules present from 3 m onwards. Yellow-brown highly weathered sandstone was present at 4-9 m, followed by black/grey-black highly weathered sandstone to 12 m. A thin coal seam was intersected at 12-13 m, followed by black to grey-black shale and sandstone (±coal) to 25 m. Coal was intersected from 25 to 30 m, with a water strike at 25 m at the contact between the upper shale unit and underlying coal layer. Brown to grey-black shale was intersected at 30-42 m, followed by Dwyka tillite to final borehole depth. The final blow yield for the borehole was 0.2 l/s, with the only water strike being intersected at 25 m with the static water level at the borehole measured as 2.77 m bgl. Figure 5.10 shows the borehole log for DBR-02.

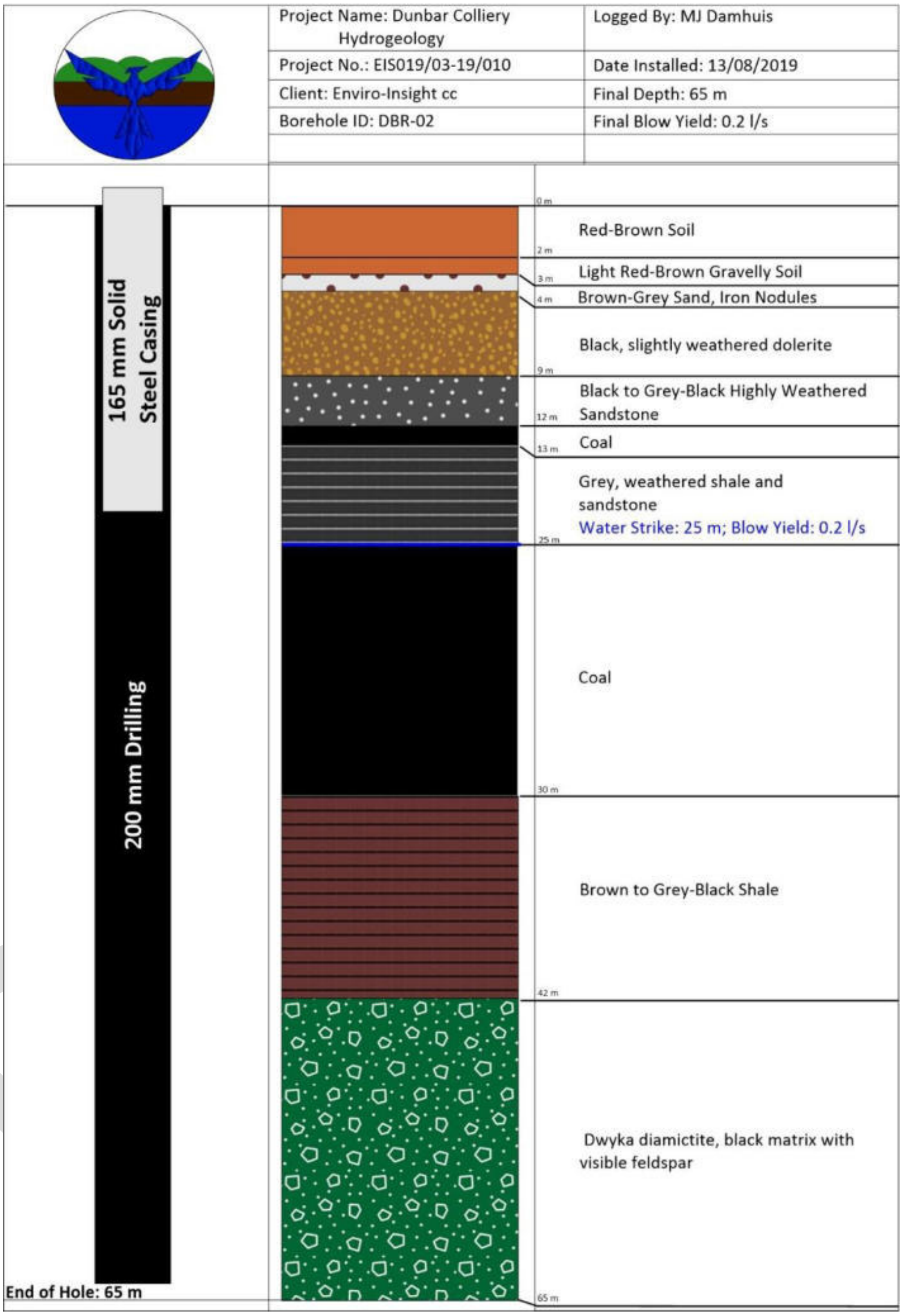

Figure 5.10: Hydrogeological Borehole Log: DBR-02

Borehole **DBR-03** was installed to a final depth of 30 m and was sited based the target locality near to opencast 2. Transported red-brown soil with abundant iron nodules was intersected to 2 m, followed by highly weathered shale and mudstone to 8 m. Slightly weathered carbonaceous shale was present from 8-10 m, followed by coal at 10-13 m and burned sandstone to 14 m. Highly weathered yellow-brown dolerite was intersected from 15-18 m, overlain by red-brown to yellow clay (14-15 m) and underlain by black, slightly weathered dolerite from 18-30 m. A minor water strike was intersected at 15 m at the contact zone between the sandstone and weathered dolerite, with a final blow yield of ~0.1 l/s (i.e. seepage water) with the static water level at the borehole measured as 6.41 m bgl. Figure 5.11 shows the borehole log for DBR-03.

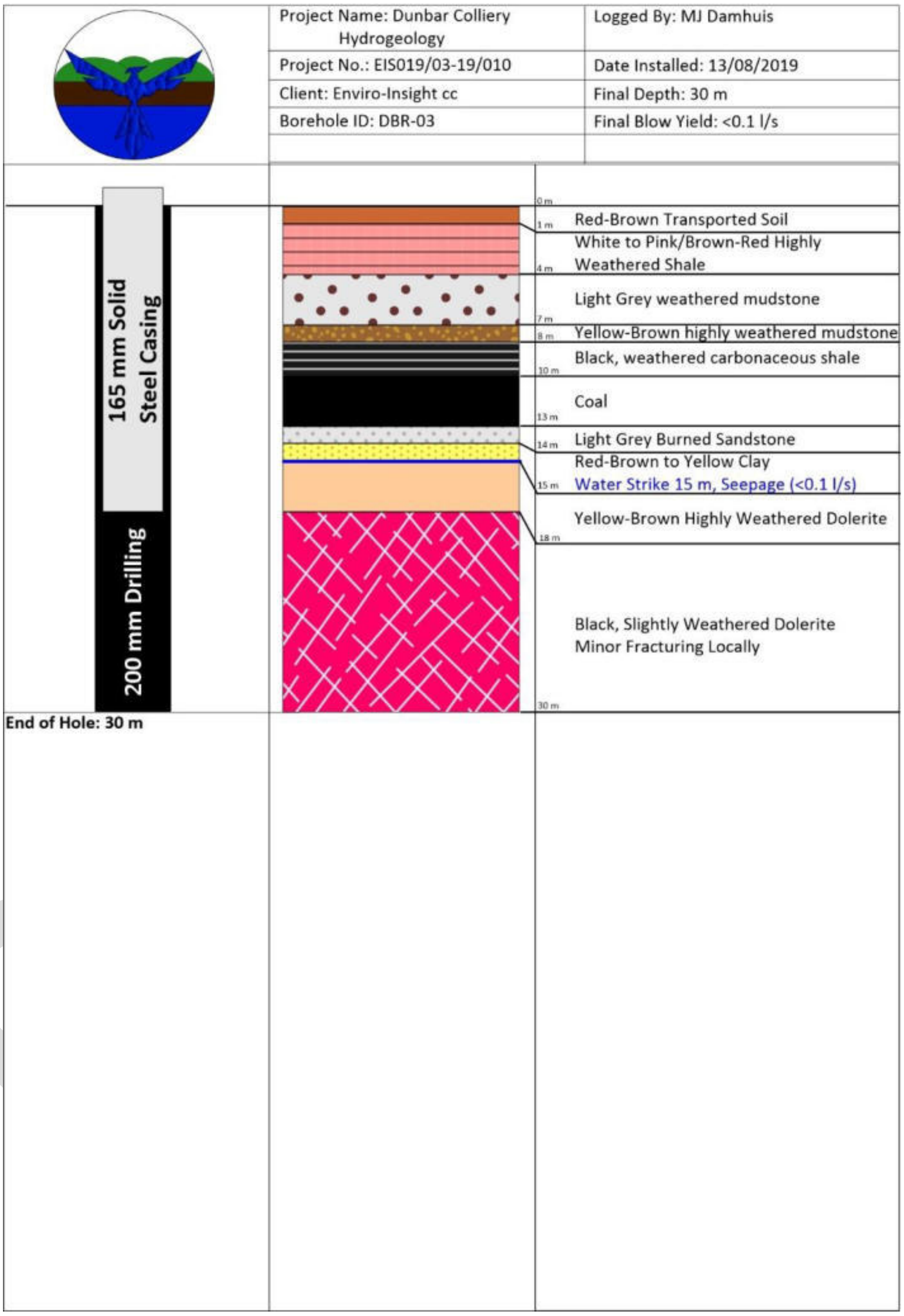

Figure 5.11: Hydrogeological Borehole Log: DBR-03

Table 5.13: Hydrocensus Results Summary

X-Coordinate (LO29, WGS84)	Y-Coordinate (LO29, WGS84)	Elevation (m amsl)	Borehole ID	Collar Height (m)	Static Water Level (m bc)	Static Water Level (m bgl)	Borehole Depth (m)	Sampled (Y/N)	Use	Contact Details
51171.4	-2896851	1620.0	DBR01	Not Accessible				N		Peter Berman
51744.9	-2894461	1638.9	DBR02	Not Accessible				N	Windmill, Domestic Use (~10 people)	Peter Berman
53375.2	-2892803	1647.8	HBK01	0.4	8.62	8.22	28	N	Open BH	Not Obtained
53468.7	-2892725	1647.5	HBK02	Not Accessible				N	Equipped, Domestic Use (~1'000 lpd)	Not Obtained
53819.6	-2892464	1644.5	HBK03	Not Accessible				N	Equipped, Domestic Use (~500 lpd)	Not Obtained
49518.2	-2894519	1621.0	KFTN64	Not Accessible			30	N	Monitoring Borehole, Screen 8-16 m	CJ van der Merwe Farm Manager Steyn: 082 672 5650
47761.1	-2895423	1600.0	MKL01	0.2	3.53	3.33	21	Y	Open BH	Middelkraal Mine
47355.6	-2894951	1589.6	MKL02	0.34	4.51	4.17	40	N	Open BH	Middelkraal Mine
47536.6	-2895195	1599.9	MKL03	0.2	3.22	3.02	53	N	Open BH	Middelkraal Mine
47861.7	-2895329	1600.0	MKL04	Not Accessible				N	Windmill	Middelkraal Mine
49771.5	-2898484	1655.4	MKR01	0.28	5.43	5.15	8.86	Y	Open BH	Marius: 082 441 6504
48630.0	-2896816	1638.9	MKR02	0.2	7.65	7.45	-	Y	Equipped, Sampled at Tap, Domestic + Livestock (~1'000 lpd)	Marius: 082 441 6504
48348.1	-2896752	1632.7	MKR03	Not Accessible				N	Windmill	Marius: 082 441 6504
48321.0	-2896736	1632.1	MKR04	0	3.76	3.76	-	N	Old mono pump, removed partially	Marius: 082 441 6504
48326.0	-2896729	1631.8	MKR05	0	3.7	3.7	-	N	Equipped, Domestic Use (~1'000 lpd)	Marius: 082 441 6504
48353.6	-2896874	1638.1	MKR06	0.34	9.19	8.85	21	N	Open BH, old monitoring borehole to be equipped	Marius: 082 441 6504
49494.0	-2894743	1628.4	WMT01	Not Accessible				Y	Sampled at Tap, Domestic (~10 people)	CJ van der Merwe Farm Manager Steyn: 082 672 5650
49512.1	-2893913	1605.8	WMT02	Not Accessible				N	Windmill	CJ van der Merwe Farm Manager Steyn: 082 672 5650
57915.3	-2894657	1660.1	DBREBH01	Not Accessible				Y	Hand Pump, Domestic Supply (~10-15 people)	Peter Berman
57271.0	-2896272	1680.0	FZN02	Not Accessible				N	Collapsed Borehole	Not Obtained
57242.4	-2896284	1680.0	FZN03	Not Accessible				N	Collapsed Borehole	Not Obtained
60277.3	-2893175	1700.0	UZT01	Not Accessible				N	Domestic Borehole (~500 lpd)	Not Obtained

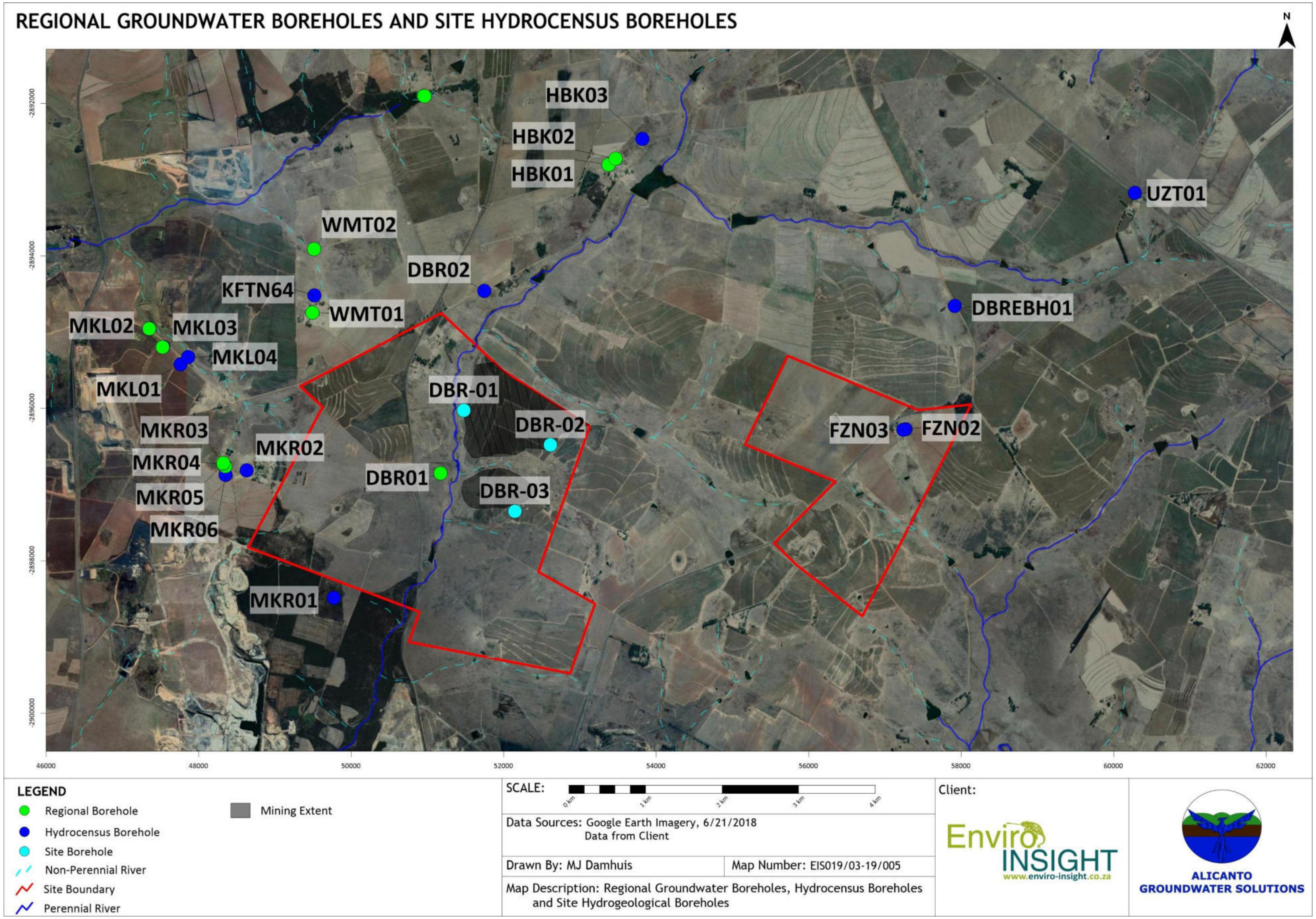

Figure 5.12: Hydrocensus and Site Borehole Positions

5.3.4. Unsaturated Zone

The unsaturated zone typically behaves as a buffer zone for water infiltrating to the aquifers of a region, as well as a storage zone for water in some instances. The nature of the unsaturated zone is important when determining aquifer vulnerability at a Site. Based on the available water levels for the Site area, the unsaturated zone is between 1 and 10 m in thickness and found up to ~15 m below ground level in areas of high weathering (e.g. borehole DBR-02).

TerraSoil (2019) completed a hydropedological investigation for the Site, a generalised soil map (Figure 5.13) was produced and the conceptual hydrological response determined (Table 5.14).

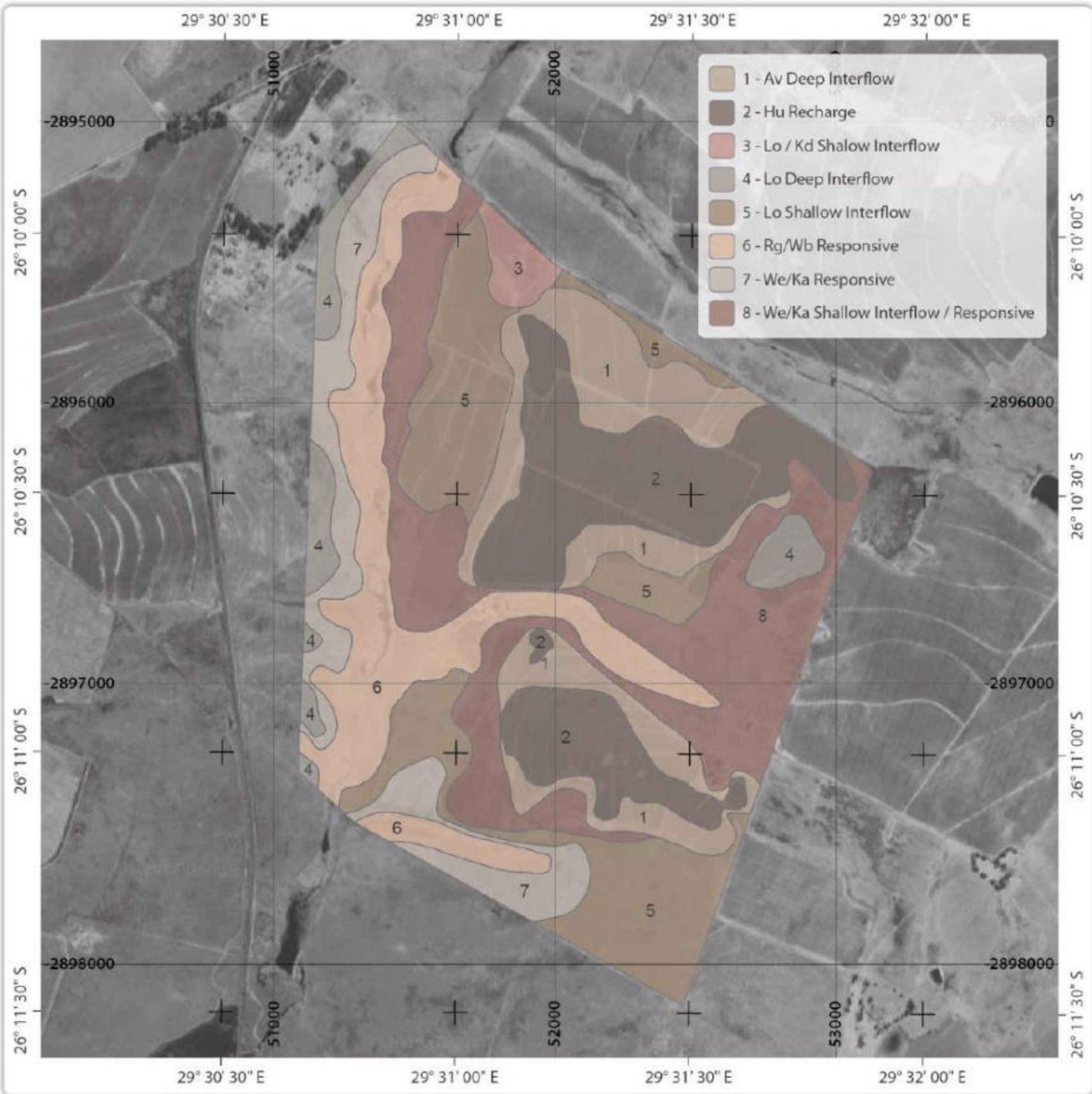

Figure 5.13: Generalised Soil Map of the Site (after TerraSoil, 2019)

Table 5.14: Summary of Soils and Hydrological Functioning (after TerraSoil, 2019)

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

Most of the proposed opencast area is underlain by recharge soils, separated from the responsive soils at the wetland area west of the opencast by a zone of shallow interflow soil and interacting directly with the shallow interflow/responsive soils south and west of the opencast area. Based on the available exploration borehole logs for the Site the average soil layer depth is ~8 m (ranging between 2 and 23 m) with weathered material expected to depths of ~15-20 m (up to 25-30 m locally).

5.3.5. Aquifer Parameters

5.3.5.a. Literature Values

Based on literature (Grobbelaar *et al.*, 2004; Hodgson & Krantz, 1998) and previous experience the Ecca Group geology generally forms poor aquifers, with most water strikes being intersected at bedding contact zones and at secondary features such as faults or intrusions. Based on observations made by Grobbelaar *et al.* (2004) the coal Seam 2 seems to produce the highest borehole yields for the Site area based on drilling and packer testing information.

Aquifer parameters such as transmissivity (T), hydraulic conductivity (K) and storativity (S) were obtained from various sources (Grobbelaar *et al.*, 2004; Vermeulen *et al.*, 2008). Transmissivity values ranged between 0.1 and 4.3 m^2/day overall, with hydraulic conductivity values varying between 0.0002 and 0.5 m/day. Regional storage values ranged between 1.15e-09 and 8.12e-03. Table 5.15 shows a summary of statistics for the aquifer parameters obtained for the Site, with the Site recharge discussed in Section 5.3.8.

Table 5.15: Summary Statistics for Aquifer Parameters available for the Site Region

Parameter	Transmissivity (m^2/day)	Storativity (-)	Hydraulic Conductivity (m/day)
Count	39	30	12
Minimum	0.10	1.15E-09	0.0002
25% Quartile	0.18	2.07E-04	0.0032
Median	0.23	5.84E-04	0.0195
75% Quartile	0.39	3.45E-03	0.0658
Maximum	4.30	8.12E-03	0.5007
Average	0.47	1.83E-03	0.0693

5.3.5.b. Site-Specific Aquifer Parameters

Each of the newly installed boreholes at the Site (Section 5.3.3.b) underwent constant discharge rate aquifer testing in order to determine site-specific aquifer parameters such as transmissivity. The results of the aquifer tests were interpreted using the Cooper-Jacob and Theis residual straight-line fitting methods. The aquifer test results are discussed in the following sections and summarised in Table 5.16, with the aquifer test data sheets and interpretation graphs presented in Appendices D and E, respectively.

Borehole **DBR-01** was tested on 14th August 2019 with the pump installed to a depth of 58 m, allowing for a drawdown of 55.49 m below the static water level of 2.51 m. Water was abstracted from the borehole at a constant rate of 0.42 l/s for a total of 195 minutes, achieving a final drawdown of 1.91 m. Following abstraction the borehole recovered to 97% of the original water level within 60 minutes. The average transmissivity for DBR-01 was 6.6 m^2/day, ranging between 6.1 and 7.1 m^2/day. Analysis of the resultant drawdown curve at the borehole showed the borehole to be situated in a semi-confined aquifer, with a potential recharge boundary (most likely the river channel located north of the borehole).

Borehole **DBR-02** was tested on 15th August 2019 with the pump installed to a depth of 58 m, allowing for a drawdown of 55.08 m below the static water level of 2.92 m. Water was abstracted from the borehole at a constant rate of 0.34 l/s for a total of 78 minutes, achieving a final drawdown of 54.69 m and reaching the pump inlet. Following abstraction the borehole recovered to 85% of the original water level after 228 minutes. The average transmissivity for DBR-02 was 0.13 m^2/day, ranging between 0.11 and 0.14 m^2/day. Analysis of the resultant drawdown curve at the borehole showed the borehole to be situated in a confined aquifer, with no boundary conditions identified from pump testing data.

Borehole **DBR-03** was tested on 16th August 2019 with the pump installed to a depth of 19 m, allowing for a drawdown of 12.32 m below the static water level of 6.68 m. Water was abstracted from the borehole at a constant rate of 0.37 l/s for a total of 25 minutes, achieving a final drawdown of 11.87

m and reaching the pump inlet. Following abstraction, the borehole recovered to 91% of the original water level after 265 minutes. The average transmissivity for DBR-03 was 0.49 m^2/day, ranging between 0.19 and 0.79 m^2/day. Analysis of the resultant drawdown curve at the borehole showed the borehole to be situated in a fractured, semi-confined aquifer, with an impermeable flow boundary condition located near to the borehole.

Table 5.16: Aquifer Test Results Summary

Borehole ID	Transmissivity - Cooper-Jacob (m^2/d)	Transmissivity - Theis-Residual (m^2/d)	Transmissivity - Average (m^2/d)
DBR-01	6.1	7.1	6.6
DBR-02	0.14	0.11	0.125
DBR-03	0.19	0.79	0.49

5.3.6. Groundwater Levels

Regional groundwater levels ranged between 3 and 15 m bgl, up to 30 m bgl locally, with an average water level of 10 m bgl, showing a 96% correlation with surface elevations (Figure 5.14) which suggests groundwater flow takes place under semi-confined conditions and generally mimics surface topography.

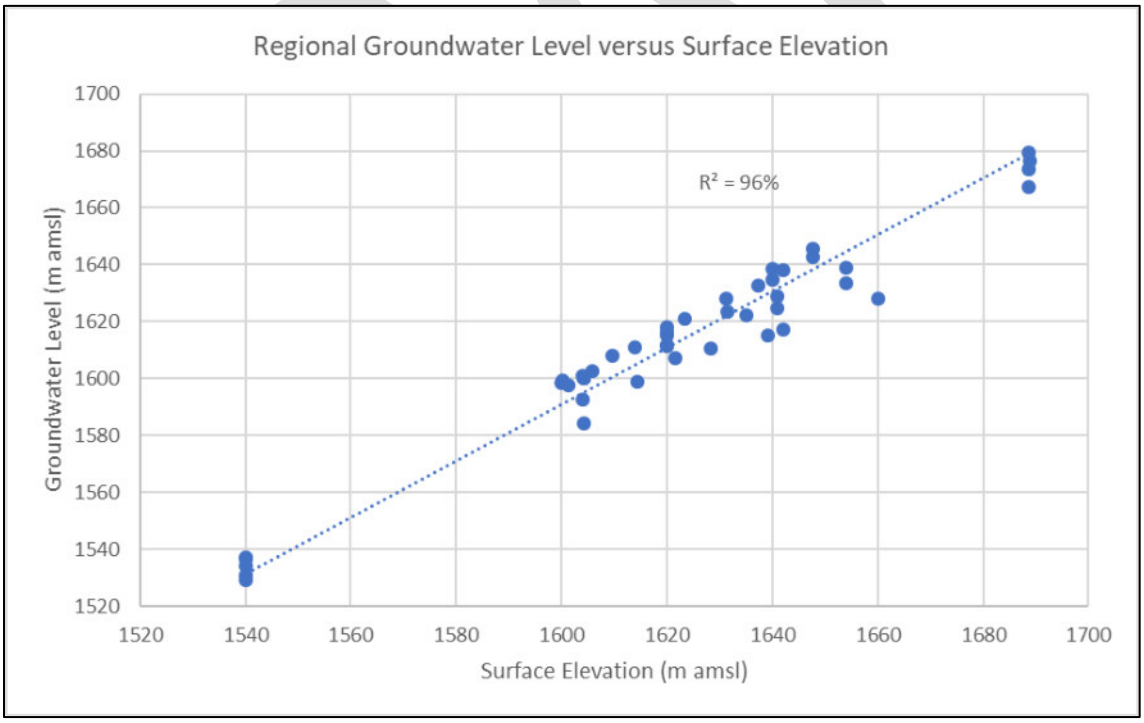

Figure 5.14: Regional Groundwater Level versus Surface Elevation

Groundwater levels at the Site and immediate surroundings were between 3 and 10 m bgl, with an average groundwater level of 4.7 m bgl. Site groundwater levels showed a 99% correlation with surface elevations (Figure 5.15), suggesting groundwater flow takes place under semi-confined conditions, generally, and mimics surface topography.

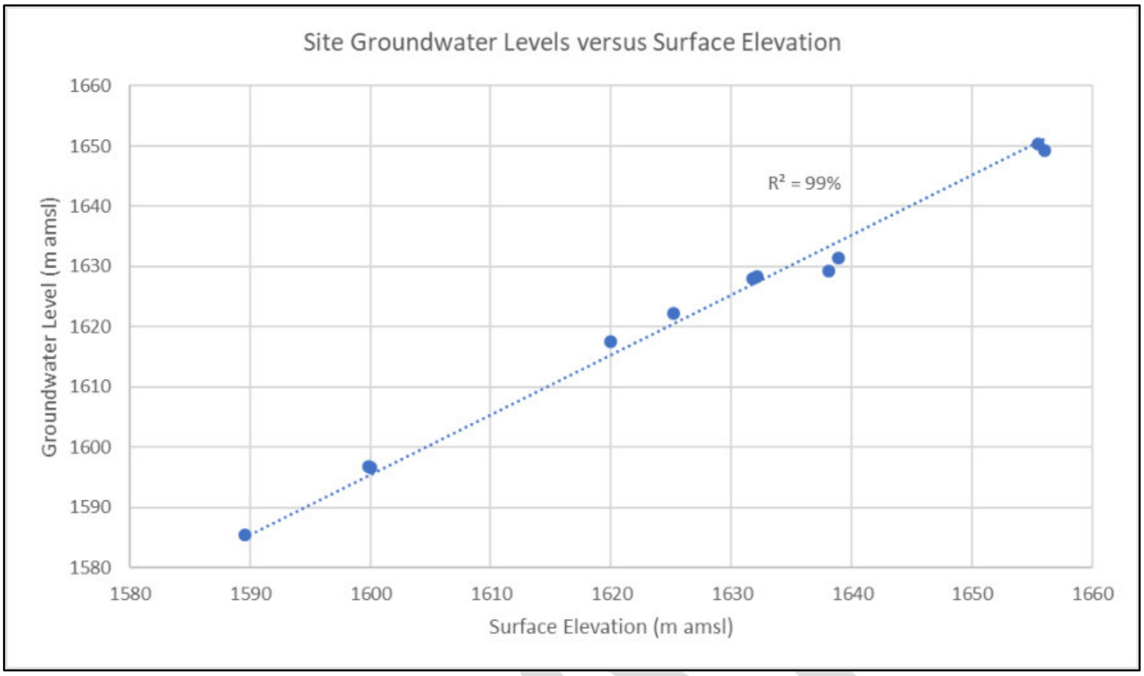

Figure 5.15: Site Groundwater Levels versus Surface Elevation

Groundwater contours were generated for the Site using the Bayesian interpolation method, as shown in Figure 5.16, with the general groundwater flow direction across the Site being from east to west.

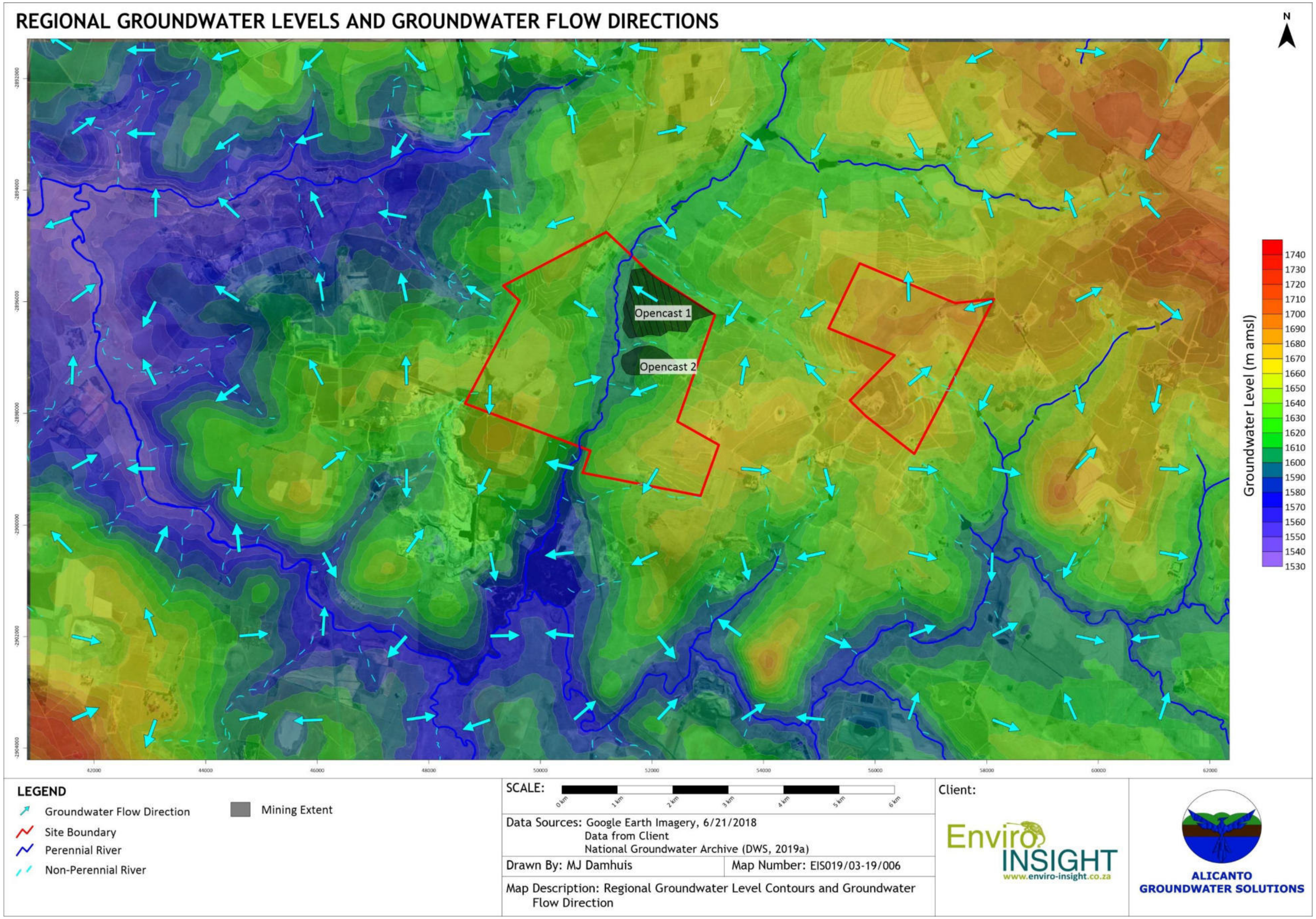

Figure 5.16: Regional Groundwater Levels

5.3.7. Groundwater Quality

5.3.7.a. Regional Groundwater Quality

Regional groundwater quality data was available from Anglo Operations (2015), GHT (2009) and Rison (2008), where groundwater quality sampling was completed as part of hydrocensus investigations completed per investigation. The distribution statistics for each of the parameters measured across the regional studies (Anglo Operations, 2015; Rison, 2008; GHT, 2009) were calculated and compared with the SANS 241: 2015 limits for drinking water quality, as well as the DWS guideline values for domestic water and irrigation, as shown in Table 5.17.

The following observations were made based on the regional groundwater quality data:

- pH, ammonium (as N) and potassium were compliant with SANS 241:2015 limits and both DWS guideline value ranges consistently;
- Localised non-compliance with SANS 241:2015 limits were noted for EC, sulphate, nitrate, fluoride, sodium, iron and manganese. These non-compliances were generally outliers when compared with the overall dataset and were likely to be situated within mining areas; and
- Average values calculated for the region were generally compliant with all applied standards and guidelines, with the exception of EC, nitrate, calcium, magnesium, iron and manganese which were all outside of the ideal DWS guideline value range for domestic water use but were below the maximum tolerance values. These non-compliances with the guideline values are more likely to be due to natural water-rock interactions with minor influence from mining and agriculture activities in the region.

A trilinear piper diagram was constructed using data from the Anglo Operations (2015) and Rison (2008) datasets, as shown in Figure 5.17. The majority of the Anglo Operations (2015) data fell within the calcium-bicarbonate water type sector of the diagram, representative of natural groundwater conditions. The Rison (2008) sampling points fell within the calcium-sulphate water type sector of the diagram, with indications of sulphate-enrichment in the anion sector of the diagram. The sulphate enrichment is most likely to be as a result of seepage from the Komati ash dam complex located near to the sampling points.

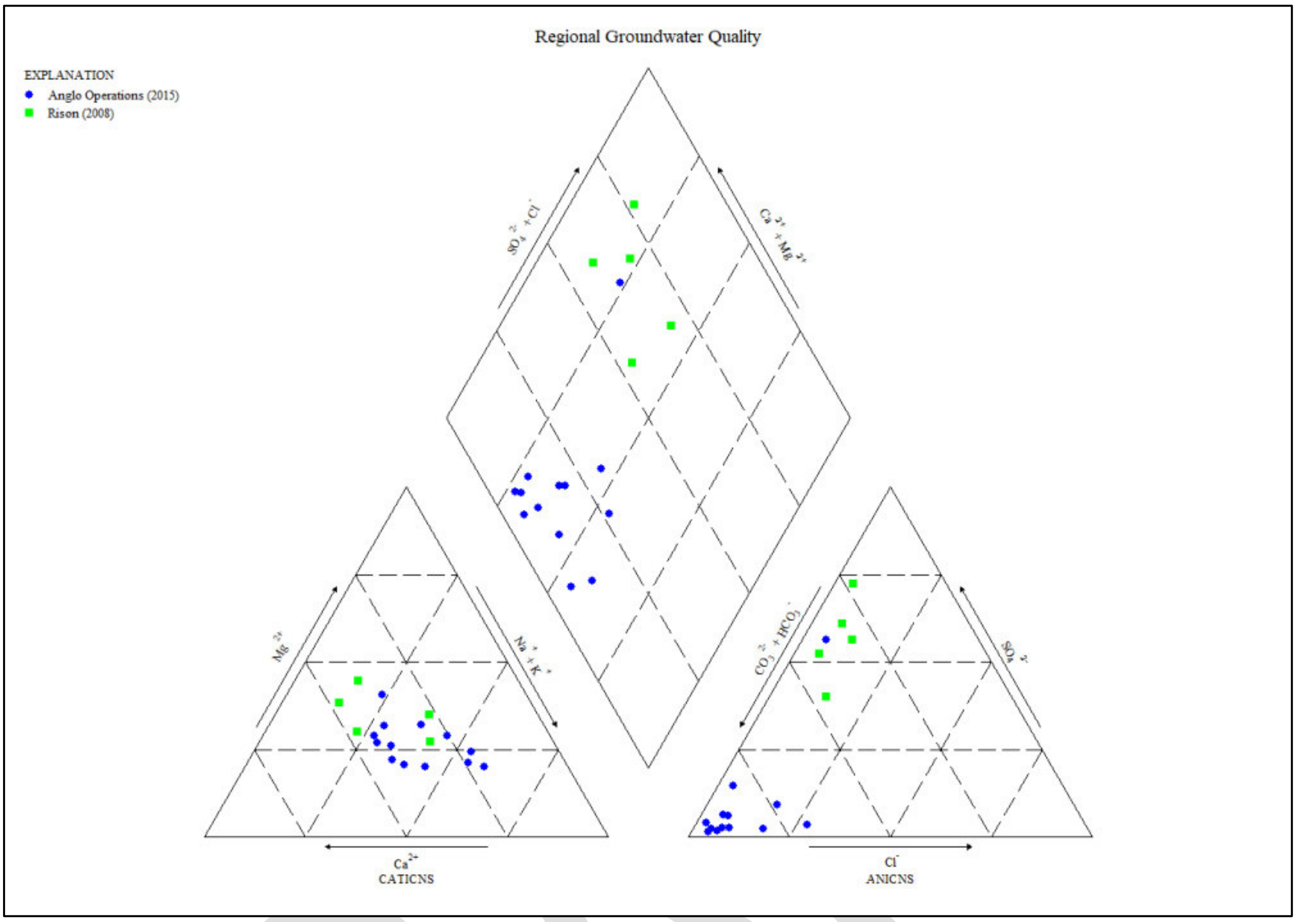

Figure 5.17: Regional Groundwater Quality Piper Diagram

5.3.7.b. Site Groundwater Quality

Five (5) groundwater samples were taken during the hydrocensus investigation and the three (3) newly installed boreholes at the Site (Figure 5.16) were sampled following aquifer testing, with the sample analysis results compared to the SANS 241: 2015 limits for drinking water quality, as well as the DWS guideline values for domestic water and irrigation, as shown in Table 5.18.

The following observations were made based on the regional groundwater quality data:

- In general, the samples were compliant with the SANS 241:2015 limits, with the following exceptions:
  - Nitrate exceeded the limit at boreholes WMT01 and DBREBH, which was most likely due to nearby agricultural activities;
  - Aluminium and iron exceeded the limit at DBR-03, which is likely to be caused by natural groundwater-rock interactions at the Site; and
  - Manganese exceeded the aesthetic limit at boreholes MKL01 and DBREBH, which is likely to be as a result of natural groundwater-rock interactions.
- When compared with the DWS water quality guideline values the following was noted:

    - Most of the hydrocensus borehole samples (excl. MKR01) had calcium and hardness levels above the target value range, with borehole DBR-01 also exceeding the target value range;
    - Boreholes MKL01 and WMT01 were above the guideline range values for magnesium, with borehole WMT01 also exceeding the guideline values for EC, TDS and chloride;
    - Nitrate was above the guideline range at boreholes MKR02 and DBR-01;
    - The pH value at MKR01 (5.91) was slightly below the guideline range values, but remained within the SANS 241:2015 limit; and
    - Manganese was above the domestic guideline range at boreholes DBR-01 and DBR-02, with lead at DBR-03 exceeding guideline values.
- EC values at boreholes MKL01, DBREBH and DBR-01 were outside the guideline values for irrigation, as well as manganese at borehole DBR-03.

The Site groundwater quality data was used to construct a trilinear piper diagram (Figure 5.18), with the following observations made:

- Boreholes DBR-02, MKR02 and MKL01 were calcium-bicarbonate water type;
- Borehole MKR01 was sodium-bicarbonate water type, with sodium enrichment most likely as a result of evaporation during the dry season;
- Boreholes DBREBH, DBR-01 and WMT01 were calcium-chloride type waters, with DBREBH showing chloride enrichment; and
- Borehole DBR-03 was calcium-sulphate type water.

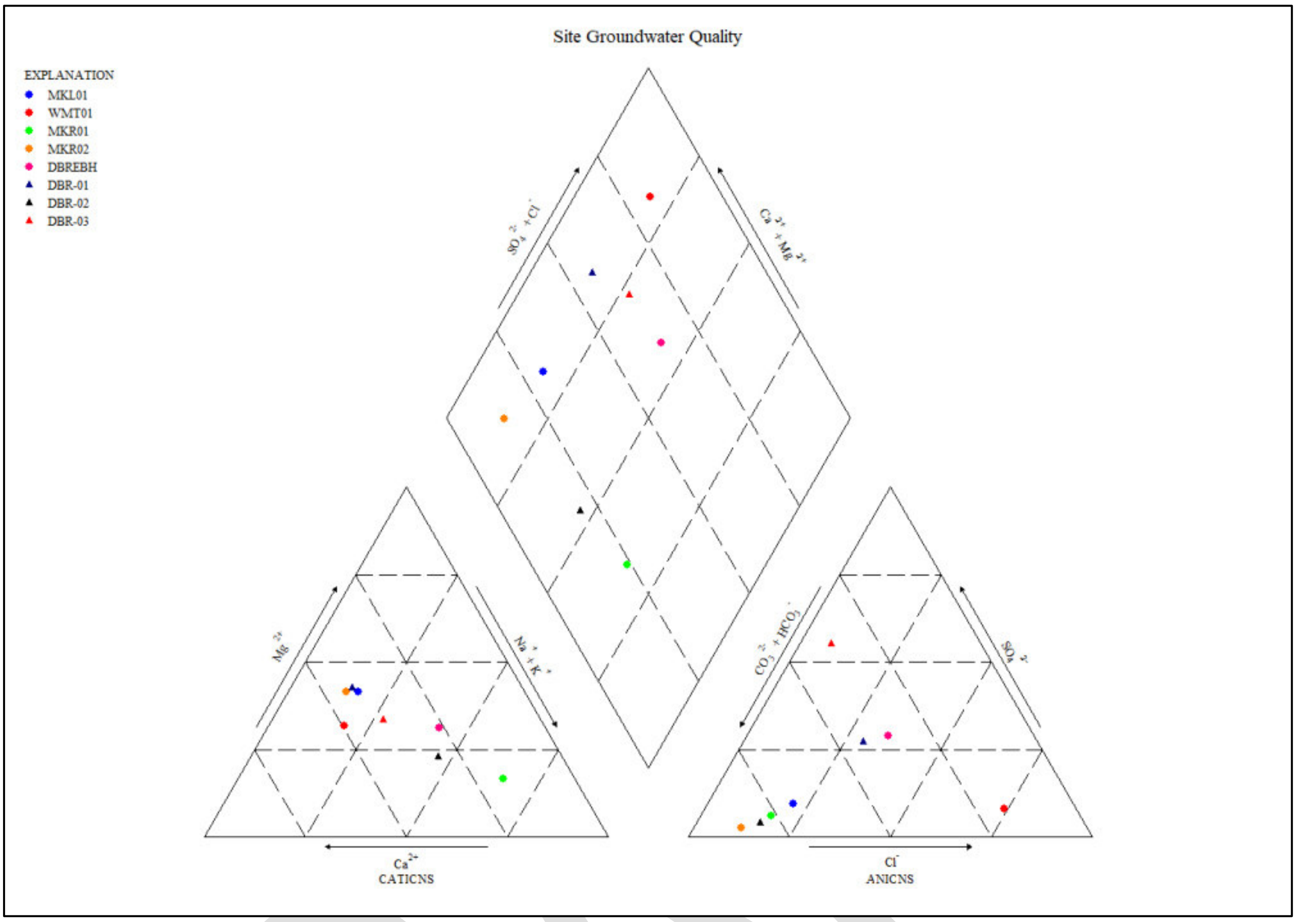

Figure 5.18: Site Groundwater Quality Piper Diagram

Table 5.17: Regional Groundwater Quality Statistics

Parameter	Units	SANS 241:2015 Limit	SAWQG: Domestic Use Target Range (Maximum Acceptable)	SAWQG: Agriculture - Irrigation Target Range (Maximum Acceptable)	Minimum	25% Quartile	Median	75% Quartile	Maximum	Average
pH at 25°C	pH	5.0 - 9.7	6.0 - 9.0 (<4; >11)	6.5 - 8.4	6.40	7.13	7.40	7.70	8.40	7.38
Electrical Conductivity (EC)	mS/m	170	0 - 70 (450)	0 - 40 (540)	7.73	39.70	54.00	86.55	348.00	80.76
Total Dissolved Solids (TDS)	mg/l	1200	0 - 450 (3000)	NS	58.00	160.00	228.00	318.00	1004.00	281.85
Total Alkalinity	mg CaCO3/l	NS	NS	NS	22.00	130.00	163.00	239.00	684.00	186.56
Chloride as Cl	mg/l	300	0 - 100 (1200)	0 - 100 (700)	5.00	14.00	26.00	60.50	299.00	49.14
Sulphate as SO4	mg/l	Aesthetic - 250 Chronic Health - 500	0 - 200 (1000)	NS	1.00	7.22	16.20	100.75	1545.00	196.26
Nitrate (NO3) as N	mg/l	11	0 - 6 (20)	0 - 5 (30)	0.11	0.60	1.36	32.02	161.82	20.63
Ammonium (NH4) as N	mg/l	NS	NS	NS	0.70	1.23	1.90	3.10	10.00	3.17
Orthophosphate (PO4) as P	mg/l	NS	NS	NS	2.00	2.00	2.00	2.00	2.00	2.00
Fluoride as F	mg/l	1	0 - 1 (2000)	0 - 2 (15)	0.10	0.24	0.35	0.55	1.62	0.43
Calcium as Ca	mg/l	NS	0 - 32 (80)	NS	4.11	25.60	35.40	82.00	255.00	68.63
Magnesium as Mg	mg/l	NS	0 - 30 (400)	NS	2.00	10.75	16.90	24.00	236.00	35.79
Sodium as Na	mg/l	200	0 - 100 (5000)	0 - 70 (460)	6.00	16.50	24.90	48.80	374.00	51.12
Potassium as K	mg/l	NS	0 - 50 (400)	NS	1.11	3.55	4.70	9.85	46.00	8.52
Iron as Fe	mg/l	Aesthetic - 0.3 Chronic Health - 2	0 - 0.1 (100)	0 - 5 (20)	0.01	0.05	0.09	0.40	2.10	0.44
Manganese as Mn	mg/l	Aesthetic - 0.1 Chronic Health - 0.4	0 - 0.05 (20)	0 - 0.02 (10)	0.01	0.02	0.07	0.30	1.40	0.27
Boron as B	mg/l	2.4	NS	0 - 0.5 (15)	0.01	0.05	0.06	0.07	0.09	0.06

Red - Indicates exceedance of SANS 241:2015 Limit

Orange - Indicates values outside of the DWS Guideline Target Values for Domestic Use

Green - Indicates values outside of the DWS Guideline Target Values for Irrigation

Table 5.18: Site Groundwater Quality Results

Sample ID	Units	SANS 241:2015 Limit	SAWQG: Domestic Use Target Range (Maximum Acceptable)	SAWQG: Agriculture - Irrigation Target Range (Maximum Acceptable)	MKL01	WMT01	MKR01	MKR02	DBREBH	PC01	PC02	PC03
Parameter					04-Jul-2019	04-Jul-2019	04-Jul-2019	04-Jul-2019	05-Jul-2019	19-Aug-2019	19-Aug-2019	19-Aug-2019
pH at 25°C	pH	5.0 - 9.7	6.0 - 9.0 (<4; >11)	6.5 - 8.4	7.23	7.08	5.91	7.83	6.64	7.53	7.1	6.69
Electrical Conductivity (EC)	mS/m	170	0 - 70 (450)	0 - 40 (540)	59.6	127	8.02	38.4	64.7	45.3	33.4	11.2
Total Dissolved Solids (TDS)	mg/l	1200	0 - 450 (3000)	NS	367	748	60	271	438	315	234	109
Total Alkalinity	mg $CaCO_3$/l	NS	NS	NS	244	79.2	4.66	156	105	87.9	147	BDL
Chloride as Cl	mg/l	300	0 - 100 (1200)	0 - 100 (700)	43.1	190	6.58	12.5	59.3	35.1	17	55.1
Sulphate as SO_4	mg/l	Aesthetic - 250 Chronic Health - 500	0 - 200 (1000)	NS	26.3	27.7	3.12	3.88	66.2	43.6	5.99	BDL
Nitrate (NO_3) as N	mg/l	11	0 - 6 (20)	0 - 5 (30)	0.279	53.3	0.929	8	21	10.3	BDL	3.14
Ammonium (NH_4) as N	mg/l	NS	NS	NS	0.013	BDL	0.011	BDL	0.038	0.245	0.034	0.223
Ammonia (NH_3) as N	mg/l	1.5	0 - 1.0 (10)	NS	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Orthophosphate (PO_4) as P	mg/l	NS	NS	NS	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Fluoride as F	mg/l	1	0 - 1 (2000)	0 - 2 (15)	BDL	BDL	BDL	BDL	0.312	BDL	0.415	0.93
Calcium as Ca	mg/l	NS	0 - 32 (80)	NS	50.9	109	1.4	33.6	33.7	35.5	20.1	9.76
Magnesium as Mg	mg/l	NS	0 - 30 (400)	NS	31	42.2	0.799	19.1	24	21.8	9.12	5.08
Sodium as Na	mg/l	200	0 - 100 (5000)	0 - 70 (460)	22	40.8	4.61	9.72	60.6	12.9	32.6	6.5
Potassium as K	mg/l	NS	0 - 50 (400)	NS	4.23	11.7	2.29	5.02	2.35	3.3	4.25	2.49
Aluminium as Al	mg/l	0.3	0 - 0.15 (0.5)	0 - 5.0 (20)	BDL	BDL	0.229	BDL	0.003	BDL	BDL	4.48
Iron as Fe	mg/l	Aesthetic - 0.3 Chronic Health - 2	0 - 0.1 (100)	0 - 5 (20)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	1.69
Manganese as Mn	mg/l	Aesthetic - 0.1 Chronic Health - 0.4	0 - 0.05 (20)	0 - 0.02 (10)	*0.156*	BDL	0.002	BDL	*0.123*	0.056	0.351	0.032
Copper as Cu	mg/l	2	0 - 1 (200)	0 - 0.2 (5)	0.01	0.027	0.002	0.013	0.01	0.008	0.004	0.013
Nickel as Ni	mg/l	0.07	NS	0 - 0.2 (2)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.004
Zinc as Zn	mg/l	5	0 - 3 (700)	0 - 1.0 (5)	0.021	0.129	0.039	0.076	0.377	BDL	BDL	0.012
Cobalt as Co	mg/l	NS	NS	0 - 0.05 (5)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Cadmium as Cd	mg/l	0.003	0 - 0.005 (1)	0 - 0.01 (0.05)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Lead as Pb	mg/l	0.01	0 - 0.01 (0.3)	0 - 0.2 (2)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.012
Total Hardness	mg $CaCO_3$/l	NS	50 - 100	NS	255	447	7	162	183	178	88	45
Dissolved Organic Carbon	mg/l	NS	0 - 5 (20)	NS	4.85	3.62	4.02	2.69	3.93	3.36	3.33	22.3
Arsenic as As	mg/l	0.01	0 - 0.01 (10)	0 - 0.1 (2)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Boron as B	mg/l	2.4	NS	0 - 0.5 (15)	0.053	0.021	BDL	BDL	BDL	BDL	BDL	0.116
Barium as Ba	mg/l	0.7	NS	NS	0.153	0.475	0.028	0.013	0.114	0.261	0.135	0.276
Berylium as Be	mg/l	NS	NS	0 - 0.1 (0.5)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Bismuth as Bi	mg/l	NS	NS	NS	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Gallium as Ga	mg/l	NS	NS	NS	0.005	0.007	BDL	0.004	0.003	0.003	0.001	0.02
Lithium as Li	mg/l	NS	NS	0 - 2.5	0.006	0.04	BDL	0.011	0.001	0.001	0.022	0.006
Molybdenum as Mo	mg/l	NS	NS	0 - 0.01 (0.05)	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Strontium as Sr	mg/l	NS	NS	NS	0.207	0.524	0.007	0.17	0.279	0.345	0.14	0.059
Vanadium as V	mg/l	NS	0 - 0.1 (1)	0 - 0.1 (1)	0.002	BDL	BDL	0.008	BDL	BDL	BDL	0.01
Bicarbonate Alkalinity	mg $CaCO_3$/l	NS	NS	NS	244	79.1	4.66	155	105	87.6	147	BDL
Carbonate Alkalinity	mg $CaCO_3$/l	NS	NS	NS	0.393	0.089	BDL	0.976	0.043	0.282	0.174	BDL

BDL - Below Detection Limit
NS - No Standard Specified
Red - Indicates exceedance of SANS 241:2015 Limit
Orange - Indicates values outside of the DWS Guideline Target Values for Domestic Use
Green - Indicates values outside of the DWS Guideline Target Values for Irrigation

5.3.8. Groundwater Sources and Sinks

5.3.8.a. Groundwater Recharge

Regional recharge values based on literature (Grobbelaar *et al*., 2004) range between 1 and 3% of MAP, with recharge to mining infrastructure and operations varying between 8% and 80% according to Hodgson & Krantz (1998) as presented in Table 5.19.

Table 5.19: Recharge to Mine Workings & Infrastructure (after Hodgson & Krantz, 1998)

Parameter	Unit	Value	Additional Comments
Rain onto Levelled Spoils	%MAP	15-30%	Seepage
Rain onto Levelled Spoils	%MAP	20%	Seepage (Average)
Rain onto Rehabilitated Spoils	%MAP	5-10%	Seepage
Rain onto Rehabilitated Spoils	%MAP	8%	Seepage (Average)
Rain onto Unrehabilitated Spoils	%MAP	30-80%	Runoff & Seepage
Rain onto Unrehabilitated Spoils	%MAP	60%	Runoff & Seepage (Average)

Regional and Site recharge values were calculated using the chloride mass balance method, where rainfall chloride concentration was assumed to be 1.3 mg/l (Van Wyk *et al*., 2011) and dry deposition was assumed to be 10% of rainfall chloride concentration. Regional recharge values were between 1 and 4%, with calculated Site recharge values ranging between 2 and 4% which are within the range of those presented in literature for the Site region and were thus considered realistic.

5.3.8.b. Groundwater Contribution to Baseflow

Daily flow rate data was available for the DWS river monitoring station B1H018 (DWS, 2019b) located on the Olifants River south of the Site for the period between 1989 and 2019. The resultant hydrograph for the monitoring station was separated and the groundwater contribution to baseflow in the river was 0.1 m^3/second (100 m^3/day per 100 m of river channel).

5.3.8.c. Proposed Mining Activities

During the mining operational phase groundwater is likely to flow into the opencast pit areas at the Site, with the proposed mining extent and schedule shown in Figure 4.3. Mining will take place to maximum depths of ~60 m with the total life of mine (LoM) expected to be 15 years (InsaCoal, 2019).

Following extraction of the coal resources per mining block, the resultant pits will be backfilled using the waste material from the proceeding mining block (i.e. rollover mine rehabilitation), which would result in additional groundwater recharge (8-10% MAP) as per Table 5.19.

6. Hydrogeological Conceptual Model

The Site is located at the boundary of the Highveld and Witbank coalfields of South Africa and is underlain predominantly by shale, sandstone and coal units of the Vryheid formation at the northern section of the Site, with felsite and pyroclastic rocks of the Rooiberg Group present at the southern section. Dolerite sill intrusions have been noted in the central region of the Site, generally found below the coal seam but crossing the seams locally (GeoCoal Servives, 2015).

Site surface elevations range between 1'600 and 1'700 m amsl, sloping gently towards the perennial Leeuwfonteinspruit at the centre of the Site and various non-perennial channels and wetland/pan features situated across the Site region. Most of the Site's rainfall occurs between October and March, with a MAP of 620 mm and MAE of 1'972 mm, indicating the Site is naturally under water deficit conditions. The perennial Leeuwfonteinspruit flows from north to south through the central region of the Site, fed by multiple non-perennial channels across the Site. The perennial Olifants River is situated ~5 km north west and south of the Site, with an unnamed perennial river situated ~5.5 km north east of the Site.

Intergranular and fractured aquifers underly the Site, where groundwater flow takes place under semi-confined conditions and generally mimics surface topography. Groundwater levels at the Site range between 3 and 10 m bgl with an average water level of ~4.7 m bgl. Water strike depths for the region are generally between 15 and 30 m, up to 60-70 m, with an average blow yield of 0.7 l/s (ranging between ~0.1 and 3 l/s). Hydrogeological borehole drilling results showed water strikes to be associated with contact zones between weathered and competent lithology, as well as contact zones between sedimentary and intrusive lithologies. Groundwater-surface water interaction is likely to take place near to perennial river streams (e.g. borehole DBR01), with the average groundwater contribution to baseflow being ~100 m^3/day per 100 m length of riverbed.

The Site groundwater system is comprised of three (3) hydraulically connected hydrogeological units, namely:

- A shallow, weathered zone hydrogeological unit;
- A deeper, fractured rock hydrogeological unit; and
- A basement hydrogeological unit.

The upper, weathered hydrogeological unit is typically found between 5 and 12 m depths, with the dominant recharge mechanism being infiltration of rainwater (1-5% of MAP) and secondary interactions with surface water bodies, locally. The average transmissivity of the weathered zone is 1-3 m^2/day, depending on the clay content of the weathered material, up to ~5-10 m^2/day at alluvial zones near to perennial rivers. The movement of groundwater in the upper weathered unit is controlled by the lower permeability shale or dolerite layers and typically mimics surface topography.

The fractured rock hydrogeological unit is found at depths ranging between 15 and 50 m with water strike intersections decreasing with depth. The matrix of the Vryheid formation geology is well-cemented, thus lowering groundwater potential in the matrix and leading to almost all economic water strikes being associated with secondary geological features such as faults, fracture zones and intrusive contact zones (e.g. contact zones at dolerite sills or dykes). Recharge to the fractured rock unit is mainly as a result of storage water released from the upper weathered unit, with outcrop zones being recharged from rainfall infiltration (<1-2% MAP). Transmissivity values for the fractured rock unit ranged between 0.5 and 7 m^2/day, with fracture zones showing transmissivities of ~0.5-1.5 m^2/day and contact zones between lithology units having transmissivity values of ~3-7 m^2/day.

The basement hydrogeological unit is generally regarded as insignificant due to its low yielding nature, great depth (>100 m) and limited recharge potential due to the overlying Dwyka tillite or felsite units. The transmissivity values of the basement unit are expected to be in the order of 0.05 and 0.1 m^2/day.

Figure 6.1 shows a hydrogeological conceptual section for the Site.

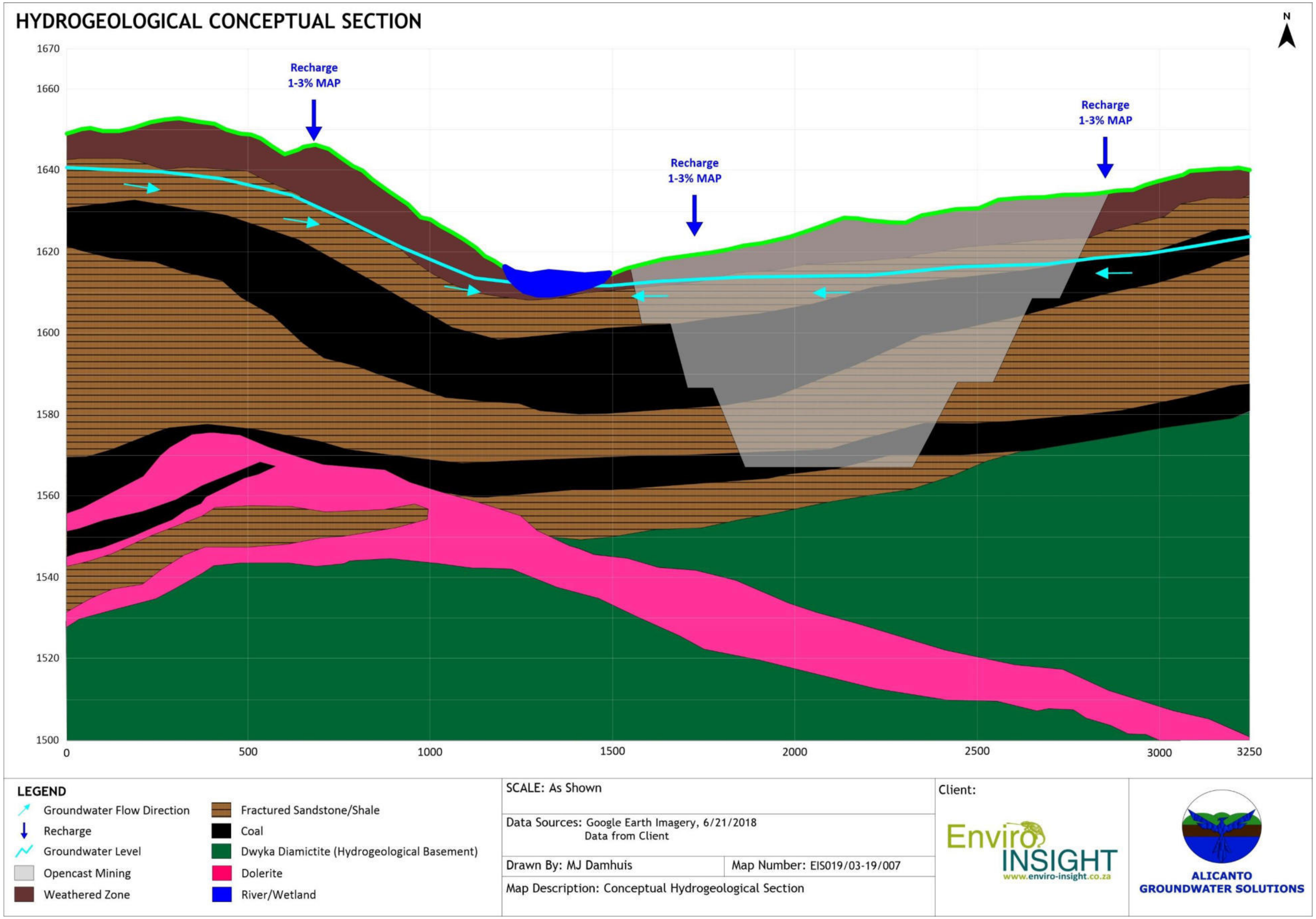

Figure 6.1: Hydrogeological Conceptual Section

7. Groundwater Reserve Determination

7.1. Unit of Analysis Delineation

The unit of analysis (UA) for the Site was taken to be the model boundary area, as discussed in Section 8 and shown in Figure 7.1, which represented the extent of the groundwater environment at the Site and likely to interact with the mining activities.

7.2. Basic Human Needs Assessment

According to the GRDM Software database the combined population for the quaternary catchments B11A and B11B was reported to be 9'500 people in total (DWS, 2013), which translated to an average population of ~22 people per km^2. Using these values, the total population of the UA was estimated as 3'185 people, which is likely to be a high estimate as most of the UA is used for agriculture and is not populated.

Using a daily water requirement of 25 l/person/day the total basic human need volume from groundwater for the UA was 0.03 Mm^3/a.

7.3. Groundwater Contribution to Baseflow

Daily flow rate data was available for the DWS river monitoring station B1H018 (DWS, 2019b) located on the Olifants River south of the Site for the period between 1989 and 2019. The resultant hydrograph for the monitoring station was separated and the groundwater contribution to baseflow in the river was 0.1 m^3/second (100 m^3/day per 100 m of river channel) which equated to a total of 1.95 Mm^3/a.

7.4. Groundwater Recharge

Regional and Site recharge values were calculated using the chloride mass balance method, where rainfall chloride concentration was assumed to be 1.3 mg/l (Van Wyk *et al.*, 2011) and dry deposition was assumed to be 10% of rainfall chloride concentration. Regional recharge values were between 1 and 4%, with calculated Site recharge values ranging between 2 and 4% which are within the range of those presented in literature for the Site region and were thus considered realistic. An average recharge value of 3% was used for the reserve determination and the annual recharge to groundwater calculated as 2.69 Mm^3/a.

7.5. Existing Abstraction

Limited information was available regarding actual abstraction volumes from the hydrocensus boreholes, however, according to the GRDM Software database (DWS, 2013) the groundwater use within the UA was 0.3 Mm^3/a.

7.6. Proposed Abstraction

Site dust suppression water supply to the Site would be from a groundwater abstraction borehole, with a proposed daily abstraction rate of 45 m^3 or 0.02 Mm^3/a.

7.7. Reserve Determination

The groundwater component of the reserve is the part of the groundwater resource which sustains both human needs and contributes to environmental water requirements (e.g. baseflow). The groundwater component of the reserve is calculated as per Equation 1 taken from Dennis *et al.*, 2013.

Equation 1: Groundwater Component of the Reserve

$$Reserve\ (\%) = \frac{Basic\ Human\ Needs + Groundwater\ Contribution\ to\ Baseflow}{Recharge} \times 100\%$$

The groundwater component of the reserve was calculated as 74%, leaving 0.71 Mm^3/a as allocable groundwater resources. The proposed abstraction volume (0.02 Mm^3/a) was 2.82% of the allocable groundwater resource, as shown in Table 7.1.

Table 7.1: Groundwater Reserve Calculation

Description	Unit	Value
Unit of Analysis Area	m^2	144 836 218
Mean Annual Precipitation (MAP)	mm/a	620
Recharge to Groundwater	Mm^3/a	2.69
Basic Human Need	Mm^3/a	0.03
Groundwater Contribution to Baseflow	Mm^3/a	1.95
Existing Abstraction	Mm^3/a	0.3
Proposed Abstraction	Mm^3/a	0.02
Total Recharge (Inflow)	Mm^3/a	2.69
Groundwater Reserve	%	74%
Allocable Reserve	Mm^3/a	0.71
Proposed Abstraction as % Allocable Reserve	%	2.82%

7.8. Aquifer Vulnerability Assessment

The Site aquifer vulnerability was determined using the modified DRASTI[1] method where the UA was divided into areas of ~0.4 km^2 (i.e. 635x635 m grid cells) (Yang & Wang, 2010) and the aquifer vulnerability is based on a number of factors, namely:

- Depth to Groundwater (D) – providing an indication of the distance and time contaminants would need to travel through the unsaturated zone to the groundwater table;
- Recharge (R) – which aids in the mobilisation of surface contaminants to the groundwater table;
- Aquifer Material (A) – the nature of the geological units which are water-bearing (e.g. fractured, porous etc.);
- Soil (S) – soil type(s) present at the Site, which may influence the travel time and concentration of contaminants reaching the groundwater table;
- Topography (T) – which provides an indication of the amount of runoff versus infiltration of surface contaminants; and
- Impact of the vadose zone (I) – the material found in the unsaturated zone which may slow the infiltration of contaminants.

The factors were assigned relative weightings between 1 and 5, based on their contribution to the overall aquifer vulnerability, with 5 being the most significant and 1 being the least. The weightings assigned are shown in Table 7.2.

Table 7.2: DRASTI Parameter Weightings

Parameter		Weighting
Depth to Groundwater	D	5
Recharge to Groundwater	R	4
Aquifer Material	A	3
Soil Type(s)	S	5
Topography	T	3
Impact of the Vadose Zone	I	4

The factor values and their weightings were used to calculate the DRASTI vulnerability index (DVI) per grid cell using Equation 2 below, with the resultant DVI distribution across the Site presented in Figure 7.2. The Site aquifer system was medium vulnerability, with localised zones of high vulnerability associated with alluvial material zones and river/wetland areas around the Site.

[1] Modified from the DRASTIC method, where C (hydraulic conductivity) is excluded due to the highly variable nature of the parameter in fractured rock aquifers typically found in South African environments.

Equation 2: DRASTI Vulnerability Index Equation

$$DVI = D_R D_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W$$

Where:

D_R, R_R, A_R, S_R, T_R, I_R are numerical values assigned; and

D_W, R_W, A_W, S_W, T_W, I_W are the weightings assigned to each parameter.

7.9. Aquifer Classification

Based on the hydrocensus results the Site aquifer is a 'Minor Aquifer System', due to the local population engaged during the hydrocensus investigation not being dependent on groundwater. Aquifer system management and second variable classifications ratings were assigned as per Table 7.3 and groundwater quality management classification system ratings assigned as per Table 7.4 in order to determine the groundwater quality management (GQM) index. The GQM index was calculated using Equation 3, with the calculated level of protection being 4 (i.e. medium level of protection according to Table 7.5).

Equation 3: GQM Index

$$GQM\ Index = Aquifer\ System\ Management\ \times Aquifer\ Vulnerability = 2\ \times 2 = 4$$

Table 7.3: Aquifer System Management and Second Variable Classification Ratings

Aquifer System Management Classification		
Class	**Points**	**Site Points**
Sole Source Aquifer System	6	2
Major Aquifer System	4	
Minor Aquifer System	2	
Non-Aquifer System	0	
Special Aquifer System	0-6	
Second Variable Classification (weathering/fracturing)		
Class	**Points**	**Site Points**
High	3	2
Medium	2	
Low	1	

Table 7.4: Groundwater Quality Management Classification System Ratings

Aquifer System Management Classification		
Class	**Points**	**Site Points**
Sole Source Aquifer System	6	2
Major Aquifer System	4	
Minor Aquifer System	2	
Non-Aquifer System	0	
Special Aquifer System	0-6	
Aquifer Vulnerability Classification		
Class	**Points**	**Site Points**
High	3	2
Medium	2	
Low	1	

Table 7.5: GQM Index for the Site

GQM Index	Level of Protection	Site GQM Index
<1	Limited	4
1-3	Low Level	
3-6	Medium Level	
6-10	High Level	
>10	Strictly Non-Degradation	

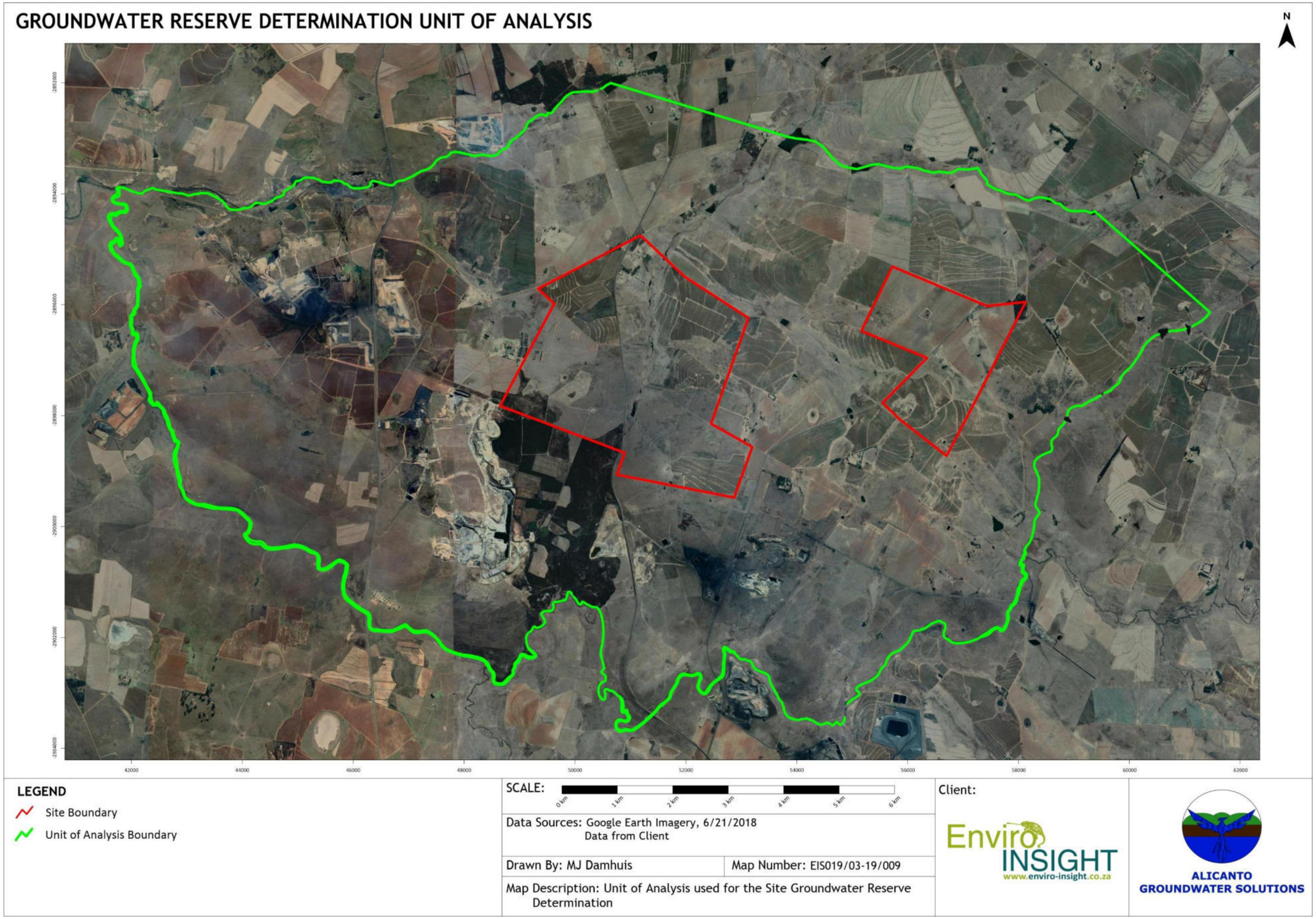

Figure 7.1: GRDM Unit of Analysis

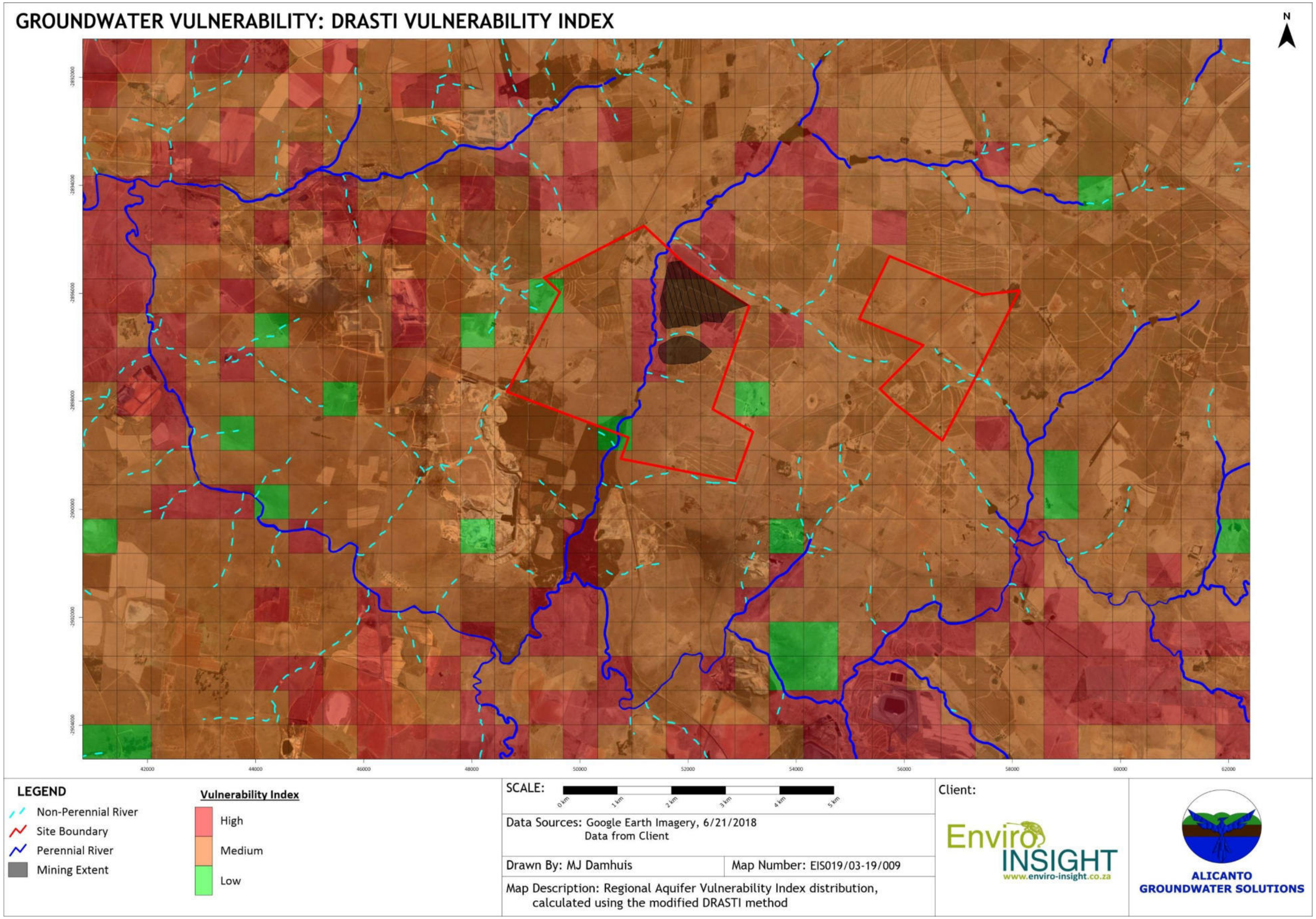

Figure 7.2: Aquifer Vulnerability Assessment - DVI Distribution

8. Numerical Modelling

8.1. Software and Code Selection

A groundwater flow and contaminant transport model was constructed for the Site using Processing MODFLOW for Windows (PMWIN) 8 (Simcore Software, 2012) which uses the MODFLOW finite difference code developed by the USGS (Macdonald & Harbaugh, 1988) and is a widely accepted numerical modelling code for solving groundwater flow problems. Groundwater contaminant transport was simulated using the MT3D MS code within PMWIN.

8.1.1. Code Description

The governing groundwater equation for 3D groundwater flow is presented in the equation below, which when coupled with specified hydraulic head conditions and the definition of model boundary conditions constitutes a numerical groundwater model (MacDonald & Harbaugh, 1988).

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial x}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)-W=S_S\frac{\partial h}{\partial t}$$

Where: x, y and z are coordinates aligned along the major axes of hydraulic conductivity K_{xx}, K_{yy}, K_{zz};

h is hydraulic head;

W represents the groundwater sources/sinks per unit volume;

S_S is specific storage of the porous material; and

t is time.

MODFLOW uses the finite difference method to solve the governing groundwater equation, where the continuity equation is applied (i.e. the sum of all inflows and outflows to a model cell is equal to the change of storage within that cell).

8.2. Numerical Model Construction

8.2.1. Flow Model Setup

The Site groundwater model X and Y extents were 21'510 m and 12'900 m, respectively, with a total average model thickness at the Site area of 100 m. The model was run using MODFLOW 2000/2005 and the governing groundwater equation solved using the Newton (MODFLOW-NWT) solver.

The model domain was vertically split into three (3) layers representative of the hydrogeological system at the Site, with the layer properties summarised in Table 8.1.

Table 8.1: Numerical Model Layer Properties

Layer	Description	Layer Type	Thickness (m)	Depth (m)
1	Weathered Zone	Semi-Confined	15	15
2	Fractured Rock Unit	Semi-Confined	50	65
3	Basement/Competent Rock Unit	Confined	35	100

Regional cell sizes of 50x50 m were applied, refined to 20x20 m at the Site area, as shown in Figure 8.1. Stress period durations were 360 days, based on the mining schedule provided, split into 30-day time steps.

8.2.2. Flow Model Boundaries

Numerical model boundaries for the Site were selected to represent natural barriers to groundwater flow, where possible, and to delineate a finite model domain for the simulations at the Site. Model boundaries were selected to incorporate both the proposed mining activities at the Site and the existing, historical mining activities located at the southern extent of the Site.

Perennial rivers were set as the northern, southern, eastern and western model boundaries, with limited sections at the northern model domain set as general head boundaries situated far away enough from the mining activities to not interact with the simulation results.

Figure 8.1 shows the numerical model boundaries.

8.2.3. Transport Model Boundaries

The transport model boundaries used in the simulations were the same as described for the flow model in Section 8.2.2 and presented in Figure 8.1.

8.2.4. Transport Model Setup

The transport model used the same layer configuration as the flow model (Section 8.2.1), with longitudinal dispersivity set as 50 m, 20 m and 10 m for layers 1, 2 and 3, respectively. The 3rd-Order TVD Scheme (ULTIMATE) advection package was used for the models, with contaminant sources represented by the recharge package (for rehabilitated pit areas and waste dumps) within MT3D-MS.

8.2.5. Initial Parameters

The initial hydrogeological parameters were assigned based on the available information for the Site and the surrounding areas. Table 8.2 summarises the initial parameters assigned to the model, as well as their applicable ranges based on the available information.

Table 8.2: Initial Model Parameters

Parameter	Description	Unit	Value	Lower Limit	Upper Limit
				Unit	Unit
Horizontal Hydraulic Conductivity	Weathered Zone	m/d	0.167	0.05	0.5
	Alluvial	m/d	0.333	0.1	2
	Vryheid	m/d	0.015	0.05	0.2
	Dolerite	m/d	0.002	0.0005	0.05
	Felsite	m/d	0.010	0.001	0.05
	Basement	m/d	0.001	0.0005	0.01
Vertical Anisotropy	All Layers	-	1.000	0.5	2
Effective Porosity	Weathered Zone	%	5.0%		
	Alluvial	%	10.0%		
	Vryheid	%	2.5%		
	Dolerite	%	1.0%		
	Felsite	%	2.0%		
	Basement	%	0.5%		
Recharge	Regional	%MAP	2%	1%	5%
Specific Storage	Weathered Zone	-	1.00E-04	1.00E-05	1.00E-03
	Alluvial	-	2.00E-03	2.00E-04	2.00E-02
	Vryheid	-	1.00E-06	1.00E-07	4.00E-06
	Dolerite	-	1.00E-07	1.00E-08	4.00E-07
	Felsite	-	1.50E-07	1.50E-08	6.00E-07
	Basement	-	1.00E-09	1.00E-10	4.00E-09
Longitudinal Dispersivity	Layer 1	m	50		
	Layer 2	m	20		
	Layer 3	m	10		

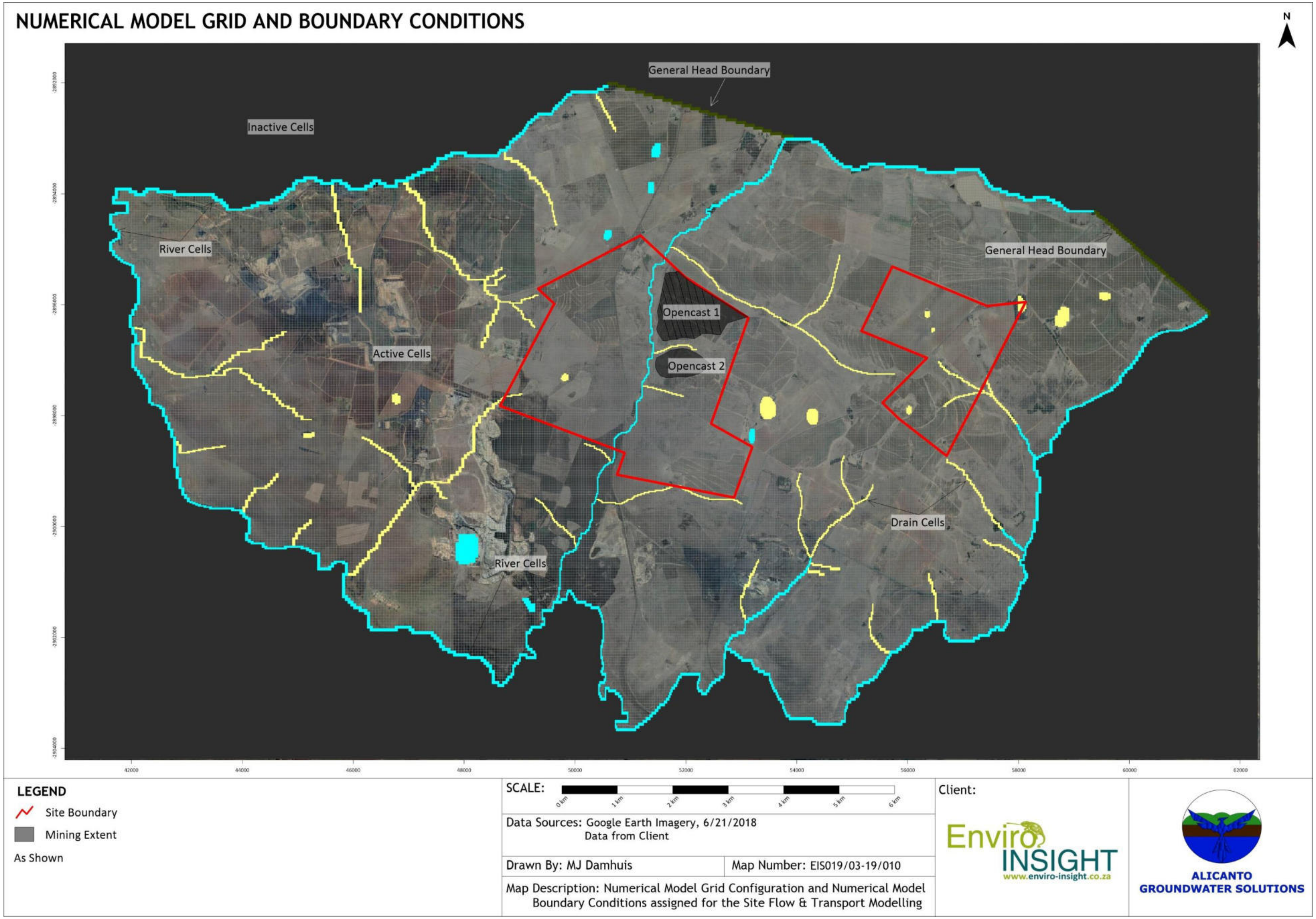

Figure 8.1: Numerical Model Grid and Boundary Conditions

8.3. Model Calibration

8.3.1. Steady State Flow Calibration

Steady state flow model calibration was completed using head observation data from the NGA (DWS, 2019a), Rison (2008) and GHT (2009) and a combination of manual and automated calibration methods.

The total head variance across the dataset was 87.07 m, setting a residual head criterion of 8.71 m (after Mandle, 2002). A final mean error (ME) and mean absolute error (MAE) of -1.69 and 4.10 m, respectively, was achieved. The final root mean square error (RMSE) was 5.36, which was lower than 10% of the dataset head variation (i.e. 8.71 m), thus the steady state model was considered calibrated. Table 8.3 presents a summary of steady state model calibration parameters.

Table 8.3: Steady State Model Calibration Results

Parameter	Value
Observed Head Variance (m)	87.07
Residual Head Criteria (m)	8.71
Mean Error (m)	-1.69
Mean Absolute Error (m)	4.10
Root Mean Square Error (m)	5.36

8.3.2. Transient State Flow Calibration

Transient state flow model calibration was completed using head observation collected during the project hydrocensus investigation and aquifer testing, using a combination of manual and automated calibration methods.

The total head variance across the dataset was 66.41 m, setting a residual head criterion of 6.64 m (after Mandle, 2002). A final mean error (ME) and mean absolute error (MAE) of 4.96 and 5.11 m, respectively, was achieved. The final root mean square error (RMSE) was 6.22, which was lower than 10% of the dataset head variation (i.e. 6.64 m), thus the transient state model was considered calibrated. Table 8.4 presents a summary of transient state model calibration parameters.

Table 8.4: Transient State Model Calibration Results

Parameter	Value
Observed Head Variance (m)	66.41
Residual Head Criteria (m)	6.64
Mean Error (m)	4.96
Mean Absolute Error (m)	5.11
Root Mean Square Error (m)	6.22

8.3.3. Transport Model Calibration

Due to the limited data available for the Site region in terms of groundwater time series water quality and source characteristics (i.e. surrounding mine operations and waste infrastructure), transport model calibration was not possible.

8.3.4. Sensitivity Analysis

A sensitivity analysis was completed for the base case numerical model, where the following parameters were modified by factors of 0.1, 0.25, 0.5, 2.5, 5 and 10 and the effect on the RMSE noted:

- Regional hydraulic conductivity;
- Regional recharge; and
- Specific storage.

Recharge and hydraulic conductivity both showed slight sensitivity when decreased with recharge showing the highest sensitivity when increased and hydraulic conductivity showing a high sensitivity when increased by one order of magnitude. Specific storage showed little sensitivity when adjusted. Figure 8.2 presents the sensitivity analysis results.

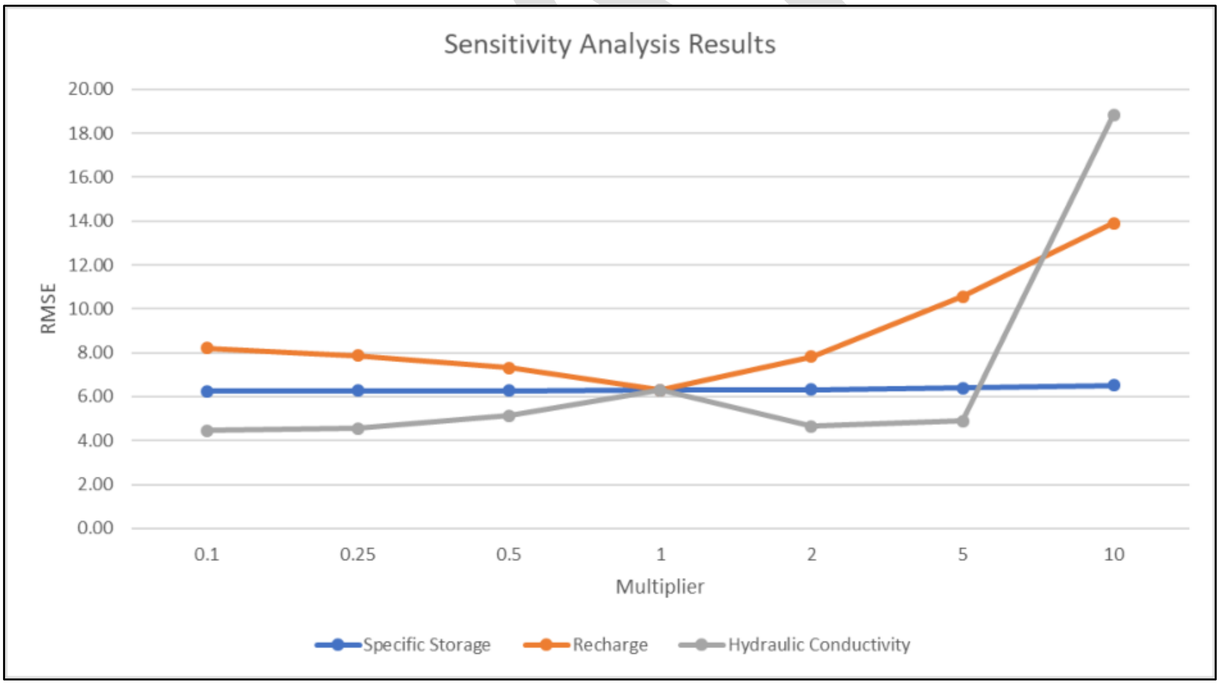

Figure 8.2: Sensitivity Analysis Results

8.4. Model Assumptions & Limitations

The following assumptions and limitations are applicable to the Site groundwater model:

- Model hydraulic parameters were based on literature values, previous investigations completed within the Site region and Site-specific aquifer testing and were assumed to be representative of Site conditions;
- Recharge to groundwater was assumed to be equally distributed across the model domain;
- Geochemistry testing results available for the Site, combined with literature geochemistry results, were assumed to be valid and representative of the Site conditions;
- Worst case scenario contaminant source concentrations were taken from Mokoena (2012) with concentrations at the backfill material and the Site stockpile areas, dumps and the PCD assigned as 670 mg/l and 300 mg/l, respectively;
- A numerical model does not provide a unique solution. Therefore, numerical modelling will always have inaccuracies due to the uncertainty in data, the capabilities/limitations of numerical modelling code to describe the natural processes and the factors selected by the modeller to resolve the non-unique solution;
- The complexities of fractured rock aquifers imply that the model can only be used as a guide to determine the order of magnitude of dewatering and contaminant transport; and
- The interpretation of modelled results should be based on the assumptions the model was built on and actual results will vary as unknown aquifer conditions and parameters vary in the natural system.

8.5. Predictive Scenario Modelling

The calibrated transient state flow and transport models were used to simulate various scenarios at the Site in order to determine the potential impacts on the receiving groundwater environment in terms of both quantity and quality changes. The scenarios that were run using the numerical model were:

- **Base Case Scenario**, where mining took place as per the mining schedule described in Section 4.4 with concurrent rehabilitation taking place and the Site PCD and stockpile areas were unlined;
- **Scenario 1**, where mining took place as per the mining schedule described in Section 4.4 with no concurrent rehabilitation taking place and the Site PCD, waste dumps and stockpile areas were unlined;
- **Scenario 2**, where the mining sequence at Opencast 1 was changed to allow for mining to progress from east to west (i.e. the opposite sequence to that presented in Section 4.4), with concurrent rehabilitation taking place and the Site PCD, waste dumps and stockpile areas were unlined;

- **Scenario 3**, where mining took place as per the Base Case Scenario, however, the Site PCD and stockpile areas were lined using clay material which reduced the seepage from the infrastructure to 0.5% of MAP;
- **Scenario 4**, where mining took place as per Scenario 2, however, the Site PCD and stockpile areas were lined using clay material which reduced the seepage from the infrastructure to 0.5% of MAP;
- **Scenario 5**, where mining takes place as per the Base Case Scenario, with a grout curtain installed at the western extent of the Opencast 1 area; and
- **Scenario 6**, where mining takes place as per Scenario 2, with a grout curtain installed at the western extent of the Opencast 1 area.

9. Hydrogeological Impact Assessment

The life of mine (LoM) is comprised of five (5) distinct, sometimes overlapping, phases, each with their own unique set of potential impacts on the receiving groundwater environment. The phases of the LoM are:

1. **Exploration Phase**, where exploratory drilling is completed at the Site in order to delineate and quantify the mineral resources at the Site and complete feasibility and design studies for the proposed mining operation;
2. **Construction Phase**, where the required infrastructure (such as offices, processing plant(s), pollution control dam, fuel storage tanks etc.) are installed at the Site and preliminary preparations completed at the proposed mining area;
3. **Operational Phase**, where the resource of interest is extracted at the Site using either opencast or underground mining methods and processed for economic beneficiation and sold to market;
4. **Closure Phase**, where rehabilitation of the mining area is started and installed infrastructure at the Site broken down and removed from the Site; and
5. **Post-Closure Phase**, following the completion of rehabilitation activities at the Site and the removal of operational equipment from Site, the rehabilitated mining environment is allowed to return to near-natural conditions with regular environmental monitoring taking place at the Site.

The Site is currently in the exploration phase of the LoM, entering the construction and operational phases of the LoM in the near future. Thus, the hydrogeological impact assessment for the Site considered the construction, operational, closure and post-closure phases of the LoM.

9.1. Construction Phase Impacts

During the construction phase at the Site, the activities would include the removal of vegetation and compaction of soil. The potential impacts on the receiving groundwater environment during the construction phase include localized groundwater dewatering (if groundwater is used to supply construction activities), contamination from hydrocarbon spills (if any) and domestic waste from the onsite barracks, contractors and staff.

Should groundwater be used to supply the construction activities (e.g. drinking water or dust suppression), localized dewatering at the borehole(s) could occur. This would be a low impact both before and after management measures are put in place due to the localized extent of dewatering and the short duration of the impact. Borehole abstraction (if any) should be managed effectively and borehole water levels and abstraction volumes from the borehole should be recorded at regular intervals, ideally monthly.

The clearing of vegetation and topsoil, as well as compaction of soil, may result in increased runoff at the Site and decreased recharge to groundwater, which is a low impact prior to management measures being put in place. The areas to be cleared and compacted should be minimised and done according to best practices, which will maintain a low impact rating.

Hydrocarbon spills from construction vehicles and/or fuel storage areas could result in localised groundwater contamination, which is a medium impact on the receiving environment. In order to manage these impacts all staff and supervisors at workshops, yellow metal laydown areas and fuel storage areas should be trained in hydrocarbon spill response and each of these areas should be equipped with the appropriate spill response kits and any contaminated soil must be disposed of correctly at a suitable location. Should these management measures be put in place the impact on the receiving environment would be reduced to a low impact.

Domestic waste will be generated by contractors and staff. This would be a low impact both before and after management measures are put in place. Domestic waste should be disposed of at a dedicated, suitable landfill site and managed according to the applicable legislation and Standard Operating Procedures (SOP's) of the mine.

The construction phase impacts on groundwater quantity and quality with no mitigation and/or management measures in place are presented in Table 9.1, with Table 9.2 presenting the impacts on the groundwater environment following the implementation of management and/or mitigation measures.

Table 9.1: Groundwater Impacts during Construction Phase (before Management/Mitigation)

Description of Activity	Impact Description	M	S	D	P	Risk	
Groundwater Quantity							
Vegetation Clearing	Clearing of vegetation and topsoil may result in increased runoff and reduced recharge to the groundwater system.	2	5	1	3	24	Low
Groundwater Dewatering	Groundwater abstraction at the Site borehole may result in localised dewatering.	2	2	1	2	10	Low
Groundwater Quality							
Hydrocarbon Spills	Hydrocarbon spills from construction vehicles and/or laydown areas and workshops may enter the groundwater system.	6	2	1	4	36	Medium
Domestic Waste Generation	During construction domestic waste will be generated by contractors and staff.	2	2	3	4	28	Low

Table 9.2: Groundwater Impacts during Construction Phase (after Management/Mitigation)

Description of Activity	Mitigation/Management Measures	M	S	D	P	Risk	
Groundwater Quantity							
Vegetation Clearing	Areas to be cleared should be limited as far as possible.	2	5	1	3	24	Low
Groundwater Dewatering	Water levels and abstraction volumes should be monitored and recorded. Borehole pump schedules should always be adhered to and water reclaimed within the system where possible to reduce usage.	2	2	1	1	5	Low
Groundwater Quality							
Hydrocarbon Spills	Workshop and Laydown areas should be properly compacted and bunded. Appropriate spill kits should always be available and contaminated soil should be removed as soon as possible and disposed of at an accredited facility.	2	2	1	2	10	Low
Domestic Waste Generation	Domestic waste should be disposed of at a dedicated, suitable landfill site and managed appropriately.	2	1	3	2	12	Low

9.2. Operational Phase Impacts

9.2.1. Groundwater Quantity Impacts

During mining operations at the Site groundwater is likely to flow into the opencast mining areas at both Opencast 1 and Opencast 2. The simulated inflows at the Opencast 1 area for the Base Case and model Scenarios 2, 3 and 4 was ~350 m^3/day, with the average simulated inflows for Scenarios 5 and 6 (i.e. where a grout curtain is installed at the western pit boundary) was ~260 m^3/day. Where the base case mining schedule is followed (i.e. Base Case, Scenario 1, Scenario 3), initial simulated pit inflows at Opencast 1 were between 400 and 500 m^3/day up to year 7, where inflows decreased to ~250 m^3/day. For model scenarios 2 and 4, where mining at Opencast 1 proceeded east to west, inflows were initially 200-300 m^3/day, increasing to ~550 m^3/day as mining approached the perennial river west of the Site. Simulated inflows for Opencast 1 for Scenarios 5 and 6 (i.e. where a grout curtain is installed ahead of mining at the western boundary of Opencast 1) were consistently between 200 and 300 m^3/day throughout the LoM at Opencast 1. Model Scenario 1 showed an average simulated inflow value of ~900 m^3/day for Opencast 1, increasing steadily over the LoM which was most likely due to the cumulative effect of groundwater inflows over the entire mining area.

Simulated inflows to Opencast 2 were ~600-650 m^3/day for all model scenarios. The simulated daily inflows per model scenario over the LoM are shown in Figure 9.1.

Figure 9.1: Simulated Inflows to Opencast 1 and Opencast 2 during the Operational Phase

The simulated drawdown extent for Opencast 1 extended ~250 m from the pit boundary for all of the model scenarios, except for model Scenario 1 where the drawdown extent reached a maximum of 300-350 m at the end of LoM. Where concurrent rehabilitation took place at the Site, drawdown was limited to the surroundings of the active mining cut and rehabilitated cuts showed recovery of water levels within 2 years after rehabilitation. The simulated drawdown extent at Opencast 2 extended ~200-250 m from the pit boundary, reaching a maximum of ~400 m at the south eastern pit extent, for all of the model scenarios.

Sensitive receptors near to the Opencast 1 and Opencast 2 areas were various wetlands at the Site and the privately-owned borehole DBR01 (west of Opencast 2). None of the simulated drawdown extents interacted with borehole DBR01, however, the simulated drawdown extent for the Base Case model scenario and Scenarios 2, 3 and 4 showed a short-term (<3 years, then groundwater levels rebounded) lowering of groundwater levels by 3-5 m at the wetland areas north, south and west of Opencast 1, as well as major lowering of water levels at the wetland north of Opencast 2 (>20 m drawdown) and an extended drawdown extent south east of the Opencast 2 pit. The impact from these model scenarios prior to management measures being implemented was medium, as shown in Table 9.3.

Model Scenario 1 showed continuous interaction with the wetland areas surrounding Opencast 1 and Opencast 2 during the LoM, which resulted in the assignment of a high impact rating (Table 9.3) prior to management measures. Scenarios 5 and 6 showed interaction with the wetland west of Opencast 1 was negligible due to the installed grout curtain, with interactions with the northern and southern wetland areas also reduced during the LoM. Water levels at the wetland north of Opencast 2 showed >20 m drawdown during mining and an extended drawdown extent simulated south east of the Opencast 2 pit. Due to the reduced interaction with the wetlands at Opencast 1 the impact from these model scenarios prior to management measures being implemented was low, as shown in Table 9.3.

The simulated drawdown extents for the Base Case Scenario and Scenarios 1, 2, 3, 4, 5 and 6 are shown in Figure 9.2, Figure 9.3, Figure 9.4, Figure 9.5, Figure 9.6, Figure 9.7 and Figure 9.8, respectively.

Table 9.3: Groundwater Quantity Impacts - Operational Phase (prior to Management/Mitigation)

Description of Activity	Model Scenario	Impact Description	M	S	D	P	Risk	
Groundwater Quantity								
Groundwater Dewatering	Base Case Scenario	Groundwater inflows to the active mining area may result in dewatering of the surrounding aquifer system(s).	4	3	2	4	36	Medium
	Scenario 1		8	3	4	5	75	High
	Scenario 2		4	3	2	4	36	Medium
	Scenario 3		4	3	2	4	36	Medium
	Scenario 4		4	3	2	4	36	Medium
	Scenario 5		2	2	2	3	18	Low
	Scenario 6		2	2	2	3	18	Low

In order to limit the extent of dewatering due to pit inflows at the Site, water levels should be taken quarterly at monitoring boreholes around the Site. Should any impact be observed in privately owned boreholes the owner shall be suitably compensated and an alternative water supply provided by the mine during operations. Following the implementation of these management measures the impact rating for model Scenario 1 was medium and the remaining model scenarios were low, as shown in Table 9.4.

Table 9.4: Groundwater Quantity Impacts - Operational Phase (after Management/Mitigation)

Description of Activity	Mitigation/Management Measures	M	S	D	P	Risk	
Groundwater Quantity							
Groundwater Dewatering	No Mitigation Possible. Groundwater levels at the Site and surroundings should be monitored on a quarterly basis in order to determine any negative trends that may occur due to dewatering of the mining area. Should mining activities negatively impact any surrounding groundwater users, the mine should compensate the affected parties accordingly and provide alternative water supply for the duration of mining operations.	4	2	2	3	24	Low
		6	3	4	4	52	Medium
		3	2	2	3	21	Low
		4	2	2	3	24	Low
		3	2	2	3	21	Low
		2	2	2	3	18	Low
		2	2	2	3	18	Low

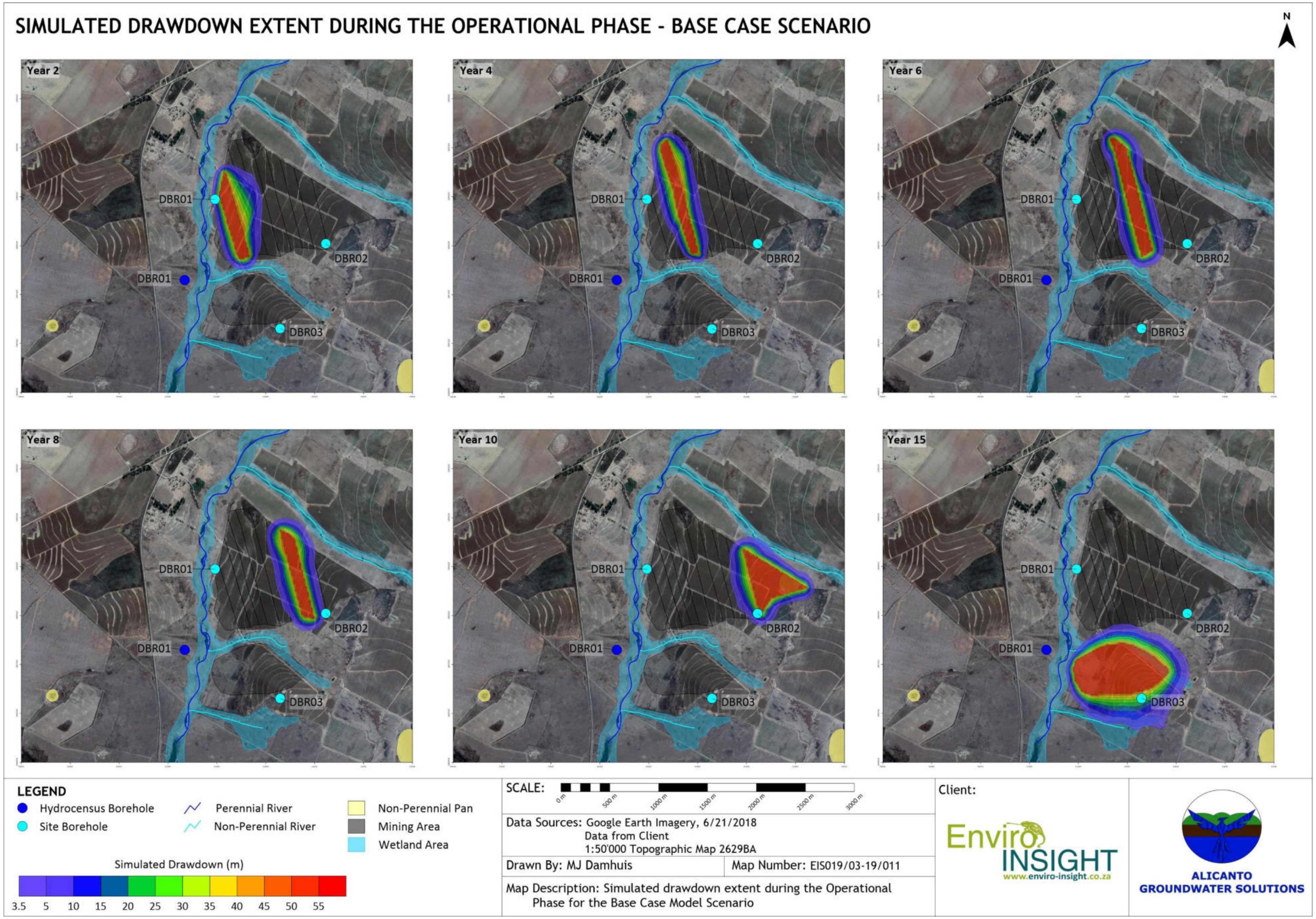

Figure 9.2: Simulated Drawdown Extent (Operational Phase) - Base Case Scenario

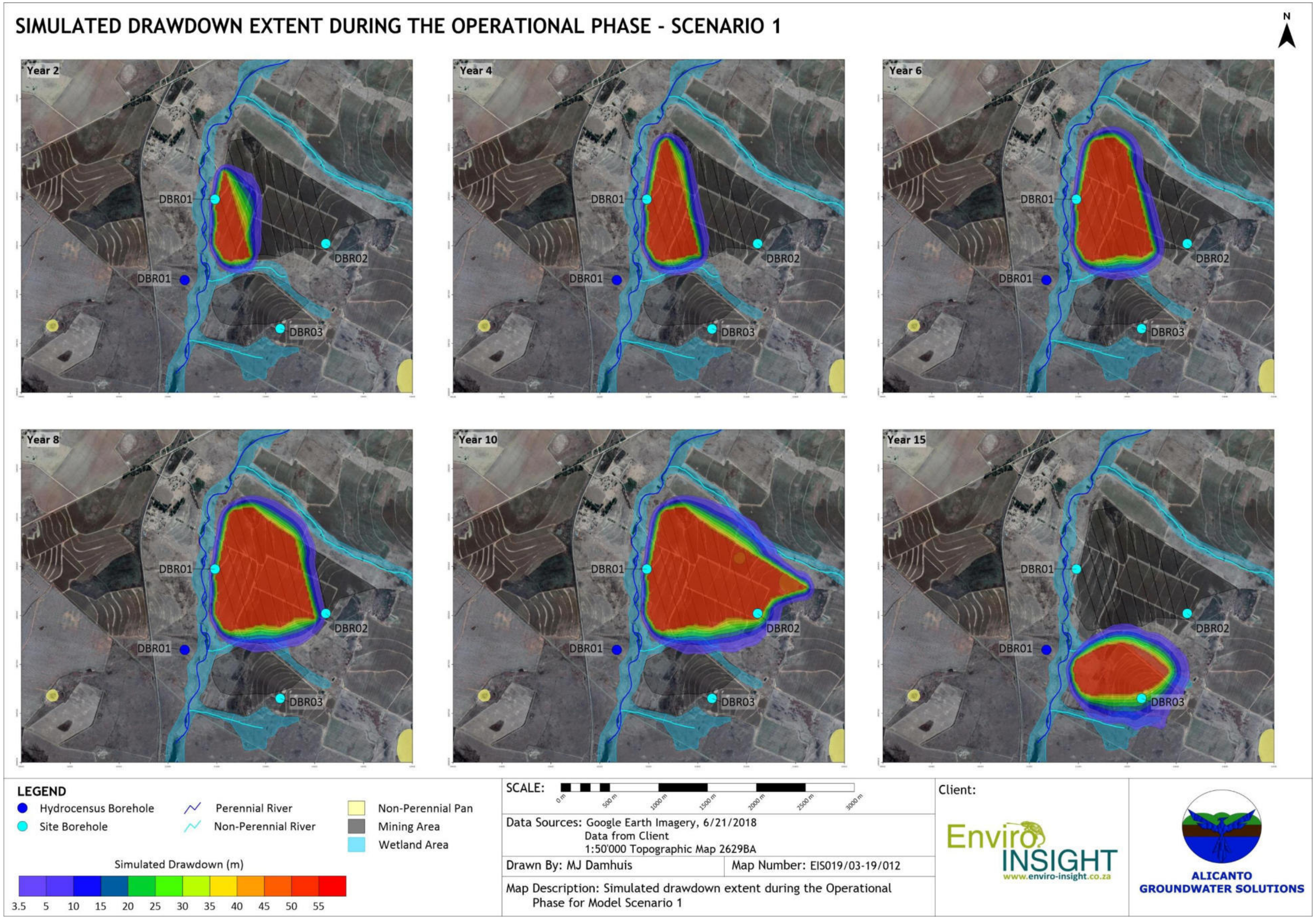

Figure 9.3: Simulated Drawdown Extent (Operational Phase) - Scenario 1

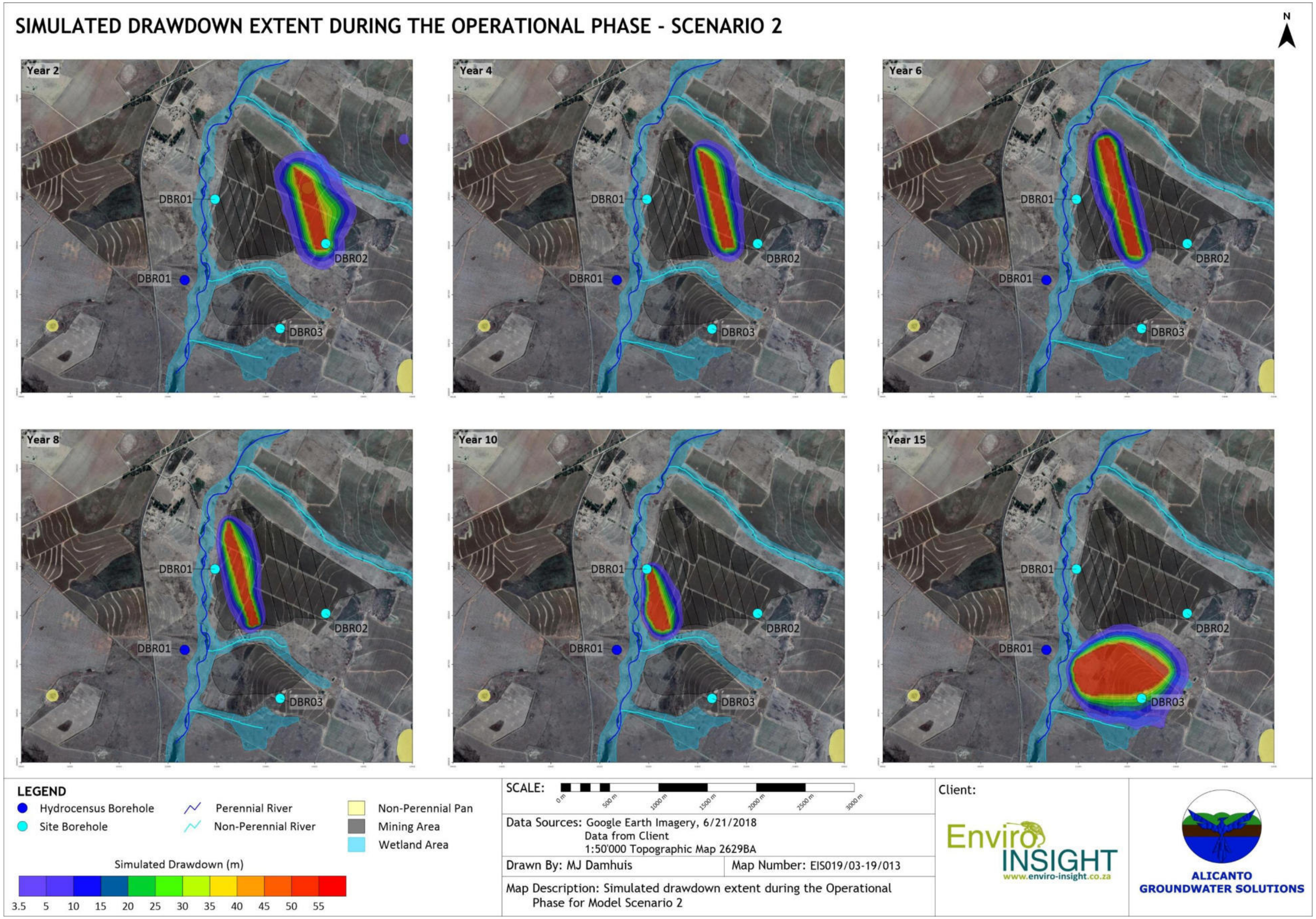

Figure 9.4: Simulated Drawdown Extent (Operational Phase) - Scenario 2

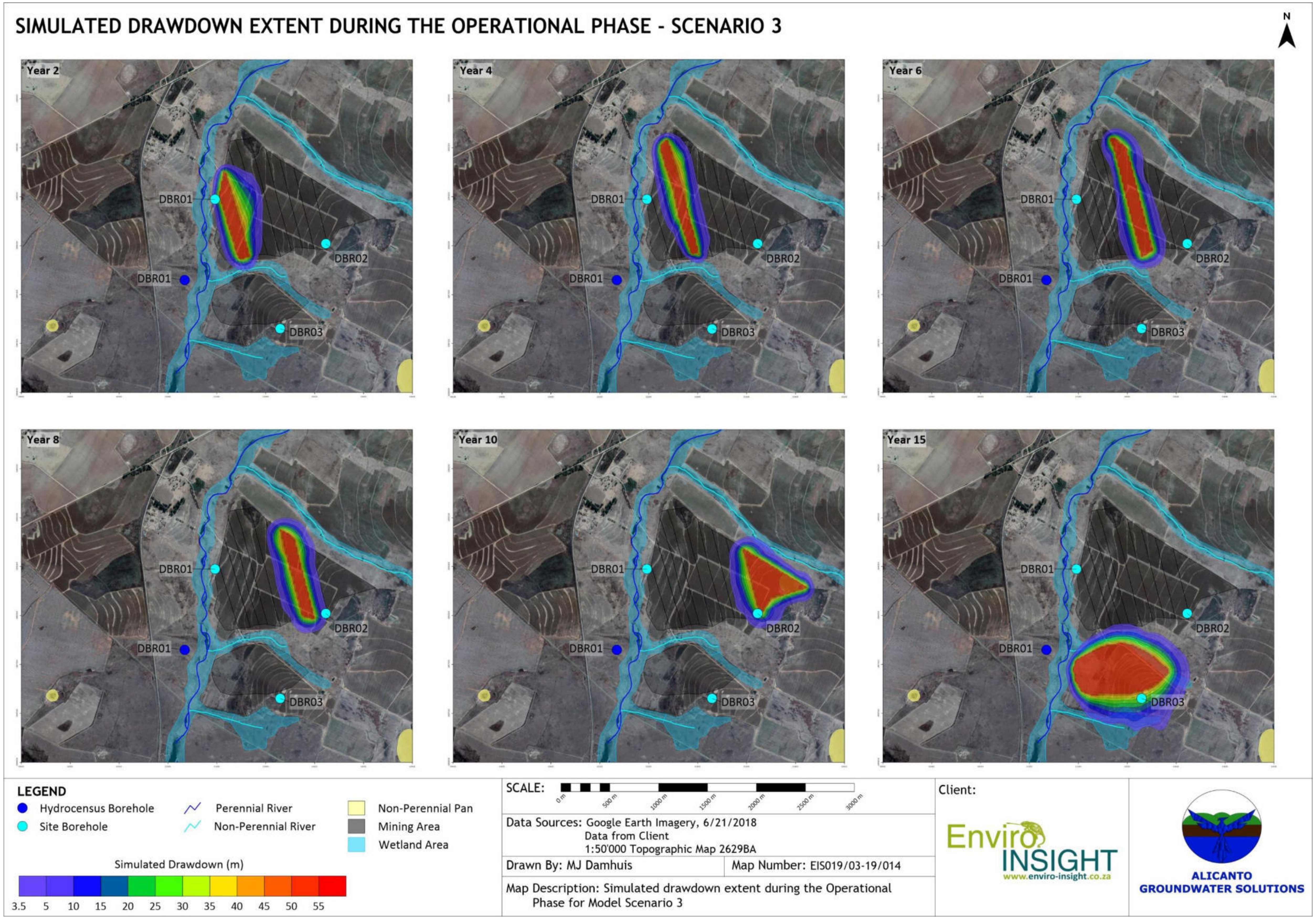

Figure 9.5: Simulated Drawdown Extent (Operational Phase) - Scenario 3

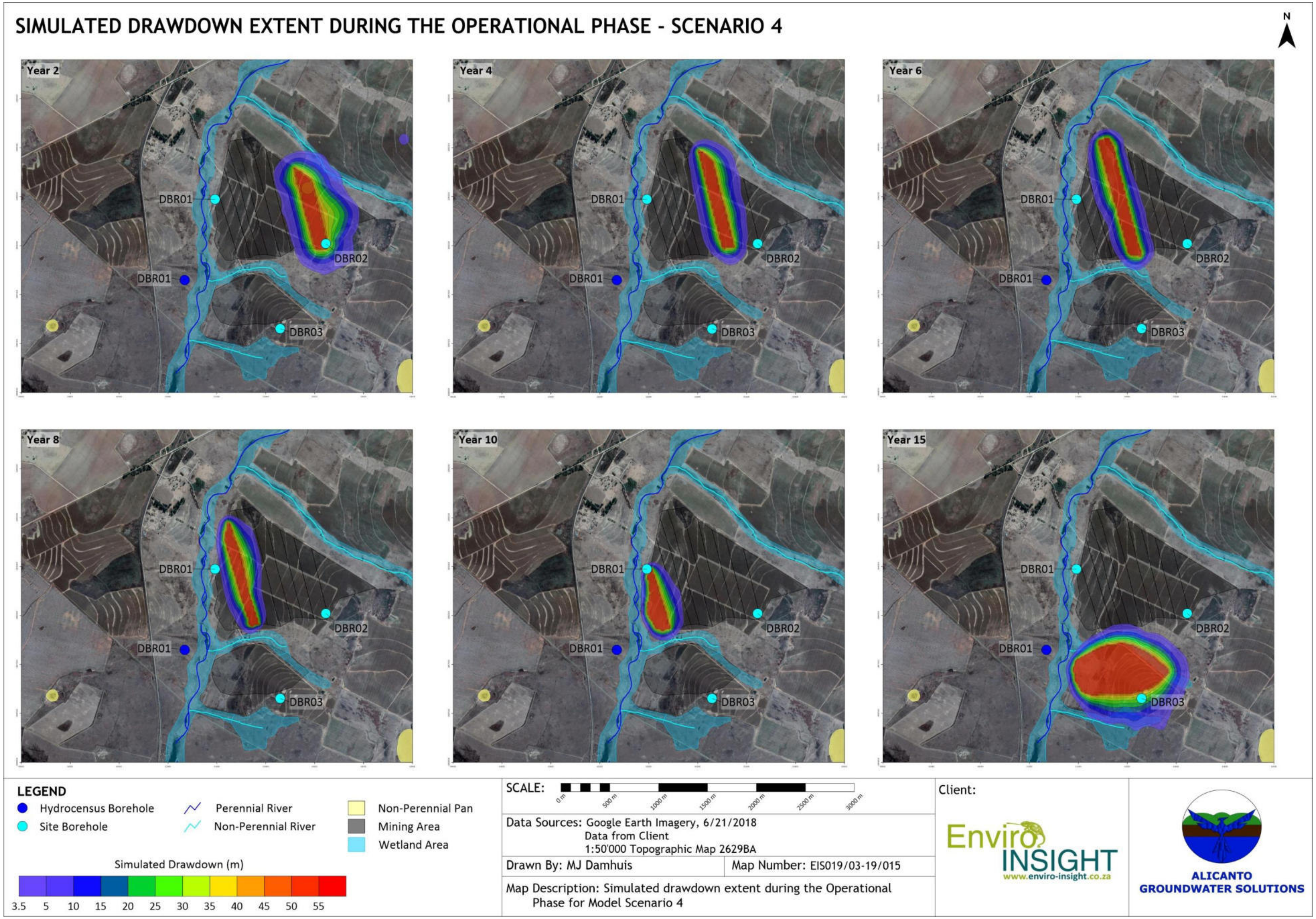

Figure 9.6: Simulated Drawdown Extent (Operational Phase) - Scenario 4

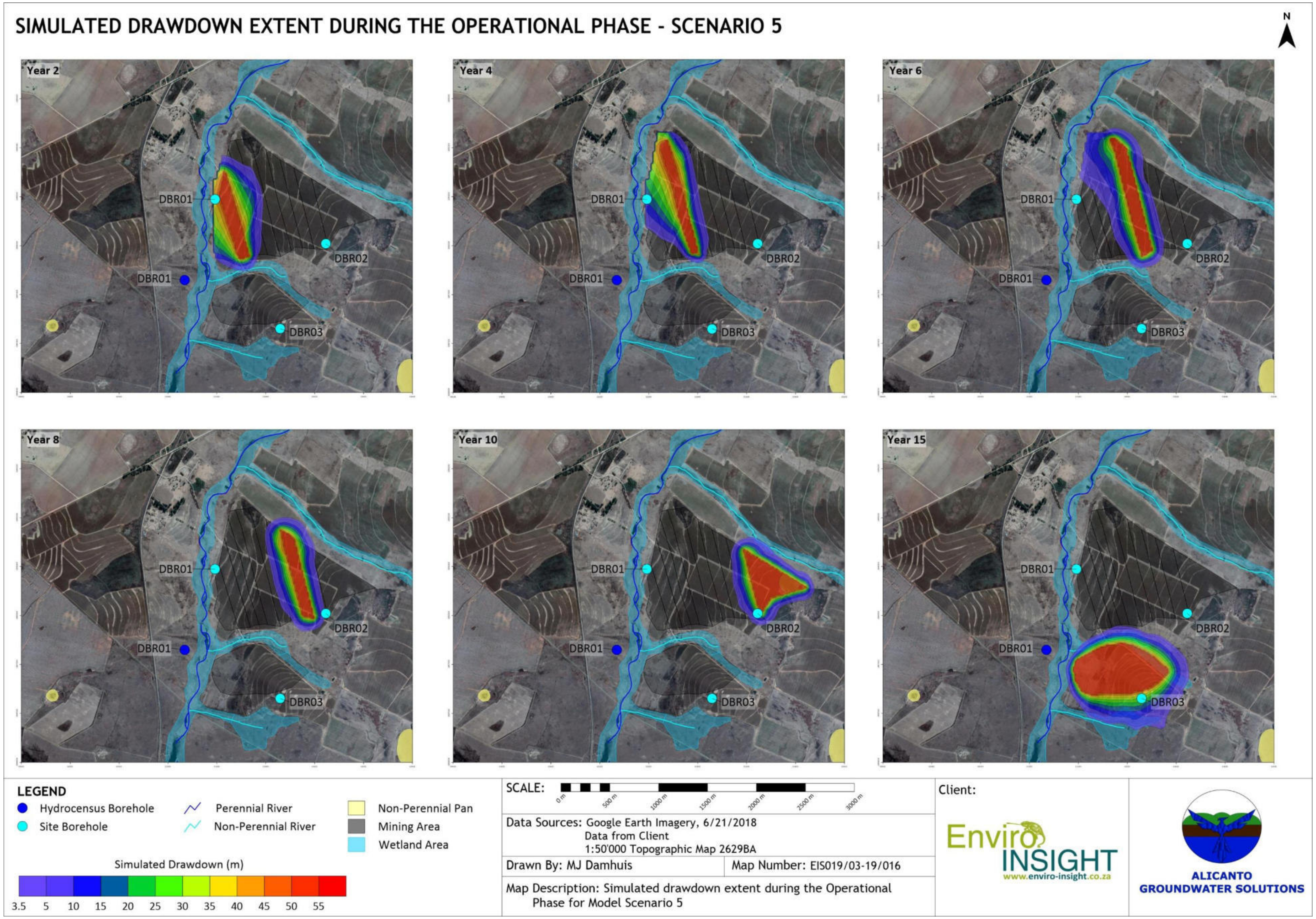

Figure 9.7: Simulated Drawdown Extent (Operational Phase) - Scenario 5

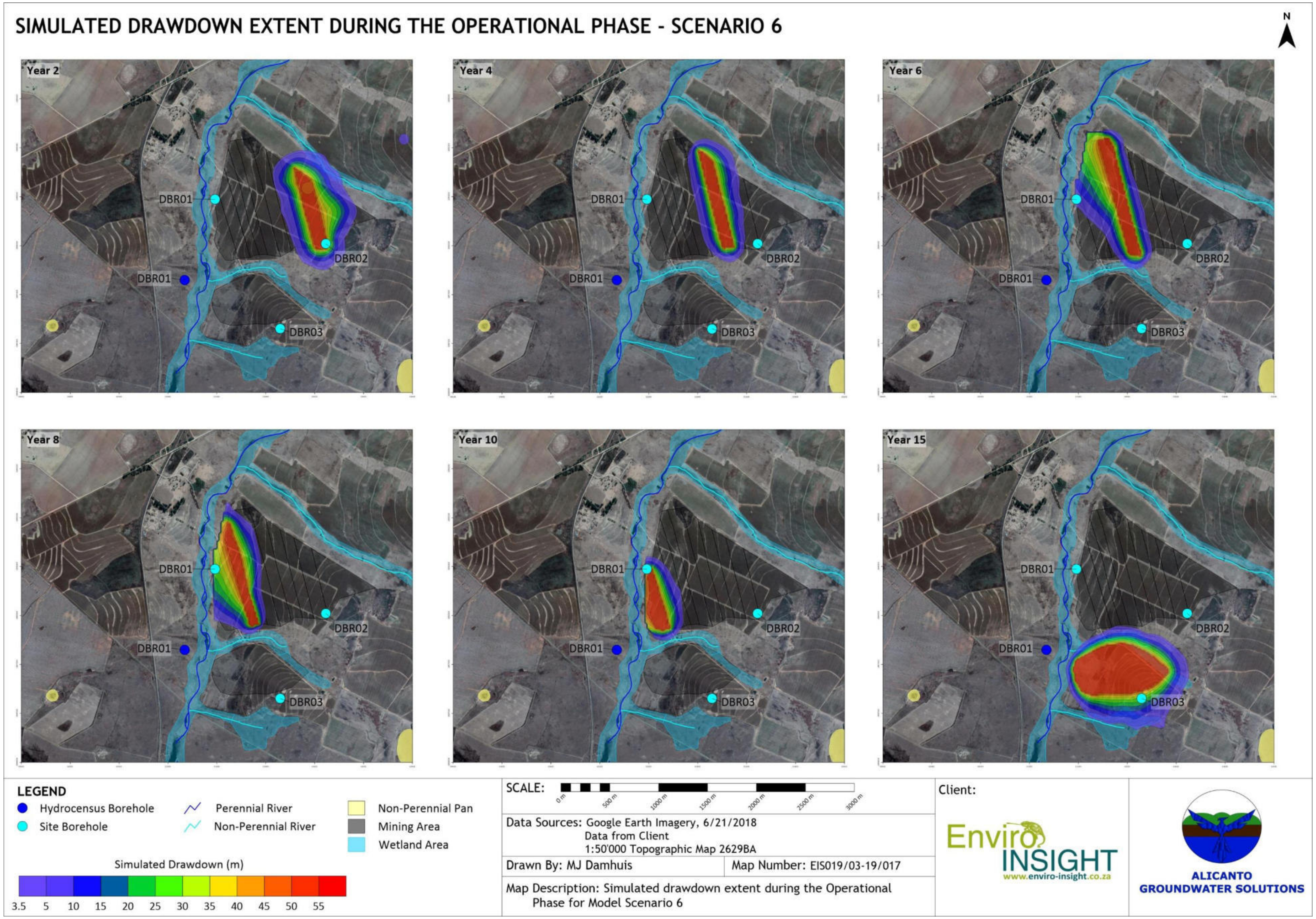

Figure 9.8: Simulated Drawdown Extent (Operational Phase) - Scenario 6

9.2.2. Groundwater Quality Impacts

The potential impacts on groundwater quality during the operational phase were potential poor-quality water leaching into the groundwater environment from the Site waste rock dumps and PCD, as well as poor quality groundwater emanating from the backfill material used during backfilling of the pits. The impact of seepage at the PCD was low, with the simulated contaminant plume showing concentrations of less than 50-75 mg/l. The simulated contaminant plume emanating from the waste rock dump and coal stockpile areas at the Site was captured by the drawdown cone at the Site and thus contributed little to the overall contaminant plume at the Site. The impact rating for the PCD, stockpile areas and waste rock dump was low, as shown in Table 9.5.

Simulated contaminant plumes from the rehabilitated opencast areas for all model scenarios (except Scenario 1 where no backfilling took place during the operational phase) was localised to within the mining extents and simulated concentrations did not exceed ~300-400 mg/l. During mining at Opencast 2, the simulated plume interacted with the wetland area south of Opencast 1, with concentrations at the wetland being ~250-350 mg/l. A medium impact rating was assigned due to the high probability of the impact occurring and interaction with the wetland area south of Opencast 1, despite the limited extent of the contaminant plume (Table 9.5).

The simulated contaminant plume extents for the Base Case Scenario and Scenarios 2, 3, 4, 5 and 6 are shown in Figure 9.9, Figure 9.10, Figure 9.11, Figure 9.12, Figure 9.13 and Figure 9.14, respectively.

Table 9.5: Groundwater Quality Impacts - Operational Phase (prior to Management/Mitigation)

Groundwater Quality								
Backfill Material Leachate	All Model Scenarios	Poor quality leachate generated within the backfill material used at the Site during concurrent rehabilitation may enter the groundwater system.	6	1	4	4	44	Medium
Poor Quality Seepage from the PCD	All Model Scenarios	Poor quality water stored at the Site PCD may seep into the groundwater system at the Site.	4	1	4	2	18	Low
Waste Rock/Coal Stockpile Leachate	All Model Scenarios	Poor quality leachate from the Site waste rock dump and coal stockpile areas may enter the groundwater system.	4	1	4	3	27	Low

A clay liner should be installed at the PCD, with the liner always inspected for any leakages and the free bord maintained during the LoM to prevent overflow. Water quality sampling should be done regularly at the PCD during the LoM. With these management measures in place the impact rating remained low (Table 9.6).

Carbonaceous material reporting to the waste rock dump areas should be covered where possible to prevent oxidation and the dumps contoured (where possible) to promote runoff and limit infiltration to the materials.

Material at the coal stockpiles should have limited standing time and surface water management at the stockpile should be maintained to promote runoff and limit standing water at the areas. Groundwater monitoring boreholes near to the dump and stockpile areas need to be regularly sampled. With these management measures in place the impact rating remained low (Table 9.6).

Sulphide-bearing material used during concurrent rehabilitation should be placed at the base of the backfilling and covered with neutral material as soon as possible, with a 200 mm clay layer placed on top of the backfill to prevent washout of material. Following the implementation of these management measures the impact rating was low (Table 9.6).

Table 9.6: Groundwater Quality Impacts - Operational Phase (after Management/Mitigation)

Groundwater Quality							
Backfill Material Leachate	Sulphide-bearing material should be placed at the base of the backfilling and covered as soon as possible with more neutral material to prevent oxidation. A 200 mm clay layer should be placed on top of the backfill material to limit water ingress.	4	1	4	3	27	Low
Poor Quality Seepage from the PCD	The liner at the PCD should be maintained and regularly inspected for any tears and/or leakage. The freebord at the PCD should be maintained at all times to avoid overflow and water quality sampling should be taken regularly at the PCD.	2	1	4	2	14	Low
Waste Rock/Coal Stockpile Leachate	Carbonaceous material stored at the waste rock dumps should be covered where possible to limit the oxidation of sulphide-bearing materials, with the dumps contoured, where possible, to encourage runoff. Material stored at the coal stockpiles should be removed as soon as possible to prevent oxidation of the material and sufficient surface water management infrastructure put in place to limit standing water at the stockpiles. Groundwater monitoring boreholes should be installed at the dump and stockpile areas and water quality samples taken regularly.	2	1	4	2	14	Low

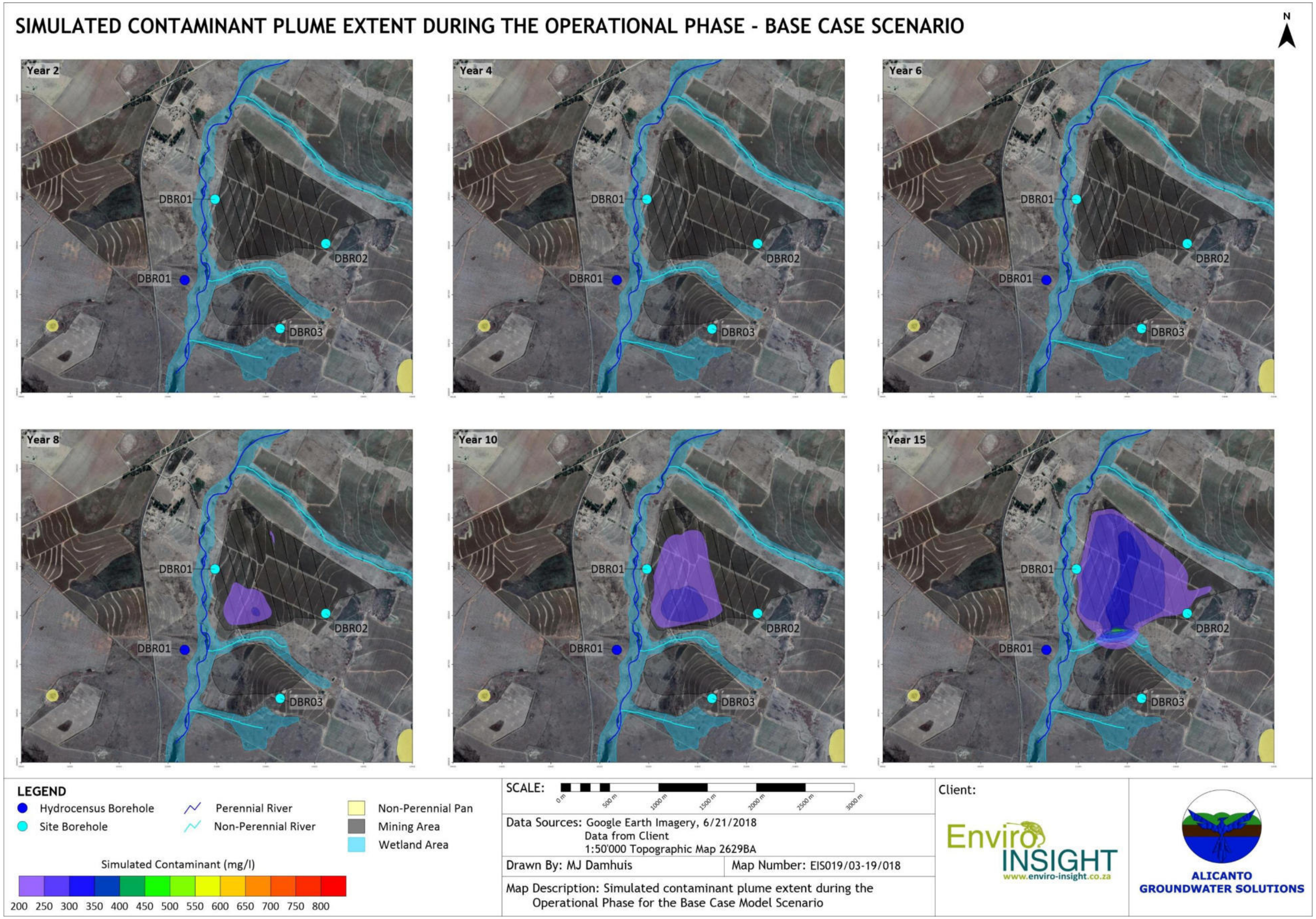

Figure 9.9: Simulated Contaminant Plume Extent (Operational Phase) - Base Case Scenario

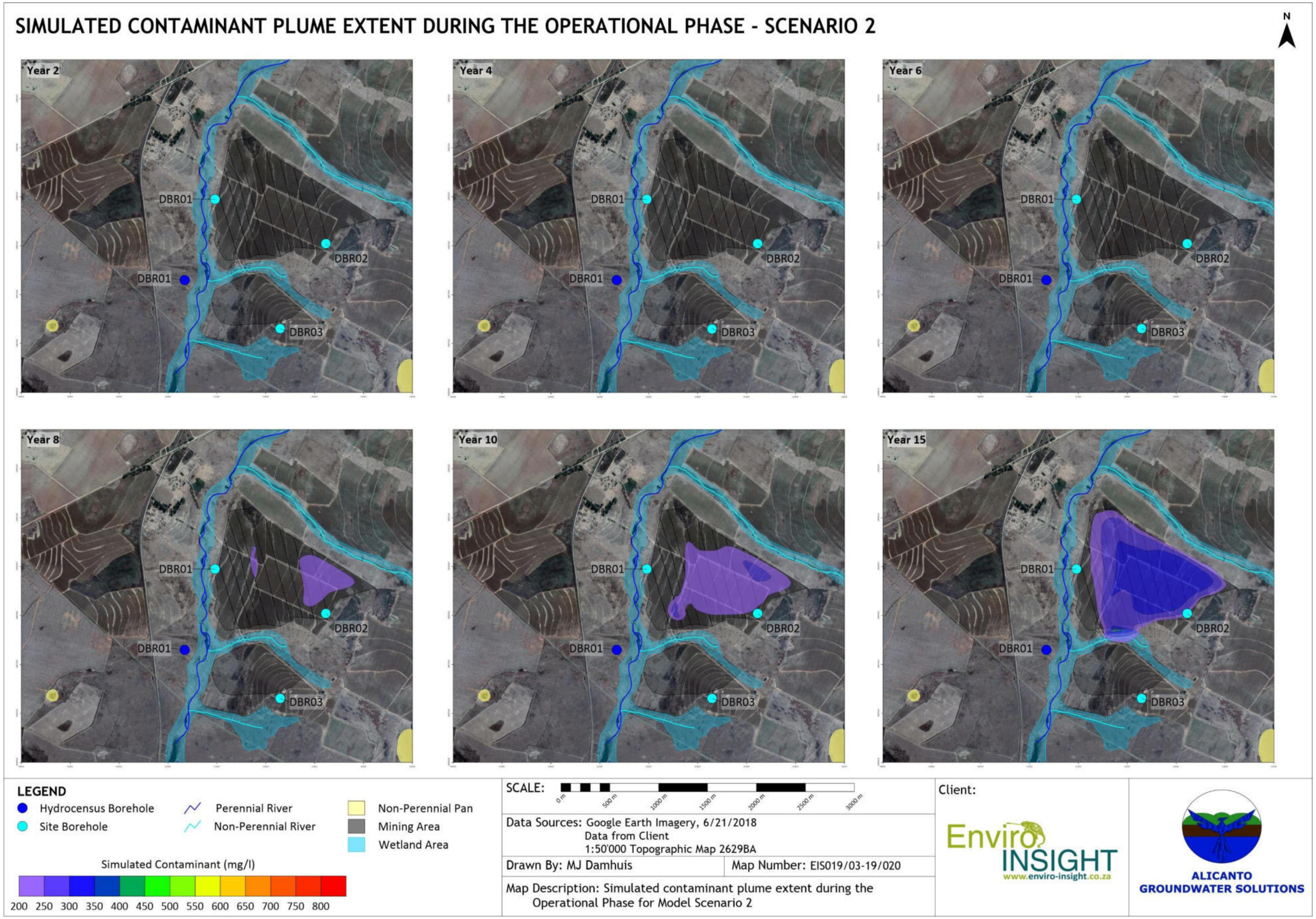

Figure 9.10: Simulated Contaminant Plume Extent (Operational Phase) - Scenario 2

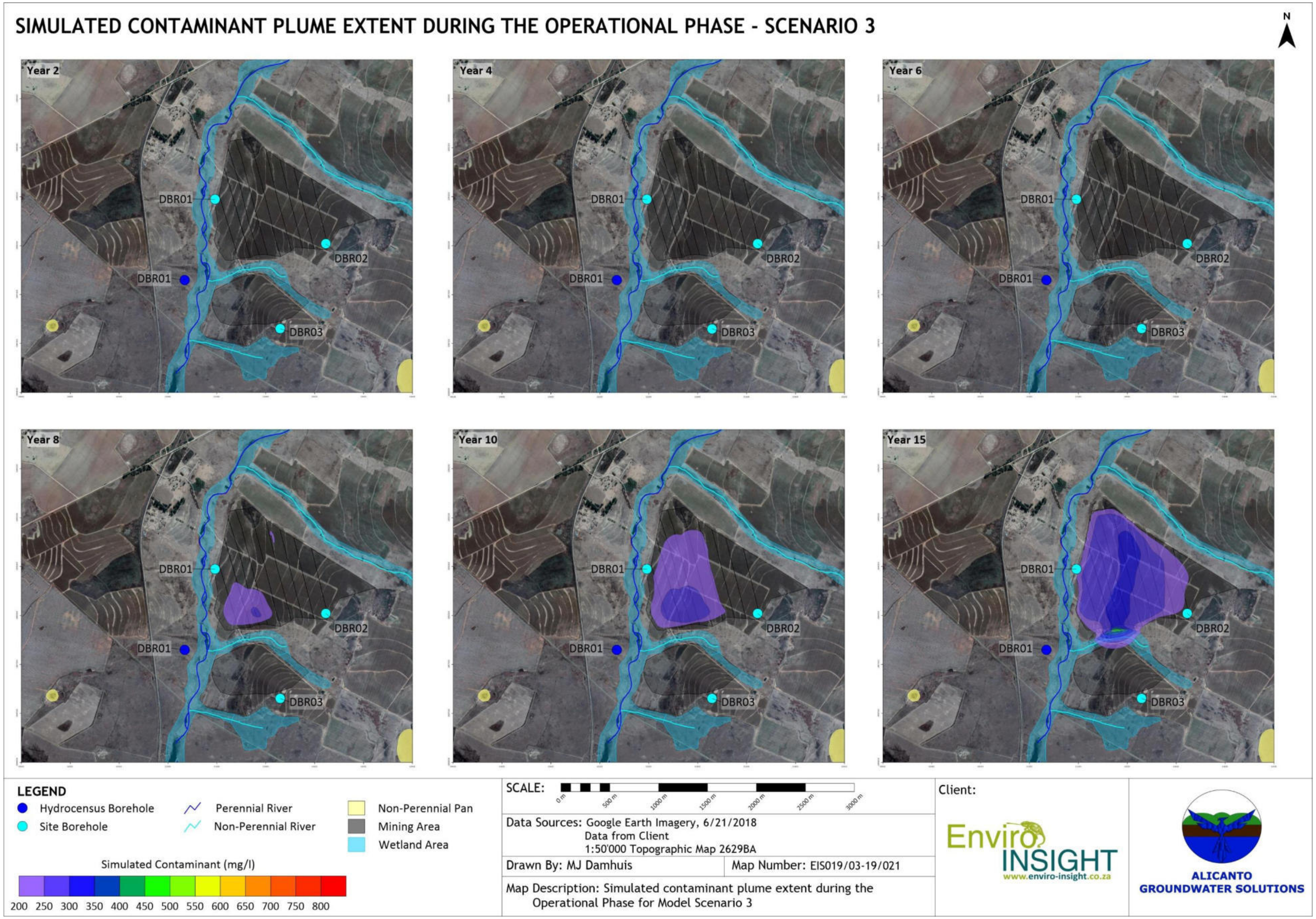

Figure 9.11: Simulated Contaminant Plume Extent (Operational Phase) - Scenario 3

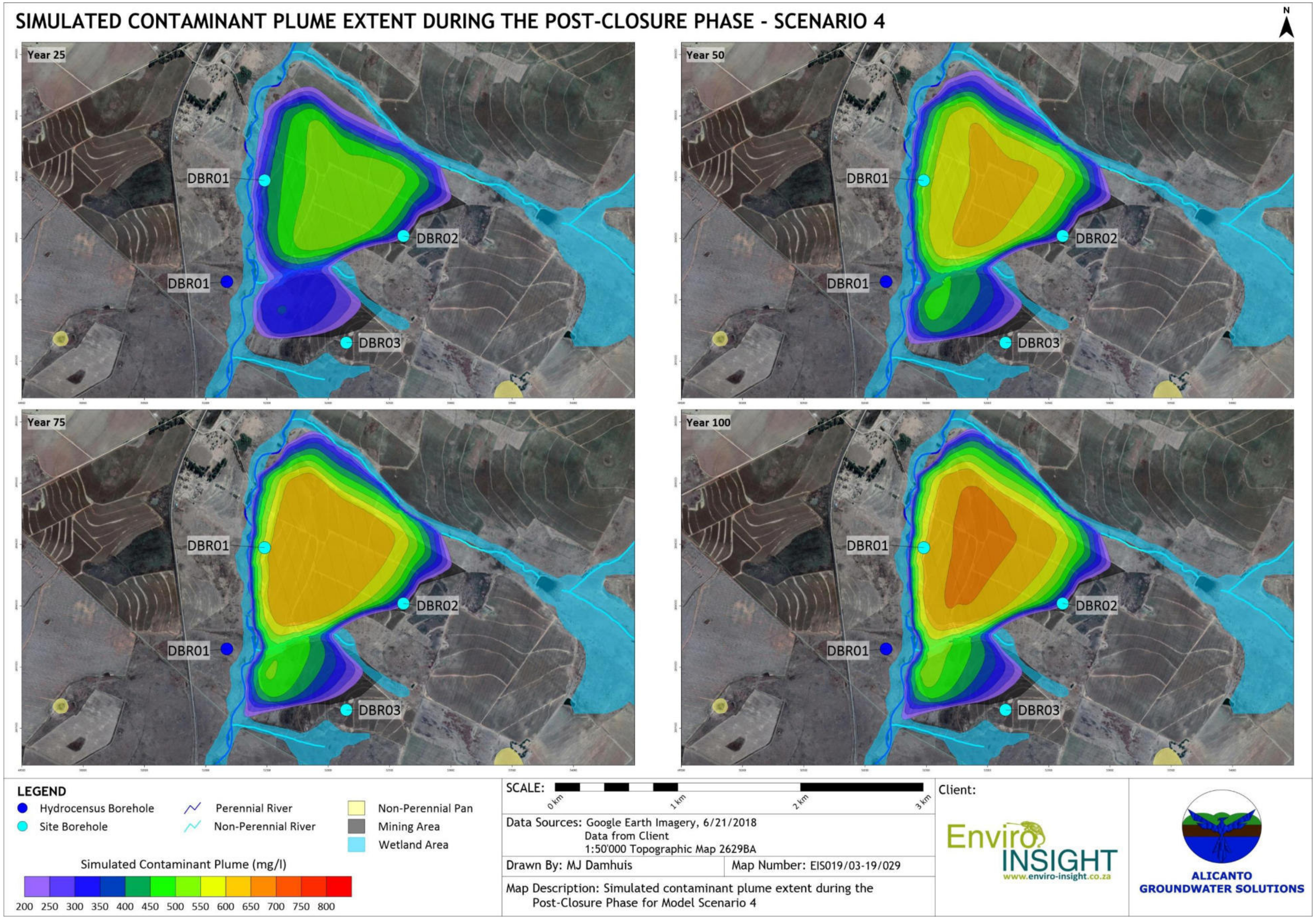

Figure 9.12: Simulated Contaminant Plume Extent (Operational Phase) - Scenario 4

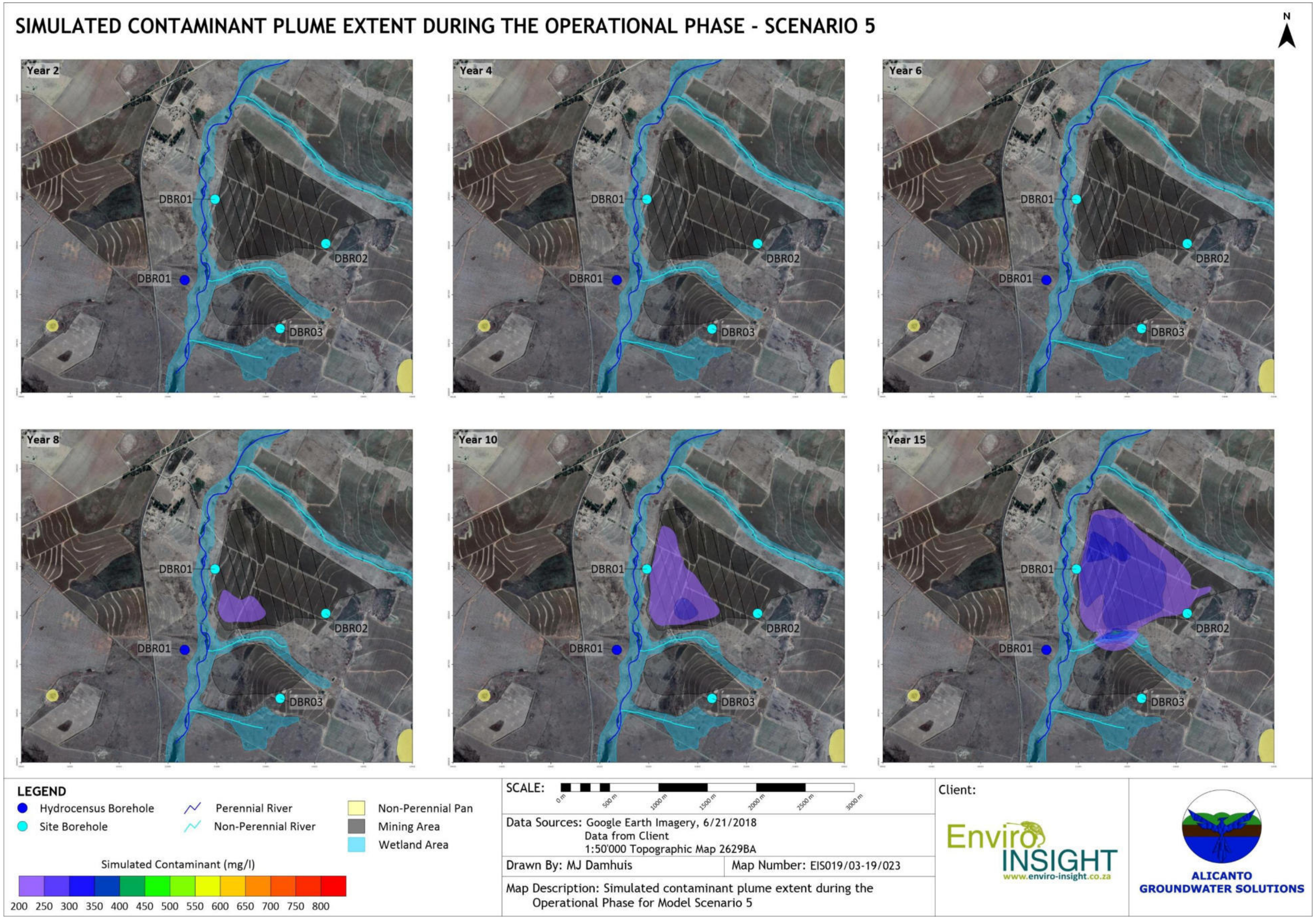

Figure 9.13: Simulated Contaminant Plume Extent (Operational Phase) - Scenario 5

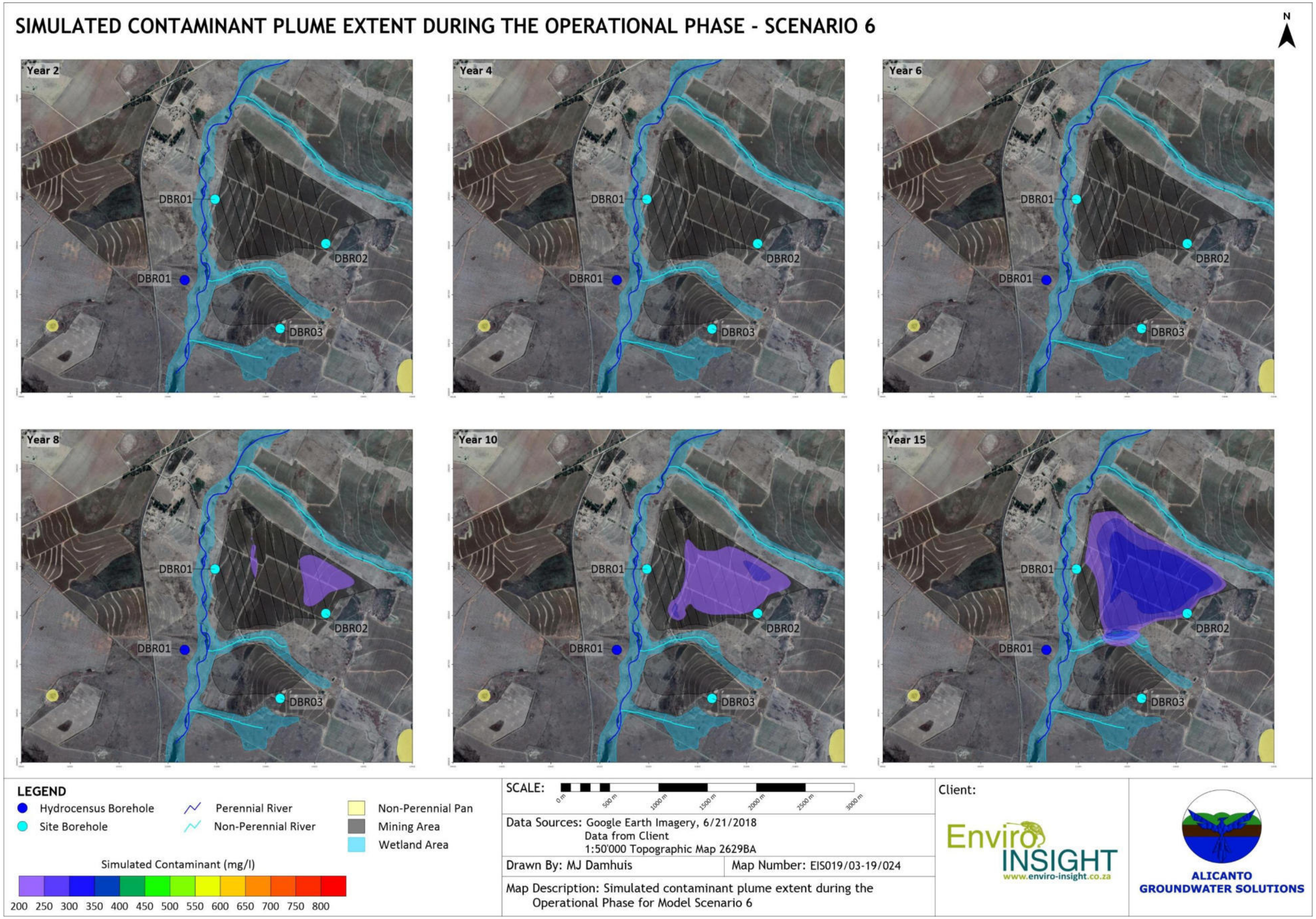

Figure 9.14: Simulated Contaminant Plume Extent (Operational Phase) - Scenario 6

9.3. Closure/Post-Closure Phase Impacts

Following the cessation of mining activities at the Site, the opencast mining area would be the only remaining potential impact source with the other mining areas having undergone non-commissioning and rehabilitation during the closure phase of the LoM.

9.3.1. Groundwater Quantity Impacts

Following the cessation of mining activities at the Site, groundwater levels will rebound towards their natural water levels, which is a low impact for all model scenarios (Table 9.7). Based on simulations, decant is possible at the central region of Opencast 1 (Figure 9.15), with decant volumes of ~250-300 m^3/day simulated. The decant product (if any) would likely flow towards the perennial river west of the Site, therefore a medium impact rating was assigned to the Site regarding decant during the post-closure period due to the potential impact of decant on the river and wetland west of Opencast 1 (Table 9.7).

Table 9.7: Groundwater Quantity Impacts during Post-Closure prior to Management/Mitigation (All Scenarios)

Description of Activity	Model Scenario	Impact Description	M	S	D	P	Risk	
Groundwater Quantity								
Groundwater Level Rebound	All Scenarios	Following the end of mining operations at the Site groundwater levels will rebound to pre-mining water levels.	2	1	4	3	21	Low
Decant	All Scenarios	Decant may occur at the Site during the rebound of water levels.	8	3	5	2	32	Medium

Groundwater monitoring boreholes at the Site should be monitored quarterly during the early stages of post-closure in order to identify groundwater level trends, following the implementation of which the impact rating remained low (Table 9.8). Should decant occur at the Site, a suitable capture and treat system should be implemented and the water treated to levels suitable for discharge to the environment. The implementation of these measures will result in the impact remaining low (Table 9.8).

Table 9.8: Groundwater Quantity Impacts during Post-Closure after Management/Mitigation (All Scenarios)

Description of Activity	Model Scenario	Mitigation/Management Measures	M	S	D	P	Risk	
Groundwater Quantity								
Groundwater Level Rebound	All Scenarios	No Mitigation Required. Groundwater levels at the Site should be measured quarterly to identify groundwater level trends.	2	1	4	2	14	Low
Decant	All Scenarios	Should decant occur at the Site, a suitable capture and treat system should be implemented and the water treated to levels suitable for discharge to the environment.	6	2	5	2	26	Low

9.3.2. Groundwater Quality Impacts

During the post-closure phase, the simulated contaminant plume migrated outwards from the mining extent towards the non-perennial river west of the Site and the wetland area north of Opencast 1. The simulated concentrations were highest at the central sector of Opencast 1, reaching a maximum of ~700-750 mg/l but remaining within the mining extent throughout the simulation period. The contaminant plume extended to ~500 m west of the mining area, with no privately-owned boreholes impacted on during post-closure. The contaminant plume was fairly limited in its extent, but due to the interaction with wetland features surrounding the mining area a medium impact was assigned, as shown in Table 9.9.

Table 9.9: Groundwater Quality Impacts during Post-Closure prior to Management/Mitigation

Groundwater Quality								
Poor Quality Leachate	All Scenarios	Poor quality leachate generated within the backfill material used at the Site during concurrent rehabilitation may enter the groundwater system.	6	2	4	3	36	Medium

During rehabilitation at the Site, sulphide-bearing material should be placed at the base of the backfilling and covered as soon as possible with more neutral material to prevent oxidation, with a 200 mm clay layer placed on top of the backfill material to limit washout of material through water ingress. If possible, the material should be covered/inundated as soon as possible to limit oxidation potential. The implementation of these management measures would lower the impact rating to low (Table 9.10).

Table 9.10: Groundwater Quality Impacts during Post-Closure after Management/Mitigation

Groundwater Quality								
Poor Quality Leachate	All Scenarios	Sulphide-bearing material should be placed at the base of the backfilling and covered as soon as possible with more neutral material to prevent oxidation and a 200 mm clay layer should be placed on top of the backfill material to limit washout of material through water ingress. If possible, the material should be covered/inundated as soon as possible to limit oxidation potential.	4	2	3	3	27	Low

The simulated contaminant plume for the Base Case Scenario and Model Scenarios 1-6 are shown in Figure 9.16, Figure 9.17, Figure 9.18, Figure 9.19, Figure 9.20, Figure 9.21 and Figure 9.22, respectively.

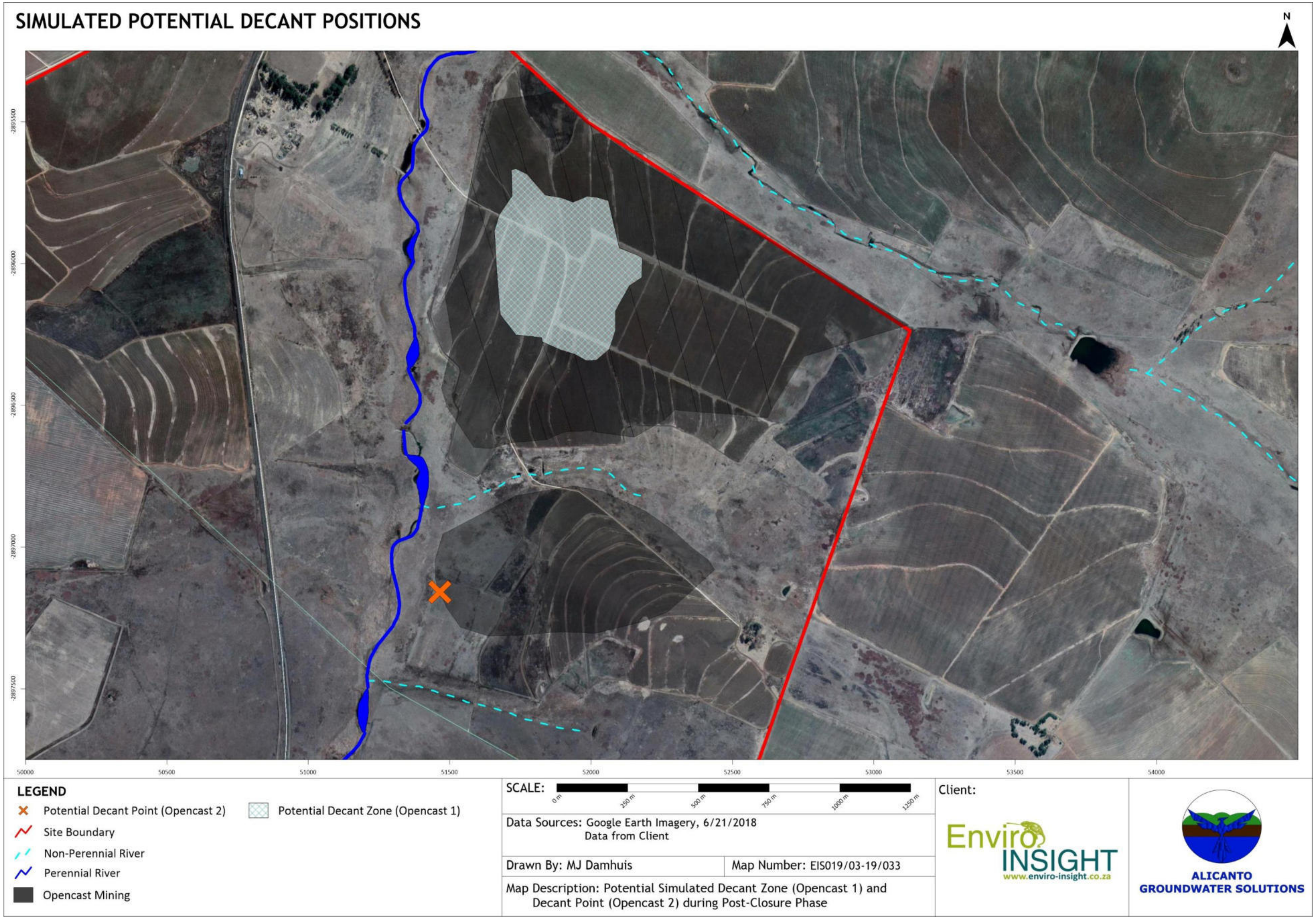

Figure 9.15: Simulated Decant Positions

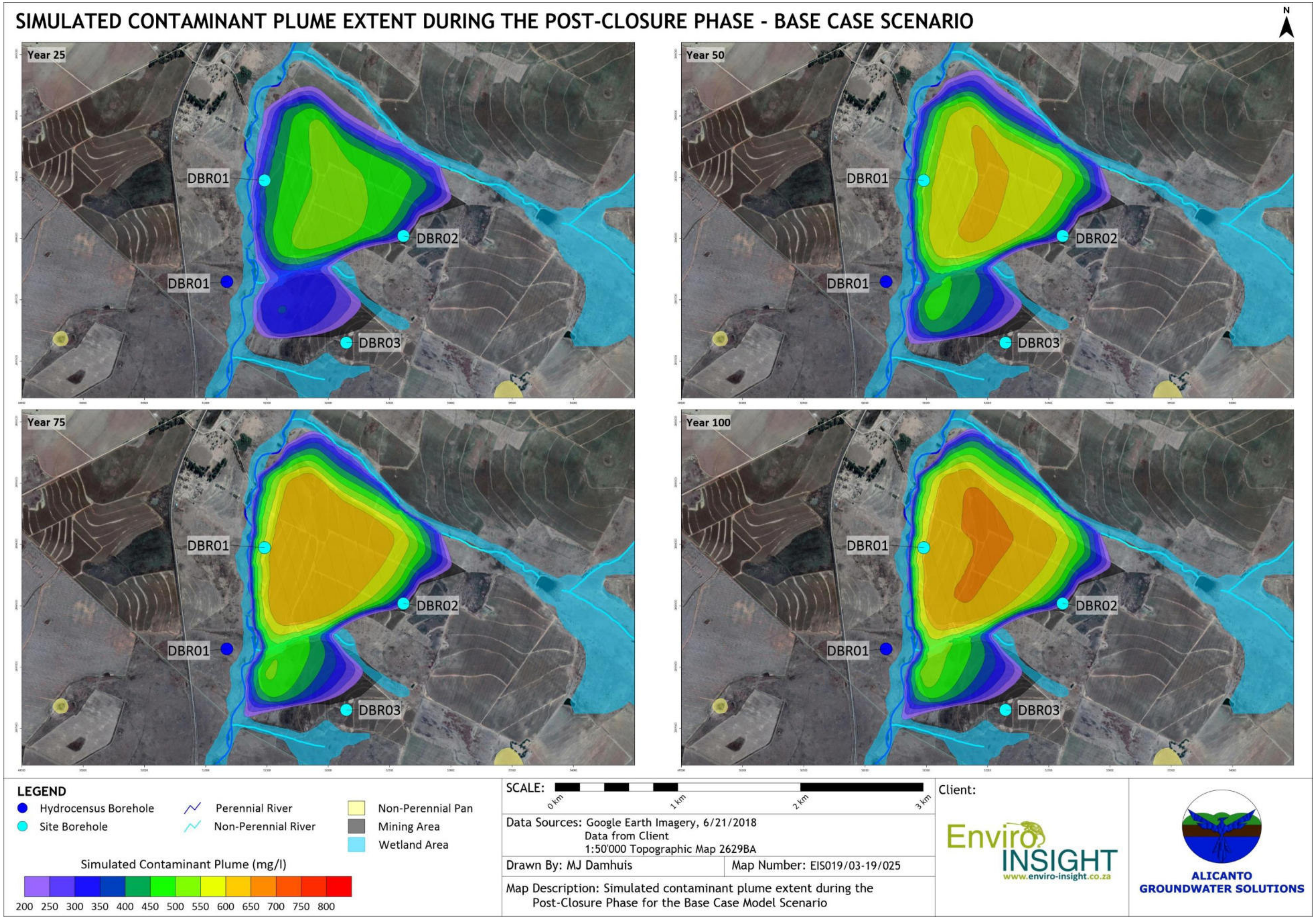

Figure 9.16: Simulated Contaminant Plume Extent (Post-Closure Phase) - Base Case Scenario

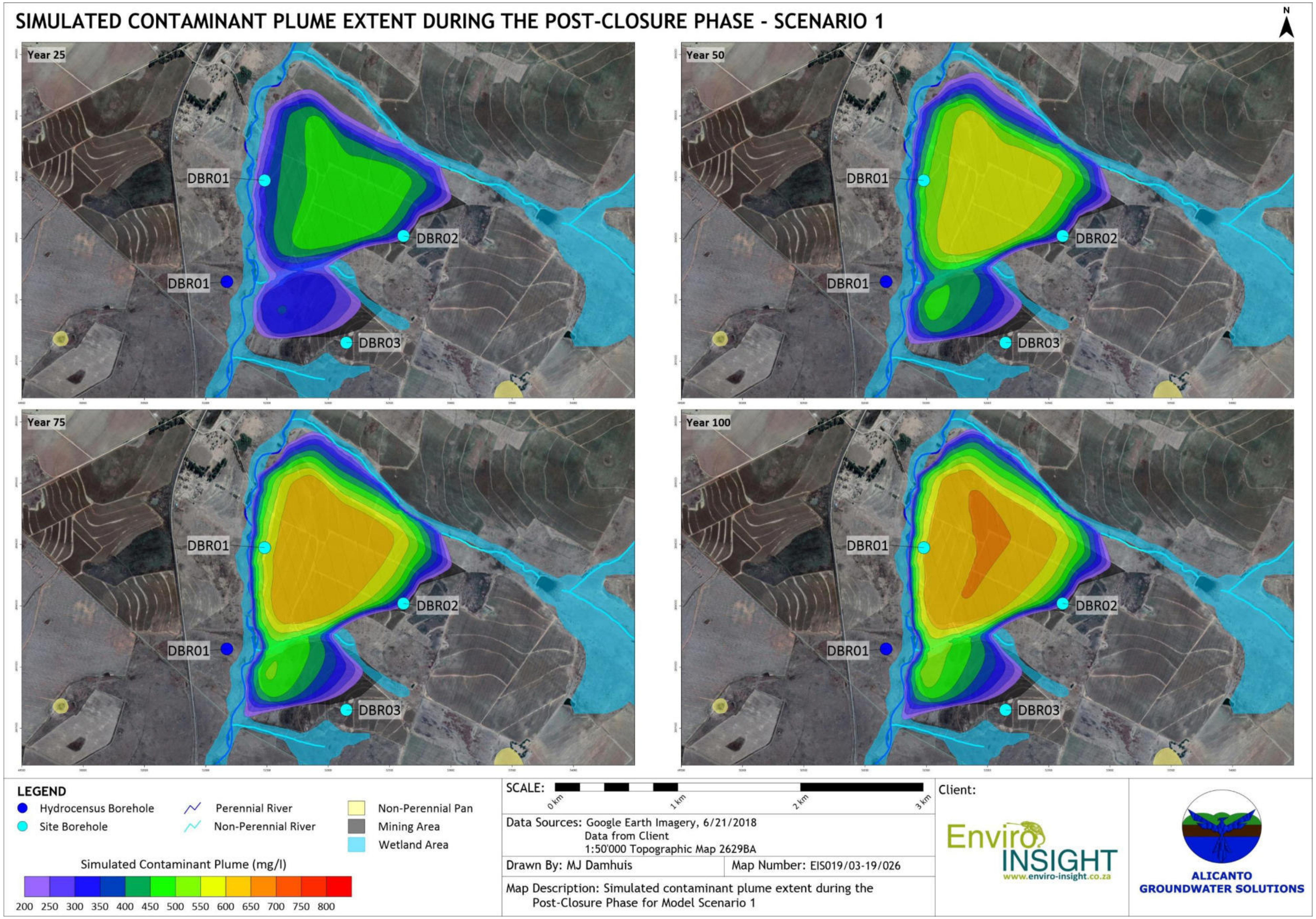

Figure 9.17: Simulated Contaminant Plume Extent (Post-Closure Phase) - Scenario 1

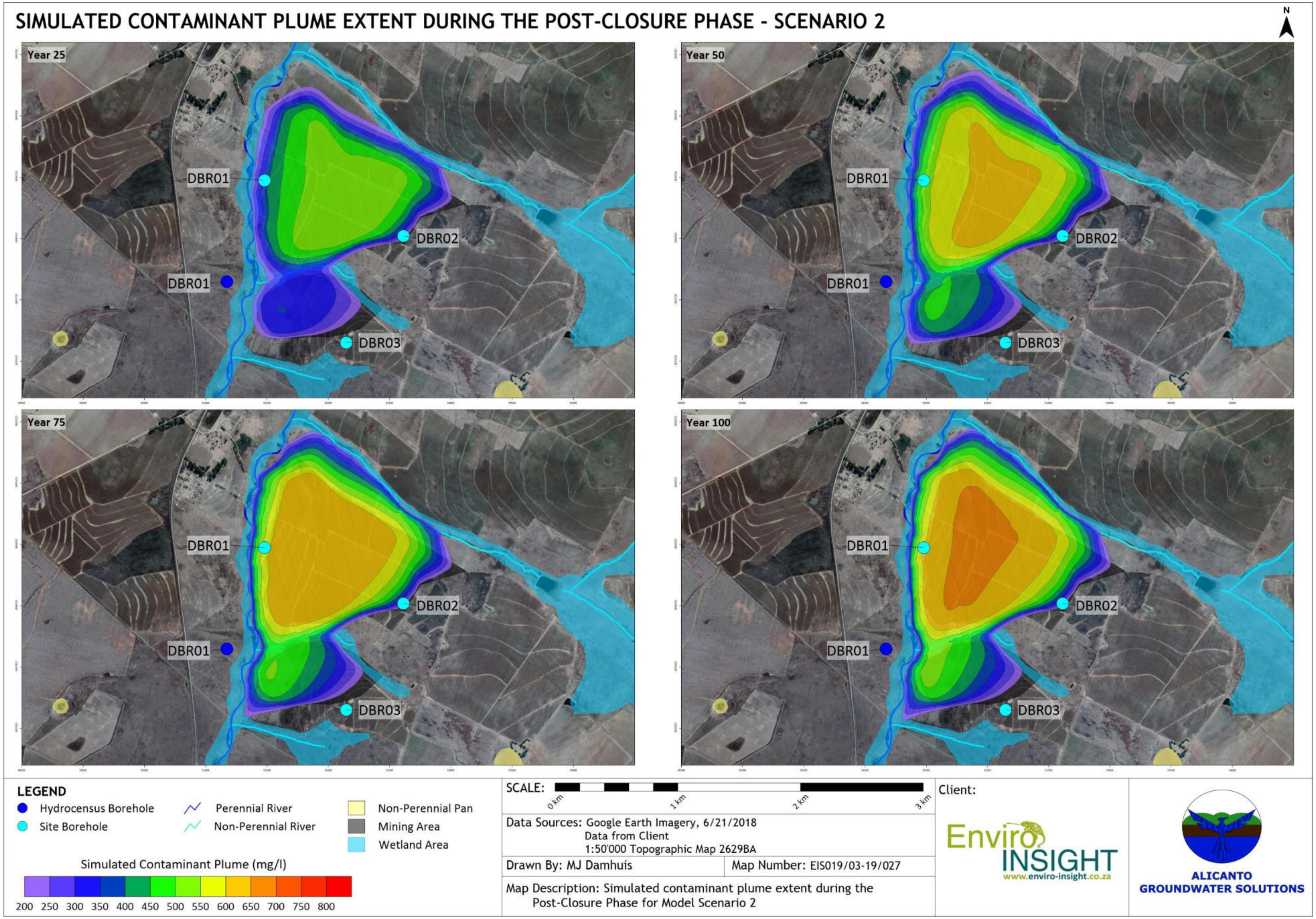

Figure 9.18: Simulated Contaminant Plume Extent (Post-Closure Phase) - Scenario 2

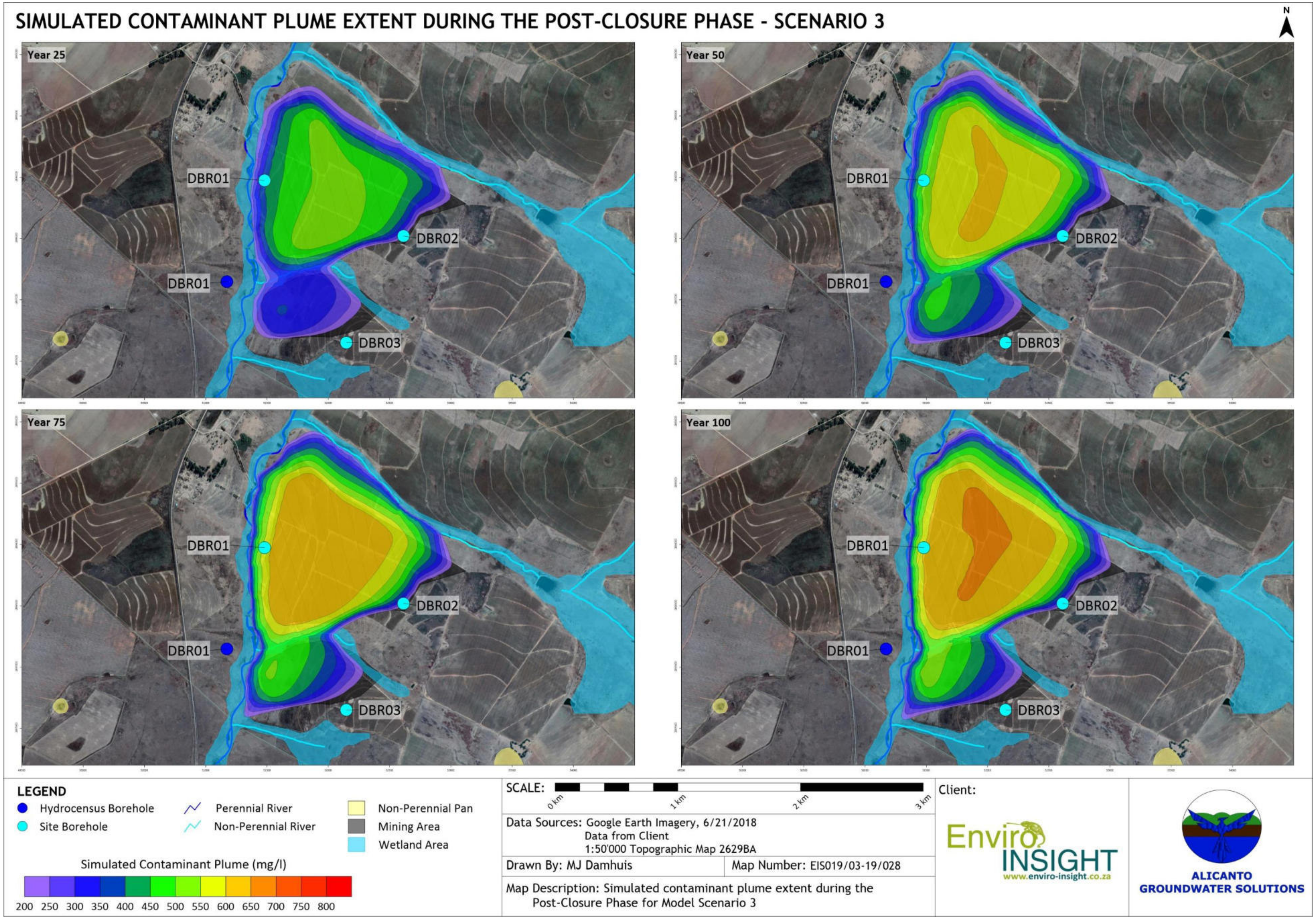

Figure 9.19: Simulated Contaminant Plume Extent (Post-Closure Phase) - Scenario 3

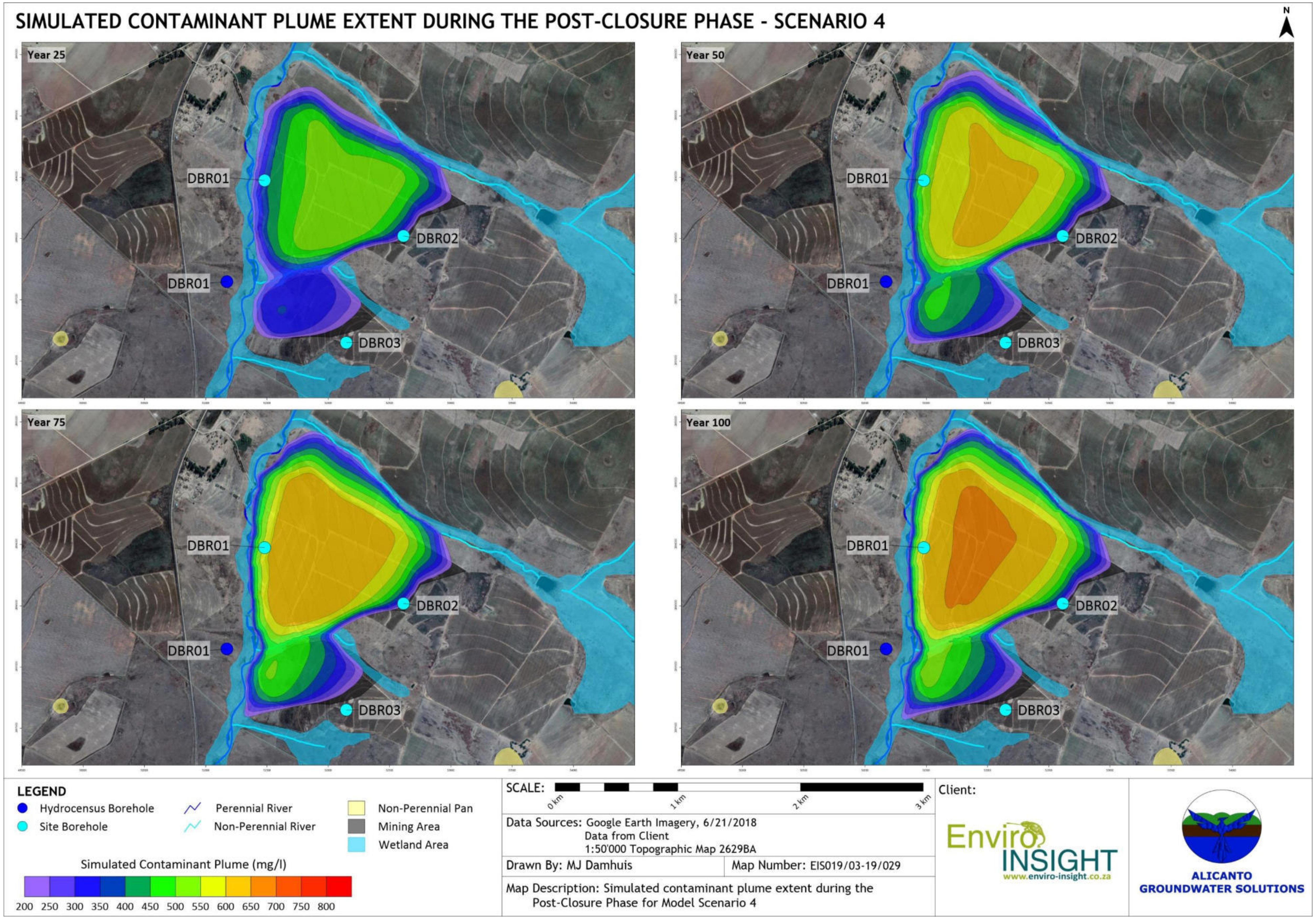

Figure 9.20: Simulated Contaminant Plume Extent (Post-Closure Phase) - Scenario 4

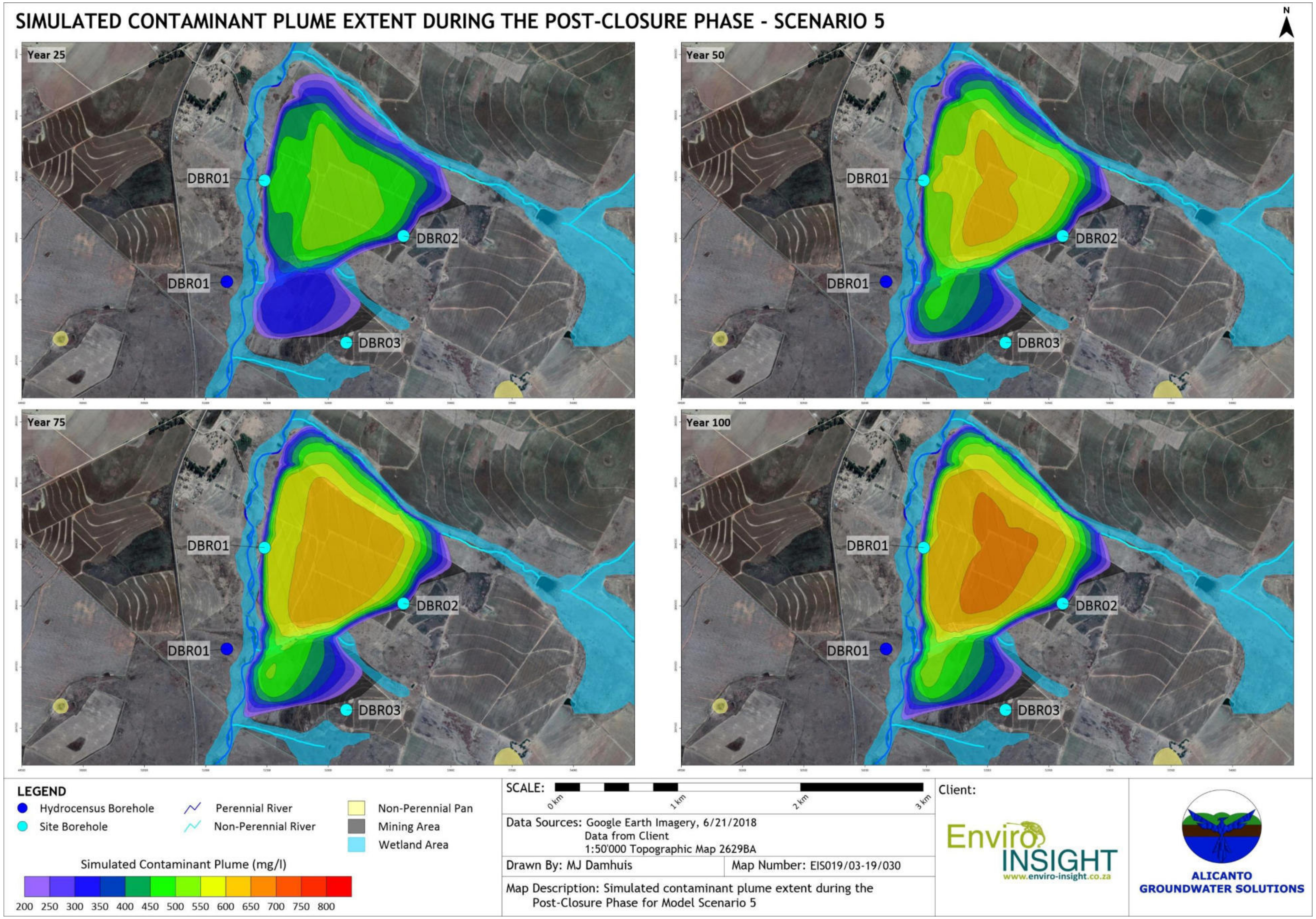

Figure 9.21: Simulated Contaminant Plume Extent (Post-Closure Phase) - Scenario 5

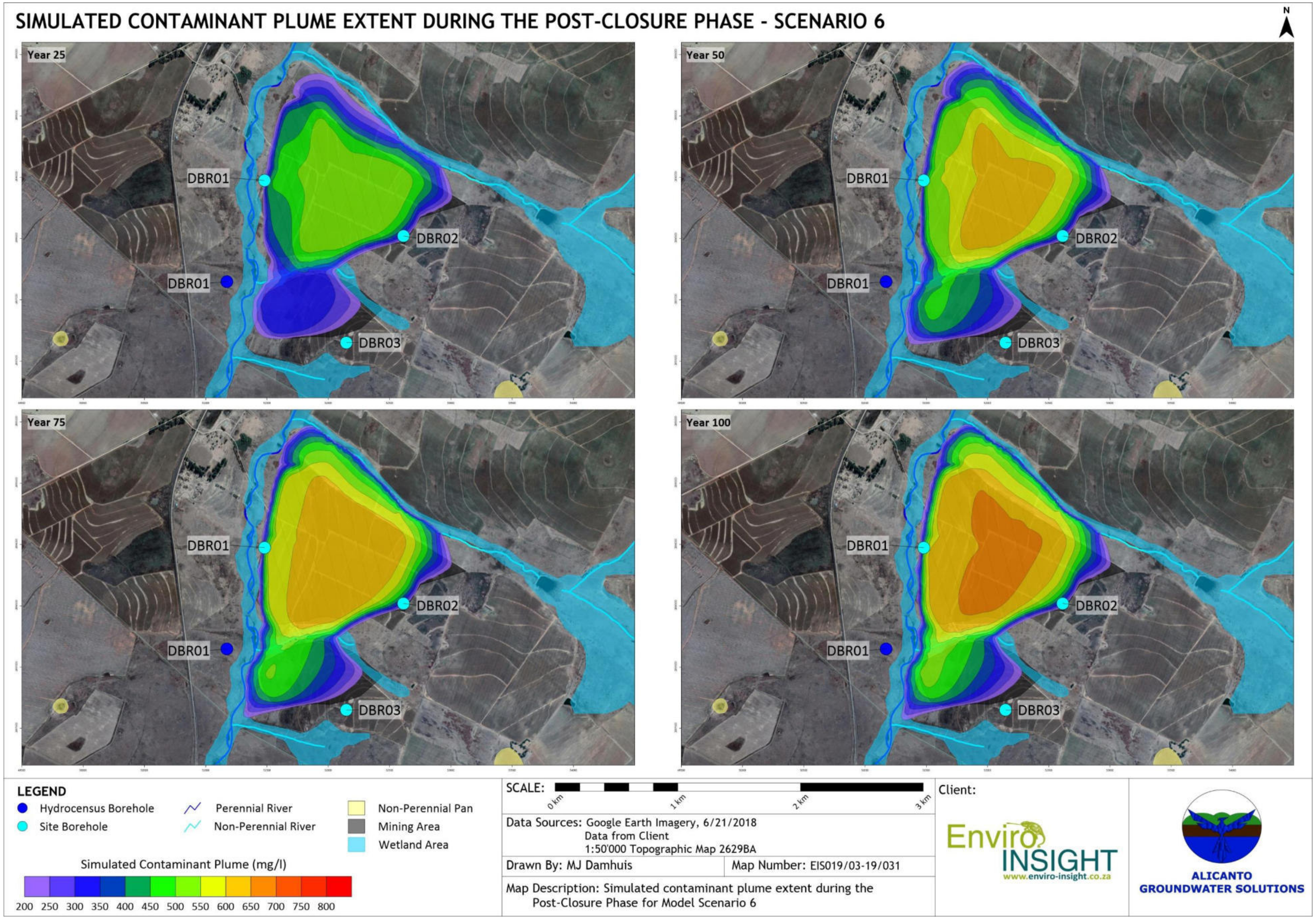

Figure 9.22: Simulated Contaminant Plume Extent (Post-Closure Phase) - Scenario 6

10. Groundwater Management Plan

10.1. Objectives

Best practice guidelines should be applied at the site to manage, prevent and minimize the impact of mining operation on the receiving hydrogeological environment while allowing for efficient and safe mining to take place at the site. The following will be embedded in water management procedures at the site:

- Maintenance of an effective response mechanism to deal with hydrogeological issues, including unexpected events and complaints; and
- Insurance of minimal environmental impacts in terms of groundwater quality and quantity due to mining activities.

10.2. General Approach

The key principles of the GWMP are as follows:

- Minimize the loss of the groundwater resource through effective monitoring and management of mine dewatering activities;
- Minimize the impact of contamination of the groundwater resource due to mining activities through effective monitoring and management of associated surface infrastructure; and
- Measure, monitor, evaluate and update management measures continuously throughout the LOM.

10.3. Water Management Controls

10.3.1. Operational Phase

Actions to be put in place during the operational phase include:

- Re-use groundwater seepage collected in the opencast storage sump (if possible);
- Minimise the footprint of dirty areas like the PCD and coal stockpiles, workshops and oil and diesel storage areas;
- Proper storm water management should be implemented. Berms should also be constructed to ensure separation of clean water and dirty water areas;
- Contain poor quality runoff from dirty areas and divert this water to pollution control dam for re-use (if possible);
- Static groundwater levels should be monitored as mentioned in Section 10.4 to ensure that any deviation of the groundwater flow from the idealised predictions is detected in time;

- The numerical model should be updated during LoM by using the measured water ingress and water levels to re-calibrate and refine the impact predictive scenario;
- If it can be proven that the mining operation is indeed affecting the quantity of groundwater available to certain users, the affected parties should be compensated. This may be done through the installation of additional boreholes for water supply purposes, or an alternative water supply;
- The monitoring results must be interpreted quarterly by a qualified hydrogeologist and network audited annually as well to ensure compliance with regulations;
- Concurrent rehabilitation should occur during mining to reduce the contact of water and air with any sulphides;
- The rehabilitated opencasts should be free draining away from the pit to reduce drainage into the pit;
- Boreholes should be drilled into the rehabilitated mine workings so that the rate of flooding and water level recovery and quality could be established. Stage curves should made which would aid in the management of closure phase;
- A detailed mine closure plan should be prepared during the operational phase, including a risk assessment, water resource impact prediction etc. as stipulated in the DWS Best Practice Guidelines. The implementation of the mine closure plan, and the application for the closure certificate can be conducted during the decommissioning phase; and
- It is recommended that a geochemical model assessment is completed during the life of the mine in order to calibrate and validate its results and to construct an effective closure plan. Monitoring of mine water is critical in order to validate the geochemical assessment. A geochemical model should be constructed that assess the effectiveness of potential mitigation measures during the operational phase so that mitigation measures could be implemented proactively.

10.3.2. Closure and Post-Closure Phase

The following objectives are envisaged for the closure phase:

- Negotiate and obtain groundwater closure objectives approved by Government during the Decommissioning Phase of the project, based on the results of the monitoring information obtained during the operational phase of the project, and through verification of the numerical model constructed for the project;
- Continue with groundwater quality and groundwater level monitoring for a period of five years after mining ceases in order to establish post-closure groundwater level and quality trends. The monitoring information must be used to update, verify and recalibrate the predictive tools used during the study to increase the confidence in the closure objectives and management plans;

- Present the results of the monitoring programme to Government on an annual basis. The post-closure monitoring programme will be re-evaluated on an annual basis in consultation with Government; and
- Negotiate mine closure with Government based on the results of the groundwater monitoring undertaken, after the five-year post-closure monitoring periods.

Actions to be put in place during the operational phase include:

- Multiple-level monitoring wells must be constructed to monitor base-flow quality within any identified sensitive zones (e.g. wetland areas) and to monitor groundwater level behaviour in the rehabilitated workings. Use the results of the monitoring programme to confirm/validate the predicted impacts on groundwater availability and quality after closure;
- Update existing predictive tools to verify long-term impacts on groundwater, if required;
- Present the results to Government on an annual basis to determine compliance with the closure objectives set during the Decommissioning Phase;
- Reduce recharge, this would entail capping the backfill of the opencast with an impermeable layer, and is encouraged if practical;
- Regular monitoring of privately-owned boreholes and surface water features at the Site (e.g. perennial river west of the Site) are essential during post-closure. Should poor water quality trends be observed at the off-Site features, scavenger wells may be installed to intercept any additional seepage and discharge the poor-quality water back to the Site PCD;
- Implement as many closure measures during the operational phase, while conducting appropriate monitoring programmes to demonstrate actual performance of the various management actions during the life of mine;
- All mined areas should be covered/flooded as soon as possible to bar oxygen from reacting with remaining pyrite;
- The final backfilled opencast topography should be engineered such that runoff is directed away from the opencast areas;
- The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the opencasts; and
- Audit the monitoring network annually.

10.4. Groundwater Monitoring

10.4.1. Monitoring Network

The groundwater monitoring network design should comply with the risk-based source-pathway - receptor principle. A groundwater-monitoring network should contain monitoring positions which can assess the groundwater status at certain areas.

Both the impact on water quality and water quantity should be catered for in the monitoring system. The boreholes in the network should cover the following: contaminant sources, receptors and potential contaminant plumes.

Furthermore, monitoring of the background water quality and levels is also required.

Groundwater monitoring should be conducted to assess the following:

- The impact of mine dewatering on the surrounding aquifers (if any). This will be achieved through monitoring of groundwater levels in the monitoring boreholes. If private boreholes are identified within the zone of impact on groundwater levels, these will be included in the monitoring programme;
- Groundwater inflow into the mine workings. This will be achieved through monitoring of groundwater levels in the monitoring boreholes as well as measuring water volumes pumped from mining areas;
- Groundwater quality trends. This will be achieved through sampling of the groundwater in the boreholes at the prescribed frequency;
- The rate of groundwater recovery and the potential for decant after mining ceases. This can be achieved through drilling of additional boreholes into the opencast workings for monitoring purposes. These boreholes should be drilled in the deepest sections of the mine. Stage curves will be drawn to assess the inflow into defunct workings; and
- Groundwater Monitoring should be undertaken to SABS and DWS requirement according to the schedule presented in Table 10.1 below.

Table 10.1: Monitoring Network Programme Summary

Monitoring position	Sampling interval	Analysis	Water Quality Standards
Operational Phase			
Rainfall	Daily at the mine	N/a	N/a
All monitoring boreholes	Monthly: measuring the depth of groundwater levels	N/a	N/a
All monitoring boreholes	Monthly: sampling for water quality analysis	Full analysis	- South African Water Quality Guidelines: Domestic Use, livestock watering
		Groundwater level	- WUL Requirements
Decommissioning and Post Closure Phases			
Rainfall	Daily at the mine	N/a	N/a
All monitoring boreholes	Quarterly: measuring the depth of groundwater levels	N/a	N/a
All monitoring boreholes	Quarterly: sampling for water quality analysis	Full analysis	- South African Water Quality Guidelines: Domestic Use, livestock watering
		Groundwater level	- WUL Requirements

The proposed monitoring network can be seen in Figure 10.1 and is summarised in Table 10.2. A total of nineteen (19) new monitoring boreholes (excluding the existing DBR01 and DBR03 boreholes) are recommended to be drilled comprised of 6 multi-level borehole sets drilled between mine workings and wetland features, 7 monitoring boreholes installed during the operational phase and 6 monitoring boreholes installed at rehabilitated mine workings following closure.

The multi-level boreholes should be installed to intersect the deeper aquifer zone, intermediate weathered zone and upper interflow/unsaturated zone, with the deepest borehole installed closest to the mining area and the shallowest installed toward the wetland/surface water feature being considered for baseflow monitoring.

This network complies with the above-mentioned criteria. It is envisaged that the frequency of monitoring remains on a monthly basis, due to the short LoM, with post-closure monitoring occurring on a quarterly basis for a period of five years after mine closure.

Table 10.2: Proposed Monitoring Network

X-Coordinate (LO29, WGS84)	Y-Coordinate (LO29, WGS84)	Borehole ID	Description	LoM Phase
52964.73	-2896583	BH01	Monitoring Borehole at Opencast 1 WRD	Operational Phase
52623.50	-2896602	BH02	Monitoring Borehole at Opencast 1 Stockpile Area	Operational Phase
52215.85	-2896656	BH03	Monitoring Borehole at Opencast 1 PCD	Operational Phase
52618.59	-2897290	BH04	Monitoring Borehole upstream of Opencast 2	Operational Phase
51599.09	-2897450	BH05	Monitoring Borehole at Opencast 2 PCD	Operational Phase
50971.06	-2897096	BH06	Background Monitoring Borehole for Opencast 2	Operational Phase
51121.68	-2896047	BH07	Background Monitoring Borehole for Opencast 1	Operational Phase
51479.15	-2896026	DBR01	Monitoring Borehole between Opencast 1 and perennial Leeuwfontein River	Existing
52147.31	-2897349	DBR02	Monitoring Borehole at Opencast 2 ROM Stockpile	Existing
51418.49	-2897249	MW01	Multi-Level Borehole Nest between Opencast 2 and Leeuwfonteinspruit Wetland	Operational Phase
51507.00	-2896911	MW02	Multi-Level Borehole Nest between Opencast 2 and Leeuwfonteinspruit Wetland	Operational Phase
51829.24	-2896783	MW03	Multi-Level Borehole Nest between Opencast 2 and northern wetland area	Operational Phase
51554.65	-2896694	MW04	Multi-Level Borehole Nest between Opencast 1 and southern/eastern wetland areas	Operational Phase
51643.35	-2895320	MW05	Multi-Level Borehole Nest between Opencast 1 and Leeuwfonteinspruit wetland area	Operational Phase
52434.77	-2895711	MW06	Multi-Level Borehole Nest between Opencast 1 and northern wetland area	Operational Phase
51675.68	-2896317	PCBH01	Monitoring Borehole at Rehabilitated Opencast 1	Closure Phase
51729.30	-2895712	PCBH02	Monitoring Borehole at Rehabilitated Opencast 1	Closure Phase
51961.62	-2896133	PCBH03	Monitoring Borehole at Rehabilitated Opencast 1	Closure Phase
52227.13	-2896210	PCBH04	Monitoring Borehole at Rehabilitated Opencast 1	Closure Phase
51606.75	-2897104	PCBH05	Monitoring Borehole at Rehabilitated Opencast 2	Closure Phase
52056.08	-2897065	PCBH06	Monitoring Borehole at Rehabilitated Opencast 2	Closure Phase

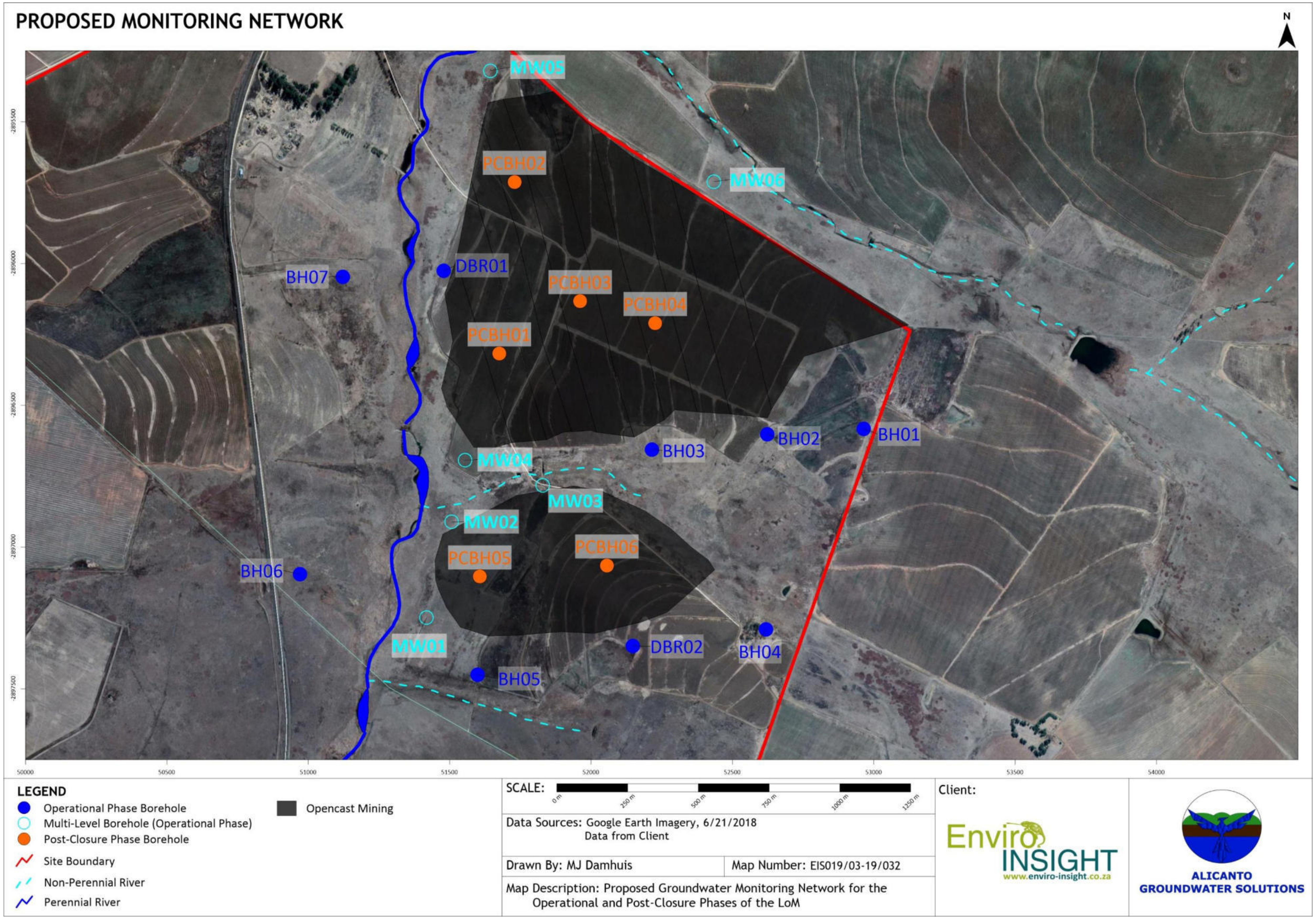

Figure 10.1: Proposed Monitoring Network

10.4.2. Monitoring Parameters

Physical Parameters:

- Groundwater levels; and
- Mine water inflows/discharge volumes (if any).

Chemical Parameters:

- Field measurements:
    - pH, EC;
- Laboratory analyses:
    - Anions and cations (Ca, Mg, Na, K, NO_3, Cl, SO_4, F, Fe, Mn, Al, Hardness & Bicarbonate, Carbonate and Total Alkalinity);
    - Other parameters (pH, EC, TDS)

Laboratory analysis techniques should comply with SANS guidelines and it is recommended that a SANAS-accredited laboratory is used. The groundwater monitoring database should be updated on a monthly basis as information becomes available and used to analyse the information and evaluate trends noted. It is critical that the database includes baseline information, i.e. pre-mining information, and background water quality and level information in order to make accurate observations of the impact of mining activities on the Site groundwater environment.

An annual compliance report should be compiled and submitted to the authorities for evaluation and comment. This report should be submitted annually for the construction, operational and decommissioning phases as well as for five years after mining ceases. The mine must develop a monitoring response protocol. This protocol will describe procedures if groundwater monitoring information indicates that action is required.

11. Acid Mine Drainage Management

Acid mine drainage (AMD) (also referred to as acid rock drainage (ARD)) is generated when sulphide bearing minerals, such as pyrite, undergo oxidation through exposure to oxygen and water (DWS, 2018). Pyrite is commonly found within coal and gold deposits in South Africa (McCarthy, 2011) and under natural conditions produces acid at rates slow enough to be neutralised by natural processes in the rock formations.

However, during the extraction of ore the rock formation is heavily fragmented (McCarthy, 2011) and exposed to the atmosphere, resulting in an increased reaction surface area of the material which results in an increased rate of acid production potentially in excess of natural neutralisation processes. Typically, within coal mining environments pyrite is associated with the coal seam itself and is removed entirely during mining activities, with AMD being generated mostly at coal stockpiles, discard dumps and unmined coal (McCarthy, 2011).

At the Site, all waste generated during mining will be stored at temporary storage facilities at the Site until it is used to backfill the opencast pit area during mining (i.e. rollover rehabilitation). Coal processing will take place on the Site and all 'dirty' water will report to a pollution control dam (PCD) at the Site. Due to the temporary nature of the stockpile areas and the PCD being limited in its size, the only risk for AMD generation at the Site is the backfill material to be used during rollover rehabilitation during the mine operational phase.

This section of the report presents recommendations on the management/mitigation of AMD generation in the Site context.

11.1. AMD Process

AMD occurs when sulphide-bearing rock is exposed to oxygen and water (DWS, 2018) and the natural neutralisation capacity (or buffer capacity) is overwhelmed by the acid generated from the material. The most common sulphide mineral associated with coal mining according to Vermeulen & Usher (2009) is pyrite (FeS_2), which can react with oxygen and water to produce sulphuric acid (H_2SO_4) through the following series of oxidation and reduction reactions[2]:

(1) $FeS_2 + 7/2\ O_2 + H_20 => Fe^{2+} + 2\ SO_4^{2-} + 2\ H^+$

(2) $Fe^{2+} + ¼\ O_2 + H^+ => Fe^{3+} + ½\ H_2O$

(3) $Fe^{3+} + 3\ H_2O => Fe(OH)_3 + 3\ H^+$

(4) $FeS_2 + 14\ Fe^{3+} + 8\ H_2O => 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+$

[2] After Stumm and Morgan (1996).

In the South African coalfields carbonate minerals such as calcite and dolomite co-exist and have the potential to neutralise AMD to a degree (Vermeulen & Usher, 2009) as shown in the additional reaction below.

(5) $FeS_2 + 2\ CaCO_3 + 3,75\ O_2 + 1,5\ H_2O \Leftrightarrow Fe(OH)_3 + 2\ SO_4^{2-} + 2\ Ca^{2+} + 2\ CO_2$

During the neutralisation reaction increases in both Ca^{2+} and SO_4^{2-} will occur to the point where the aqueous solubility of these ions is limited by the solubility of gypsum ($CaSO_4.H_2O$) (Vermeulen & Usher, 2009). Once the carbonate minerals are depleted, or the neutralisation reaction can no longer occur, AMD will occur with the remaining sulphide minerals.

Broughton & Robertson (1992) illustrated the three stages of AMD evolution, Figure 11.1, where the overall decrease in pH over time due to reactions (1) through (5). Stage I of AMD formation is characterised by fairly neutral pH values, where acid is consumed by the buffer minerals present, with SO_4 generation limited due to the precipitation of Gypsum. As the buffer minerals are depleted and AMD formation enters Stage II, pH decreases to ~4.5-6.0 and metal concentrations reach maximum concentrations while calcium and magnesium concentrations decrease. Stage III of AMD formation is characterised by pH values <4.5 and generally decreasing metal concentrations and SO4 values in excess of 2'000 mg/l, with buffering reactions generally limited to the dissolution of silicate minerals.

Table 11.1 shows a summary of the evolution of AMD as presented by GCS (2015) and Figure 11.1 presents the stages of AMD evolution as illustrated by Broughton & Robertson (1992).

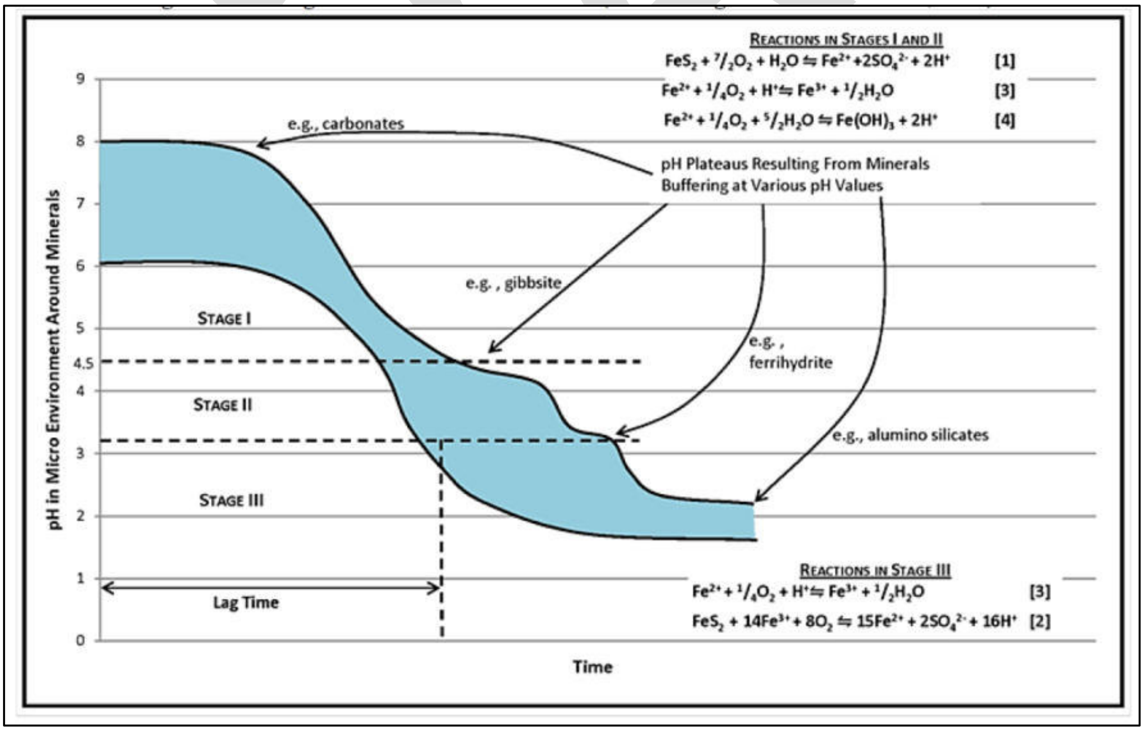

Figure 11.1: Evolution of AMD Formation (after Broughton & Robertson, 1992)

Table 11.1: Evolution of AMD (after GCS, 2015)

Component	AMD Stage 1	AMD Stage 2	AMD Stage 3
Mineralogical Reactions & Products			
Pyrite	Oxidation	Oxidation. Sulphate reaches maximum concentration in interstitial water	Depleted in upper oxidation zone. Sulphate decreases from maximum
Calcite & Dolomite	Dissolution	Depleted in upper oxidation zone	Depleted in upper oxidation zone
Gypsum	Precipitation, controls sulphate	Dissolution	Depleted in upper oxidation zone
Fe-sulphate	None	Precipitation	Some dissolute while others keep precipitating
Metals, Al, Fe, Mn	Precipitate/Adsorp	Elevated, reaches maximum value	Decrease from maximum
Traces Ni, Co, Pb, Cu	Precipitate/Adsorp	Elevated, reaches maximum value	Decrease from maximum
pH	Neutral	Acidic in unsaturated zone seepage	Acidic in unsaturated zone seepage
Water Quality Changes			
pH	6.5 - 7.5	6.5 down to <4.5	3.5 - 4.5
Alkalinity (mg CaCO3/l)	50-450	0	0
Calcium as Ca (mg/l)	100 up to 750	750 down to 300	500 - 300
Magnesium as Mg (mg/l)	50 up to 350	250 - 450 (700)	150 - 350
Sodium as Na (mg/l)	50 - 150	150 up to 250	150 - 250
Sulphate as SO4 (mg/l)	1'500 - 2'500	>2'500	>2'500
Aluminium as Al (mg/l)	<1	<100 (up to 1'000)	<100 (up to 1'000)
Iron as Fe (mg/l)	<1	<100 (up to 1'000)	<100 (up to 1'000)
Manganese as Mn (mg/l)	<1	<100	<100

* Values shown in brackets are for highly carbonaceous material.

During the operational phase of mining at the Site water will be removed from the active pit to allow for safe mining conditions. Groundwater intersected during mining is expected to be of good quality and will not be significantly degraded during operations at the Site. During opencast mining the pit walls will be exposed to the atmosphere, where oxidation of sulphide-bearing materials would be initiated.

Concurrent backfilling of the opencast pit will take place during the operational phase and following cessation of mining, the opencast pit water levels will rise and eventually flood the backfilled material and reach equilibrium with regional groundwater levels. During the flooding of the backfilled pit groundwater will encounter the oxidised material and will most likely degrade in quality, as depicted in the conceptual model of physio-chemical processes in mine backfill during opencast mining (Miller *et al.*, 1996) presented in Figure 11.2.

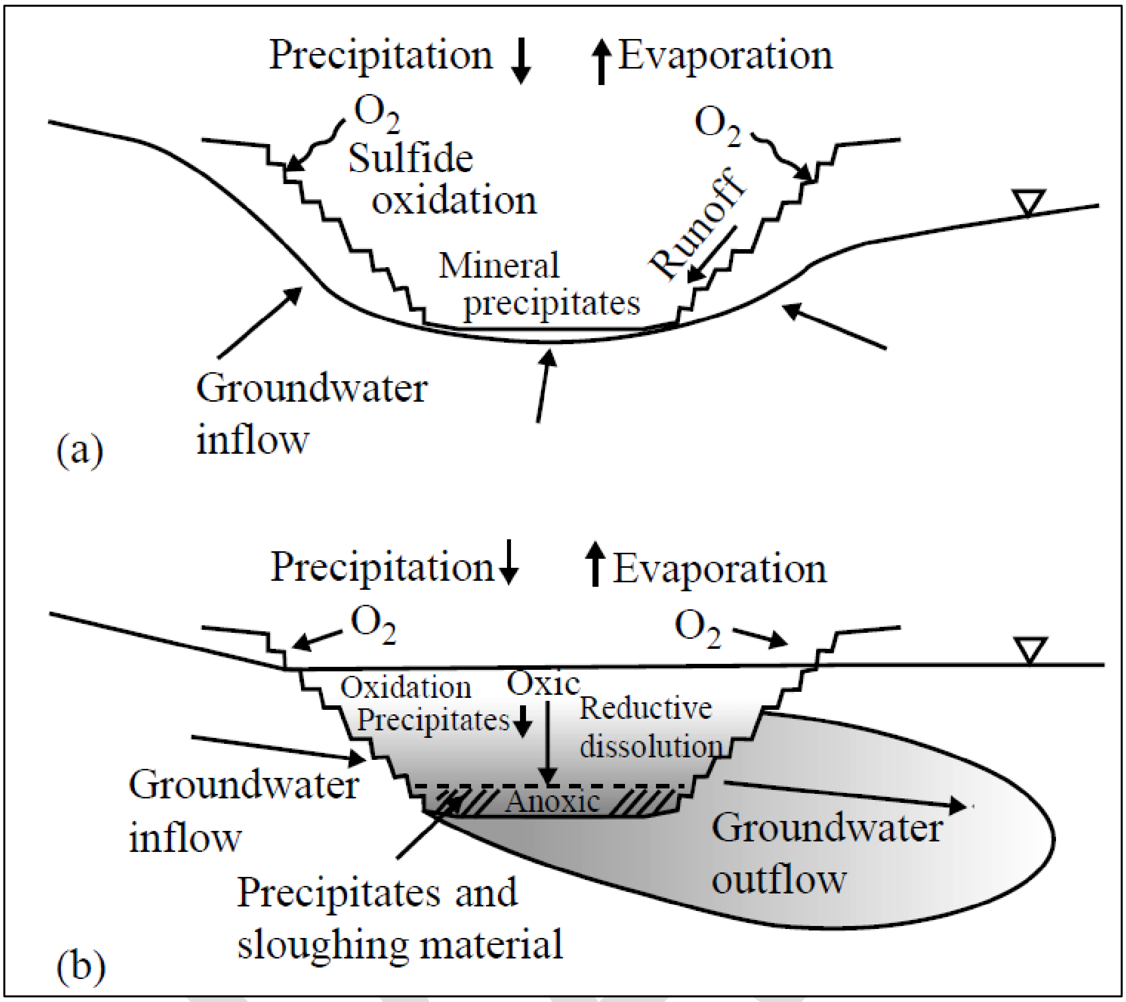

Figure 11.2: Conceptual Model of Opencast Mine Geochemistry during (a) and after mining (b) (after Miller et al., 1996)

11.2. Legislative Overview

As the majority of AMD risk at the Site falls within the closure and post-closure period of the LoM the applicable legislation for mine closure and rehabilitation was listed in this section.

Within the South African mining environment, the responsibility of mitigating any environmental impacts that may arise during, or as a result of, mining activities lies with the operating mining company. This liability exists throughout the LoM and includes commitments required for environmental remediation and/or rehabilitation.

Key legislation which governs the legislative requirements for mine rehabilitation includes:

- The Constitution of the Republic of South Africa (Act 108 of 1996);
- The National Environmental Management Act (Act 107 of 1998);
- The Mineral and Petroleum Resource Development Act (Act 28 of 2002); and
- The National Water Act (Act 36 of 1998).

Other legislation listed as applicable by Digby Wells Environmental (2012) includes:

- The Environment Conservation Act (Act 73 of 1989);
- The National Environmental Management: Biodiversity Act (Act No. 10 of 2004);
- Conservation of Agricultural Resources Act (Act 43 of 1983);
- National Forests Act (Act 84 of 1998);
- Mine Health and Safety Act (Act 29 of 1996);
- National Heritage Resources Act (Act 25 of 1999);
- Occupational Health and Safety Act of 1994;
- Atmospheric Pollution Prevention Act (Act 45 of 1965);
- Hazardous Substances Act (Act 15 of 1973);
- National Environmental Management: Air Quality Act (Act 39 of 2004);
- National Environmental Management: Waste Management Act (Act 50 of 2008);
- National Forest Act (Act 84 of 1998);
- National Veld and Forest Fire Act (Act 101 of 1998);
- Promotion of Access to Information Act (Act 2 of 2000); and
- The Promotion of Administrative Justice Act (Act 3 of 2000).

11.3. AMD Management Strategy

11.3.1. AMD Management during the Operational Phase

During the operational phase of the LoM AMD generation is limited to the backfill material used in the concurrent rehabilitation of the pit. A conceptual schematic of mining processes to be followed during the operational phase is shown in Figure 11.3, indicating the placement of backfill material and rollover rehabilitation during mining activities.

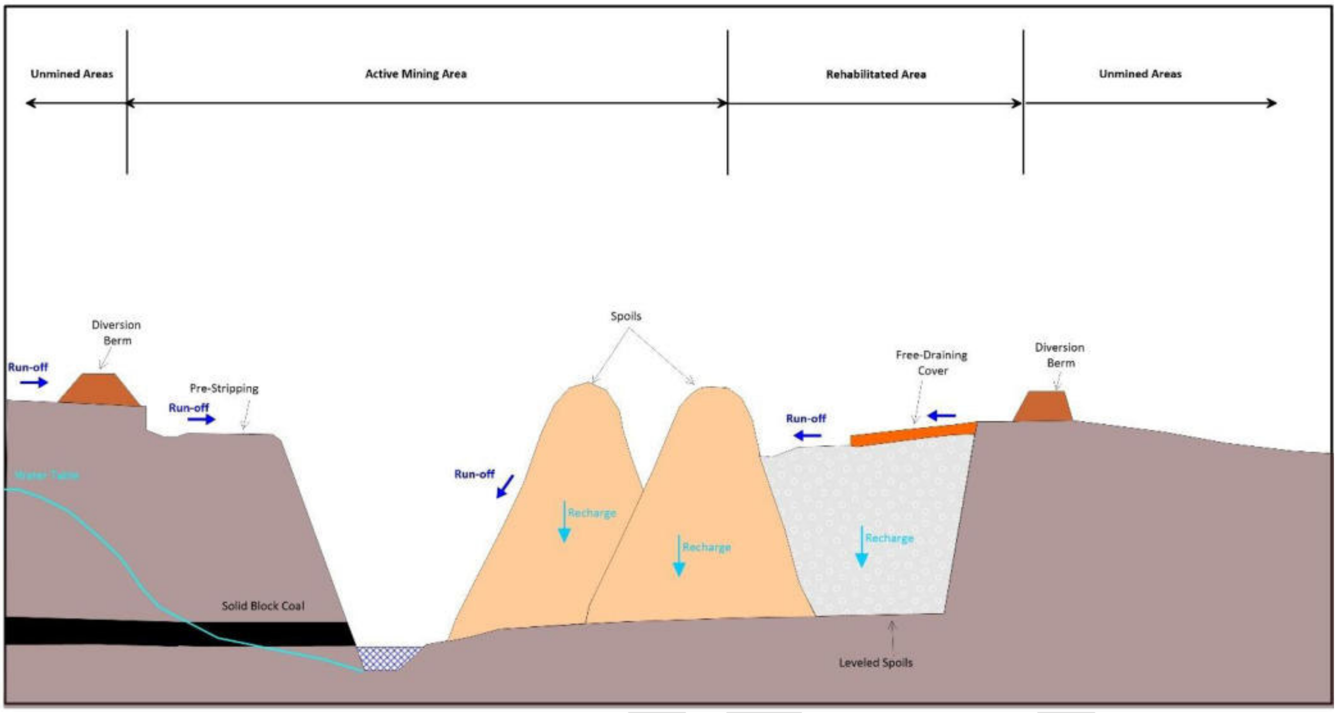

Figure 11.3: Mining Process at the Site (modified after Mokoena, 2012)

During backfilling of completed cuts at the Site it is recommended that the materials are placed in such a manner that sulphide-bearing materials are placed at the base of the pit and covered with more neutral overburden material, with the material being compacted suitably to mimic the surrounding hydrogeological environment as far as possible. The backfill material should be capped with a 200 mm clay layer to limit the ingress of water into the material during operations. It is recommended that topsoil placement is only done once the final landform has been created at the open pit area.

Any groundwater ingress into the opencast pit during the operational phase should be collected in a central sump area and discharged to the PCD complex as soon as possible, thus limiting contact time with exposed material within the pit area. During mining operations, a surface water berm should always be maintained at the limits of the pit area to prevent clean runoff entering the pit area. The Site water management plan should aim to keep clean and dirty water separate during all phases of LoM, with all water encountering mining activities being considered dirty and disposed of at the PCD complex as soon as possible.

11.3.2. AMD Management during the Closure and Post-Closure Phase

Once mining has been completed at the Site, the final mining cut will be backfilled, and a topsoil horizon placed above the 200 mm clay layer for the establishment of vegetation. During the placement of the topsoil layer it is important to avoid compaction of the soil as this will lead to destruction of the soil horizons.

During topsoil placement the following steps should be taken:

1. Assuming soils were stripped according to form, the soils should be placed according to the existing plan for the Site;
2. A soil reserve should be maintained at the Site to allow for the repair of localised subsidence (if any);
3. The replacement of soils should be done using appropriate equipment to avoid compaction and the greatest possible thickness achieved with a single lift;
4. In order to minimize compaction, it is recommended that soils are moved when they are dry;
5. Should soil layering be implemented, running over lower soil layers with heavy machinery should be minimized to avoid compaction;
6. It is recommended that soil smoothing is done using dozers as opposed to graders; and
7. Once in place, soils should be ripped to full rooting depth and where natural vegetation is not possible tilling should be done to allow for seeding of pre-selected plant species.

Simulated groundwater rebound at the Site indicated that decant is possible, although limited, at the central region of Opencast 1, with no decant expected at Opencast 2. The predicted decant volume at Opencast 1 was in the order of 250-300 m^3/day, with expected sulphate concentrations of ~400-500 mg/l.

Based on the geochemical, groundwater level and groundwater quality data available for the Site currently and the simulated groundwater impacts for the Site during the operational, closure and post-closure LoM phases several potential AMD management/treatment solutions were evaluated for the Site. These potential solutions were evaluated based on their efficiencies, overall environmental footprint (incl. space requirements, power requirements, by-product generation etc.) and are discussed in more detail the Sections which follow. The final solution for the management of AMD (if any) at the Site will be determined, designed and implemented (where possible) during the operational phase of the LoM.

11.3.2.a. Pump-and-Treat AMD Solution (Ion Exchange)

Conventional pump-and-treat solutions for AMD include ion exchange and reverse osmosis (RO) technologies, or a combination of the two (depending on metals present in the AMD). Based on the simulated volumes and SO_4 concentrations of potential AMD product at the Site an ion exchange solution would be the most effective and cost-efficient.

The process for ion exchange treatment is comprised of the following summarised steps, with Figure 11.4 presenting a schematic of the ion exchange process:

1. Decant product is captured and contained within a lined, suitably sized dam or impoundment for pumping to the treatment system;
2. Water pumped to the system undergoes Pre-treatment where detritus and organic material is removed from the water using a combination of sand filters and UV treatment;
3. Water is passed through a number of resin chambers where sulphate and metals are removed; and
4. In-line water quality monitors (for pH, SO_4 and other parameters of concern) determine the suitability of the treated water for discharge, where compliant treated water is discharged into the environment and non-compliant water is diverted back to the feed water tank for additional treatment.

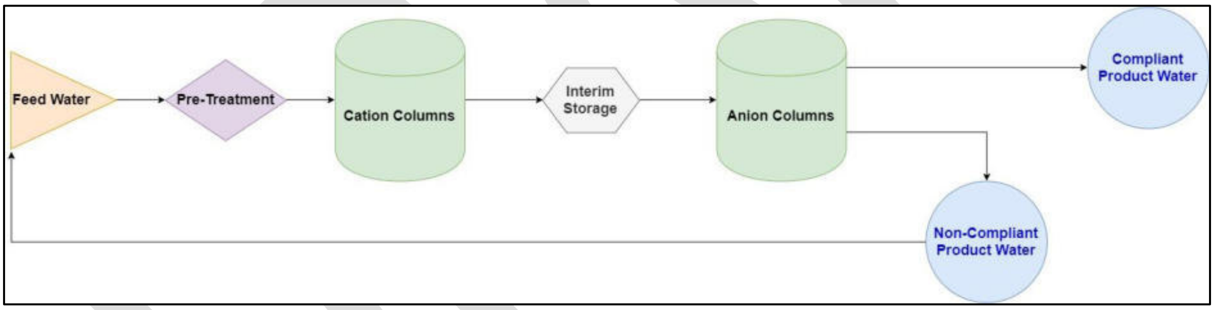

Figure 11.4: Ion Exchange Process Schematic

The ion exchange plant would be constructed at the central region of Opencast 1, near to the potential decant zone, in order to reduce the footprint of the treatment system. Treated water would ideally be discharged to the Leeuwfonteinspruit river west of the Site, as shown in Figure 11.6. In the event of decant occurring at Opencast 2, a domestic scale ion exchange plant would be constructed and used to treat the decant product to suitable water quality for discharge to the environment.

The main advantage of a pump-and-treat system for the treatment of AMD is the proven track record of the technology and the upgradeability of the solution where applicable. Howard *et al*. (2009) applied ion exchange technology for AMD within the Witwatersrand basin successfully, where sulphate concentrations were reduced from 1’290 mg/l to 50 mg/l following treatment.

A further advantage of ion exchange processes, when compared with RO, is the limited by-product generation during treatment as the ion exchange resin columns can be removed entirely and replaced when required. Disadvantages of the pump-and-treat solution are the relatively high capital and operational costs associated with the systems, as well as the relatively permanent infrastructure footprint of the plant at the Site.

11.3.2.b. Neutralisation of Backfill Material

During the backfill operations at cuts intersecting the simulated decant area (Figure 9.15), neutralising carbonate material would be added to the carbonaceous backfill material at a ratio of 1:3 (Maree *et al.*, 2013) in order to increase the neutralisation potential of the material and reduce the AMD generation “in situ” prior to decant occurring.

The addition of carbonate material is relatively inexpensive due to the availability of materials locally within the Site region and is comparatively simple to implement. The required tonnage of neutralising material would need to be determined following additional geochemical testing and modelling at the Site during the operational phase.

11.3.2.c. Constructed Wetland Treatment

A constructed wetland uses a combination of plants, invertebrates and microorganisms to improve water quality at a particular Site, with the combination selected and designed carefully to suit Site-specific conditions and treatment requirements. Based on the simulated decant volumes at the Site, a subsurface flow wetland would be most suitable. The wetland would be constructed at the central region of Opencast 1 (west of the decant zone, as shown in Figure 11.7), with decant water being channelled to the wetland and treated water discharged to the Leeuwfonteinspruit river. The estimated wetland size would be 12-15 Ha, which will be confirmed and refined during the operational phase of the mine and final designs completed prior to final mine closure. Should any decant occur at Opencast 2, the decant will be captured and discharged at the Opencast 1 constructed wetland area for treatment prior to being discharged to the Leeuwfonteinspruit river.

Constructed wetlands remove the selected contaminants of concern through several processes, included in the wetland design, which can include (as shown in Figure 11.7):

- Sedimentation and Precipitation;
- Filtration and Adsorption;
- Microbial Conversion and Degradation;
- Plant uptake; and
- Chemical Transformation and Precipitation.

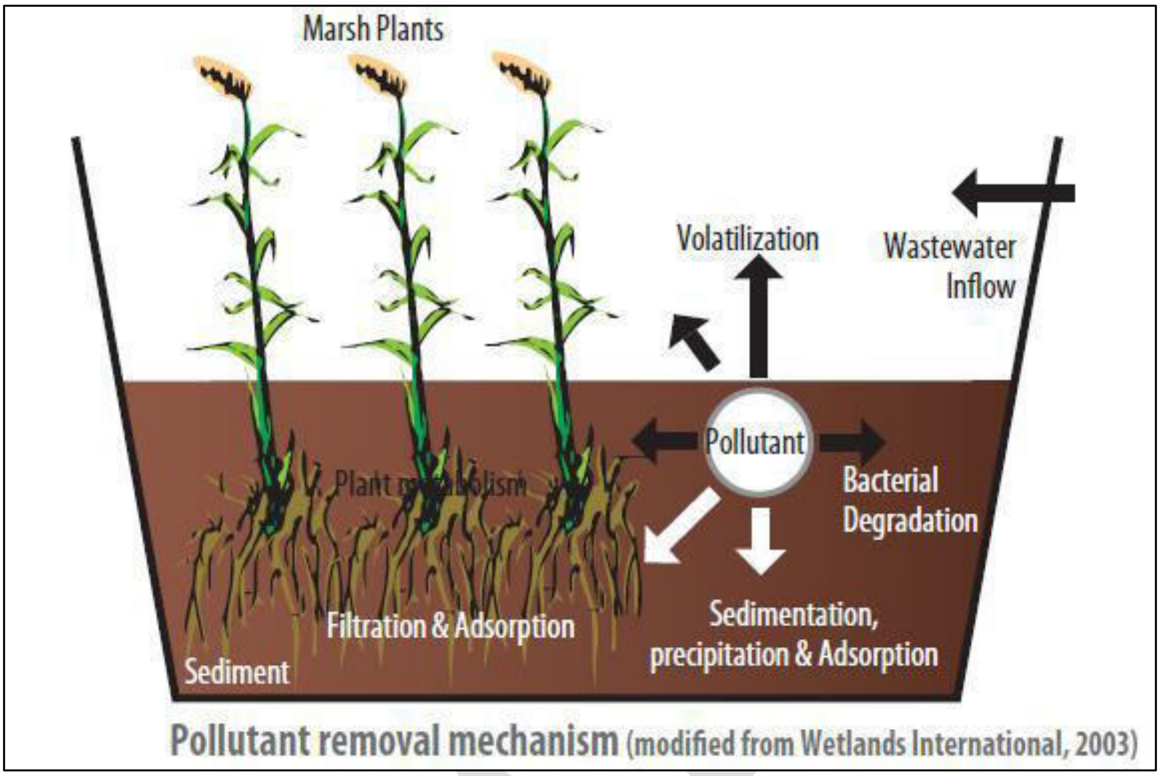

Figure 11.5: Contaminant Removal Mechanisms (after Otto and van Niekerk, 2018)

A subsurface flow wetland would be most appropriate for the Site based on the available and simulated data, with a schematic of the process shown in Figure 11.8. The wetland treatment process is comprised of several stages, namely:

1. Pre-filtration of the feed water (using gravel beds and selected vegetation);
2. An anoxic environment is created to promote sulphate-reducing bacterial activity and water is retained at an inlet pond;
3. Water flows through a macrophyte zone where vegetation, bacteria and mechanical filtration and chemical processes occur; and
4. Following retention in an outlet pond the water passes through an oxygenated environment prior to discharge to the environment.

The advantages of the constructed wetland solution include the relatively low operational costs, the tolerance of variations in flow through the wetland, provision of habitat for various plant and animal species and their ability to fit into the landscape of the Site. Disadvantages, or limitations, to consider are the relatively large footprint of the wetland compared with other treatment options and the fact that a minimum water flow is required for the wetland to survive at the Site.

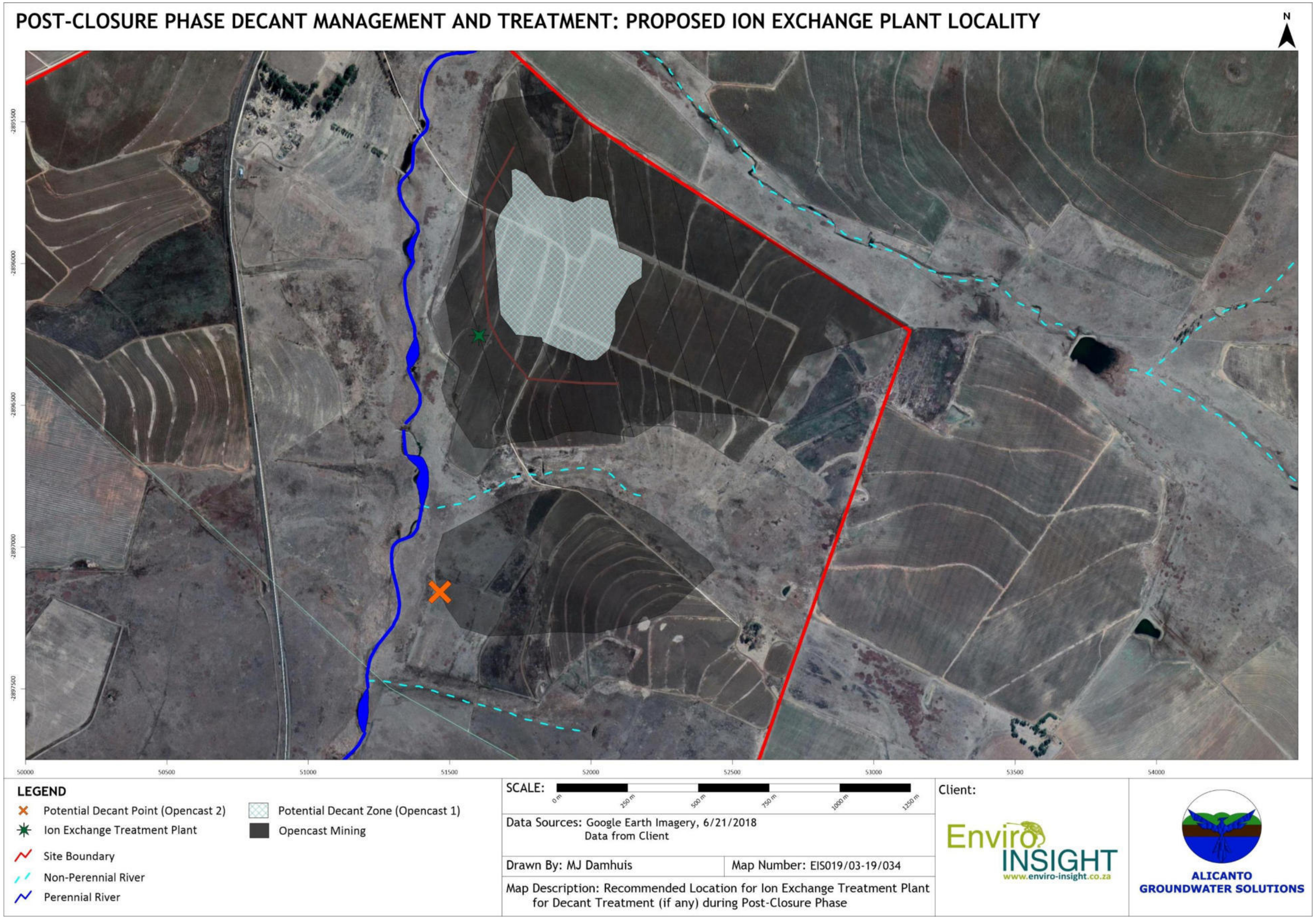

Figure 11.6: Recommended Site for Ion Exchange Treatment Plant

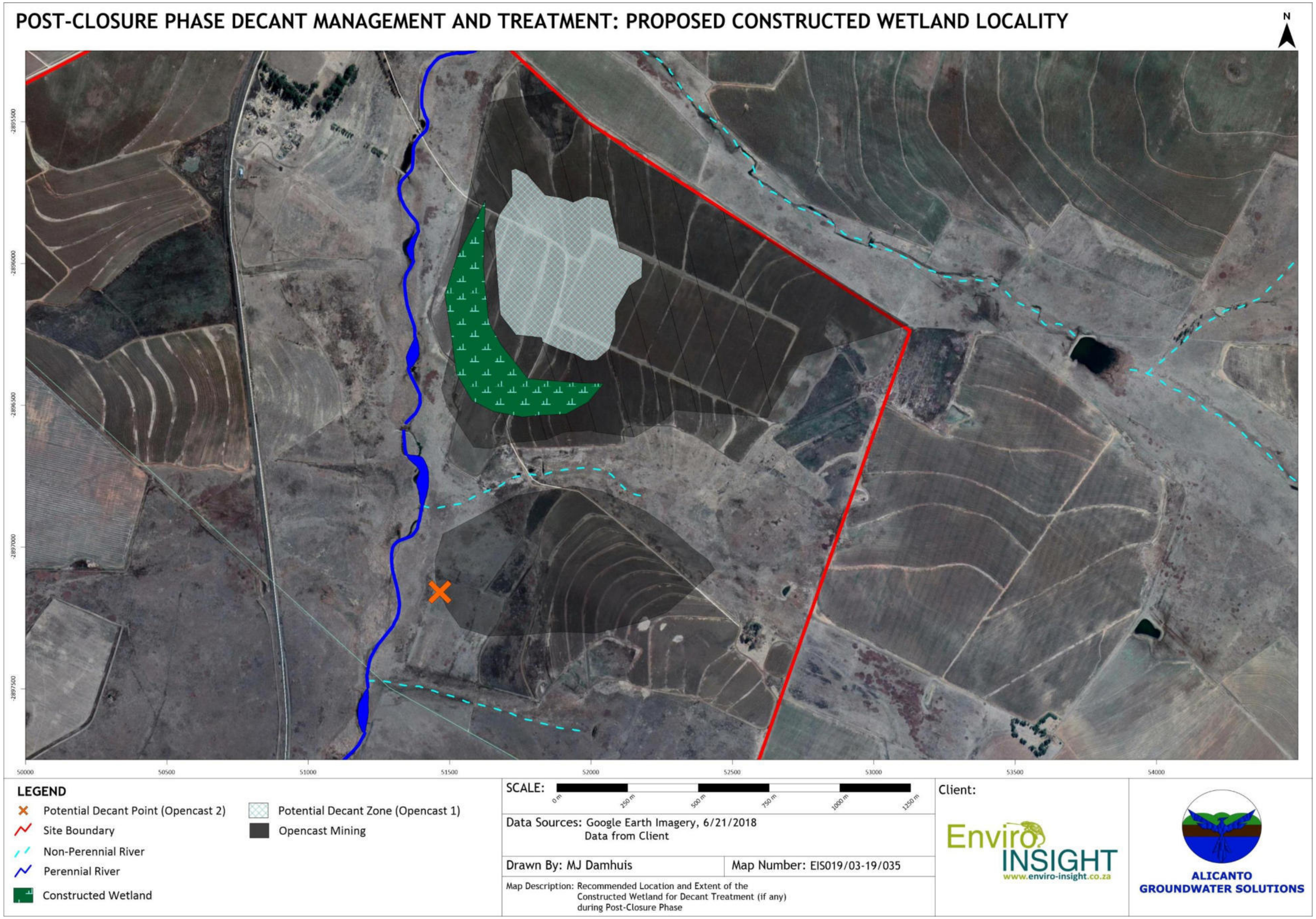

Figure 11.7: Constructed Wetland Configuration (Post-Closure Phase)

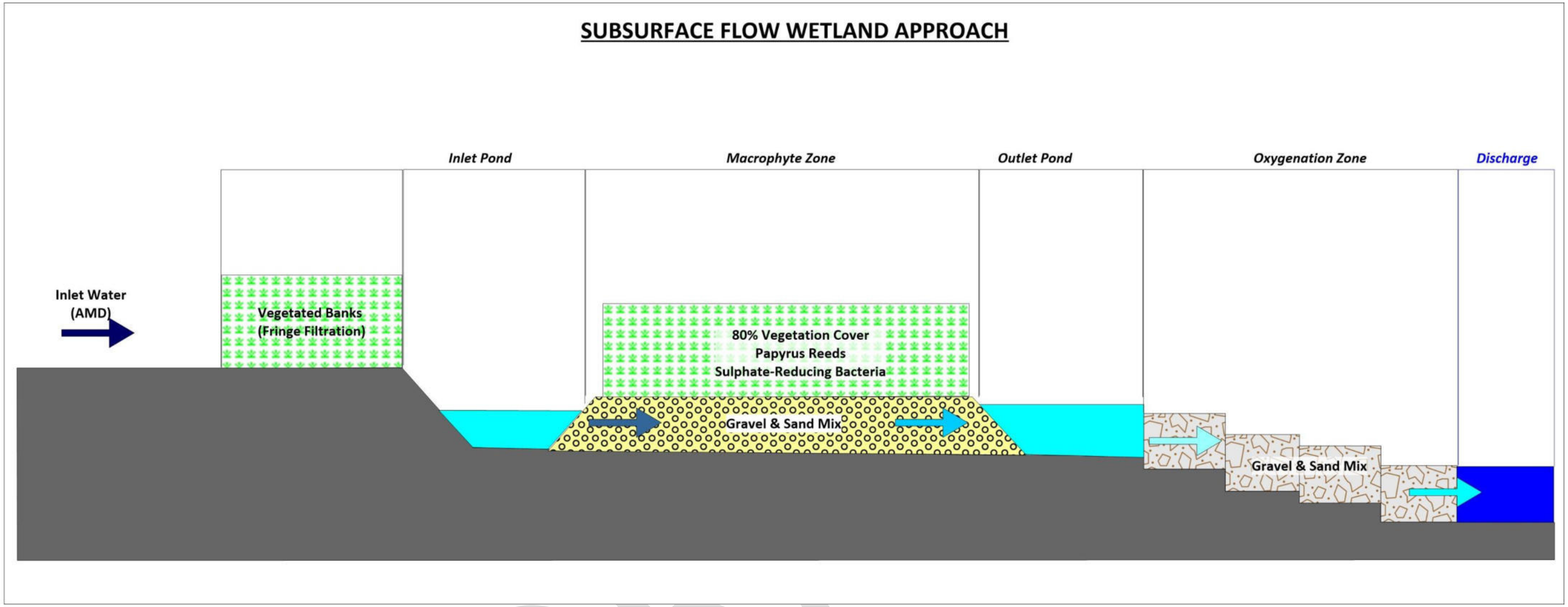

Figure 11.8: Subsurface Flow Wetland Process Schematic

12. Conclusions & Recommendations

Alicanto Groundwater Solutions (Pty) Ltd ("AGS") was appointed by Mr Corne Niemandt of Enviro-Insight (Pty) Ltd ("the Client") to conduct a hydrogeological investigation for the proposed Dunbar Coal Mine ("the Site") located near to Hendrina, Mpumalanga Province.

The hydrogeological investigation will be used in the Site's environmental authorisation processes (i.e. Environmental Impact Assessment (EIA), Water Use License Application (WULA), etc.). The objective of the investigation was to characterise the baseline hydrogeological environment at the Site and the potential impact (if any) that the proposed Site activities would have on the receiving environment.

The Site falls primarily within B11A with the western portion of the Site section falling within B11B, which are situated within the Highveld region of South Africa, with a dry winter season and wet, high intensity rainfall summer season (Nurizon, 2019). The majority of rainfall occurs between October and March, with a mean annual precipitation (MAP) of 620 mm and mean annual evaporation (MAE) of 1'972 mm. (Figure 4.2). Site surface elevations range between 1'600 and 1'700 m amsl, sloping gently towards the perennial Leeuwfonteinspruit at the centre of the Site and various non-perennial channels and wetland/pan features situated across the Site region.

Coal will be extracted from the upper Seam 4 and bottom Seam 2 resources at two (2) opencast areas (i.e. Opencast 1 and Opencast 2) at the Site using conventional truck-and-shovel opencast mining methods, the planned life of mine (LoM) for Opencast 1 is ten (10) years and five (5) years for Opencast 2, with an average production rate of 1.5 Mtpa and mining to depths of 60 m on average for both pit areas.

Geochemical samples were taken at the Site and were representative of overburden material (samples 'DRB Carb Shl' and 'DC-OVB'), as well as the 4 seam coal resource at the Site (sample 'INDB08/4L/2') and were geochemical testing, including ABA and NAG testing.

The mineralogical compositions of the samples were determined using XRD, with the following observations made:

- Organic carbon (%C) was highest in the coal sample (INDB08/4L/2) (45.49 weight %), followed by carbonaceous shale (5.59 weight %). No organic carbon was present in the overburden sample;
- Pyrite was present in small amounts in the coal sample, with no pyrite noted in the carbonaceous shale or overburden samples;
- Quartz content increased from the coal sample to carbonaceous shale with the overburden sample showing the highest quartz value; and
- Dolomite was present in the coal sample, with calcite values in the overburden and coal samples being similar.

Based on the Miller *et al*. (1997) screening criteria for NAG testing results, all of the samples collected at the Site were rock type IV (non-acid forming). Based on ABA test results the carbonaceous shale and coal samples both showed potential for acid generation (Rock Type II), while the overburden sample showed no acid generation potential (Rock Type IV). Sulphur speciation of the samples showed the coal sample to have the highest percentage of sulphur as S and sulphide sulphur, with the overburden sample showing sulphur as S to be dominant while the carbonaceous shale sample showed sulphide sulphur as dominant.

No kinetic leach testing was completed for the Site, however Mokoena (2012) performed kinetic testing on representative samples from the Site region, which were considered representative of the Site materials. Contaminants of concern for the Site were sulphate (SO_4), aluminium, manganese and iron, with the cumulative concentrations after twenty (20) weeks of testing by Mokoena (2012) for similar sample material to that found at the Site showing sulphate values ranged between ~150 and 1'850 mg/l and an average of ~670 mg/l. Aluminium, manganese and iron values were generally 0 mg/l, with non-zero value samples showing an average of 5.10 mg/l, 1.06 mg/l and 98.28 mg/l, respectively.

A Hydrocensus investigation was conducted within a 5-km radius of the Site and within the Site boundaries, during which a total of 22 boreholes were identified. A total of 9 boreholes were in use as either domestic or livestock water supply, with the remaining 13 boreholes being either monitoring boreholes or not in use. The average borehole depth was ~28 m, ranging between 8 and 53 m, with the borehole abstraction rates (based on communications with users) ranging between ~100 and 1'000 litres per day. Regional groundwater levels ranged between 3 and 15 m bgl, up to 30 m bgl locally, with an average water level of 10 m bgl, with groundwater levels at the Site and immediate surroundings between 3 and 10 m bgl, with an average groundwater level of 4.7 m bgl. Both regional and Site groundwater levels showed strong correlation to surface elevation, suggesting groundwater flow takes place under semi-confined conditions, generally, and mimics surface topography.

A total of twelve (12) geophysical lines were completed using a combination of electromagnetics (EM-34) (8 lines) and magnetics (4 lines) geophysical methods, with a total of 4'850 m of survey completed. A total of twelve (12) potential drilling targets were identified based on the geophysical survey results.

Three (3) hydrogeological boreholes were installed at the Site based on the results of the geophysical investigation, as well as previous investigations, and installed at the site to act as aquifer characterisation boreholes. The boreholes were installed to depths of 33 to 66 m using conventional air percussion drilling methods to a final diameter of 200 mm and 165 mm diameter solid steel casing installed up to the end of the weathered zone (i.e. 13-18 m below ground level (bgl)).

Water strikes in the boreholes were associated with contact zones between weathered and competent rock units, with borehole DBR-01 showing a final blow yield of 1 l/s, DBR-02 being 0.2 l/s and DBR-03 showing a seepage water intersection.

Each of the newly installed borehole underwent constant rate aquifer testing, where water was removed from the borehole at a constant rate for periods between 25 and 195 minutes and the response in water level measured. Following the constant rate test the water level recovery was measured until the water level had recovered to 90% of the original water level. The results of the aquifer tests were interpreted using the Cooper-Jacob and Theis residual straight-line fitting methods.

Borehole **DBR-01** showed an average transmissivity of 6.6 m^2/day, ranging between 6.1 and 7.1 m^2/day, with analysis of the resultant drawdown curve at the borehole showed the borehole to be situated in a semi-confined aquifer, with a potential recharge boundary (most likely the river channel located north of the borehole). Borehole **DBR-02** had an average transmissivity of 0.13 m^2/day, ranging between 0.11 and 0.14 m^2/day. Analysis of the resultant drawdown curve at the borehole showed the borehole to be situated in a confined aquifer, with no boundary conditions identified from pump testing data. Borehole **DBR-03** showed an average transmissivity of 0.49 m^2/day, ranging between 0.19 and 0.79 m^2/day. Analysis of the resultant drawdown curve at the borehole showed the borehole to be situated in a fractured, semi-confined aquifer, with an impermeable flow boundary condition located near to the borehole.

Five (5) groundwater samples were taken during the hydrocensus investigation and the three (3) newly installed boreholes at the Site were sampled following aquifer testing, with the sample analysis results compared to the SANS 241: 2015 limits for drinking water quality, as well as the DWS guideline values for domestic water and irrigation. The following observations were made based on the Site groundwater quality data:

- In general, the samples were compliant with the SANS 241:2015 limits, with the following exceptions:
  - Nitrate exceeded the limit at boreholes WMT01 and DBREBH, which was most likely due to nearby agricultural activities;
  - Aluminium and iron exceeded the limit at DBR-03, which is likely to be caused by natural groundwater-rock interactions at the Site; and
  - Manganese exceeded the aesthetic limit at boreholes MKL01 and DBREBH, which is likely to be as a result of natural groundwater-rock interactions.
- When compared with the DWS water quality guideline values the following was noted:
  - Most of the hydrocensus borehole samples (excl. MKR01) had calcium and hardness levels above the target value range, with borehole DBR-01 also exceeding the target value range;

    - Boreholes MKL01 and WMT01 were above the guideline range values for magnesium, with borehole WMT01 also exceeding the guideline values for EC, TDS and chloride;
    - Nitrate was above the guideline range at boreholes MKR02 and DBR-01;
    - The pH value at MKR01 (5.91) was slightly below the guideline range values, but remained within the SANS 241:2015 limit; and
    - Manganese was above the domestic guideline range at boreholes DBR-01 and DBR-02, with lead at DBR-03 exceeding guideline values.
- EC values at boreholes MKL01, DBREBH and DBR-01 were outside the guideline values for irrigation, as well as manganese at borehole DBR-03.

The Site groundwater quality data was used to construct a trilinear piper diagram, with the following observations made:

- Boreholes DBR-02, MKR02 and MKL01 were calcium-bicarbonate water type;
- Borehole MKR01 was sodium-bicarbonate water type, with sodium enrichment most likely as a result of evaporation during the dry season;
- Boreholes DBREBH, DBR-01 and WMT01 were calcium-chloride type waters, with DBREBH showing chloride enrichment; and
- Borehole DBR-03 was calcium-sulphate type water.

The Site groundwater system is comprised of three (3) hydraulically connected hydrogeological units, namely:

- A shallow, weathered zone hydrogeological unit;
- A deeper, fractured rock hydrogeological unit; and
- A basement hydrogeological unit.

The upper, weathered hydrogeological unit is typically found between 5 and 12 m depths, with the dominant recharge mechanism being infiltration of rainwater (1-5% of MAP) and secondary interactions with surface water bodies, locally. The average transmissivity of the weathered zone is 1-3 m^2/day, depending on the clay content of the weathered material, up to ~5-10 m^2/day at alluvial zones near to perennial rivers. The movement of groundwater in the upper weathered unit is controlled by the lower permeability shale or dolerite layers and typically mimics surface topography.

The fractured rock hydrogeological unit is found at depths ranging between 15 and 50 m with water strike intersections decreasing with depth. The matrix of the Vryheid formation geology is well-cemented, thus lowering groundwater potential in the matrix and leading to almost all economic water strikes being associated with secondary geological features such as faults, fracture zones and intrusive contact zones (e.g. contact zones at dolerite sills or dykes). Recharge to the fractured rock unit is mainly as a result of storage water released from the upper weathered unit, with outcrop zones being recharged from rainfall infiltration (<1-2% MAP). Transmissivity values for the fractured rock unit ranged between 0.5 and 7 m^2/day, with fracture zones showing transmissivities of ~0.5-1.5 m^2/day and contact zones between lithology units having transmissivity values of ~3-7 m^2/day.

The basement hydrogeological unit is generally regarded as insignificant due to its low yielding nature, great depth (>100 m) and limited recharge potential due to the overlying Dwyka tillite or felsite units. The transmissivity values of the basement unit are expected to be in the order of 0.05 and 0.1 m^2/day.

The groundwater component of the reserve was calculated as 74%, leaving 0.71 Mm^3/a as allocable groundwater resources. The proposed abstraction volume (0.02 Mm^3/a) was 2.82% of the allocable groundwater resource, with the calculation summarised in Table 12.1.

Table 12.1: Groundwater Reserve Calculation

Description	Unit	Value
Unit of Analysis Area	m^2	144 836 218
Mean Annual Precipitation (MAP)	mm/a	620
Recharge to Groundwater	Mm^3/a	2.69
Basic Human Need	Mm^3/a	0.03
Groundwater Contribution to Baseflow	Mm^3/a	1.95
Existing Abstraction	Mm^3/a	0.3
Proposed Abstraction	Mm^3/a	0.02
Total Recharge (Inflow)	Mm^3/a	2.69
Groundwater Reserve	%	74%
Allocable Reserve	Mm^3/a	0.71
Proposed Abstraction as % Allocable Reserve	%	2.82%

The Site aquifer vulnerability was determined using the modified DRASTI method, showing the Site aquifer system to be medium vulnerability, with localised zones of high vulnerability associated with alluvial material zones and river/wetland areas around the Site. Based on the hydrocensus results the Site aquifer is a 'Minor Aquifer System', due to the local population engaged during the hydrocensus investigation not being dependent on groundwater. The Groundwater Quality Management (GQM) index was calculated and the calculated level of protection was 4 (i.e. medium level of protection).

A groundwater flow and contaminant transport model was constructed for the Site using Processing MODFLOW for Windows (PMWIN) 8 (Simcore Software, 2012) which uses the MODFLOW finite difference code developed by the USGS (Macdonald & Harbaugh, 1988) and is a widely accepted numerical modelling code for solving groundwater flow problems. Groundwater contaminant transport was simulated using the MT3D MS code within PMWIN.

Perennial rivers were set as the northern, southern, eastern and western model boundaries, with limited sections at the northern model domain set as general head boundaries situated far away enough from the mining activities to not interact with the simulation results. Steady state flow model calibration was completed using head observation data from the NGA (DWS, 2019a), Rison (2008) and GHT (2009) and a combination of manual and automated calibration methods. The total head variance across the dataset was 87.07 m, setting a residual head criterion of 8.71 m (after Mandle, 2002). A final mean error (ME) and mean absolute error (MAE) of -1.69 and 4.10 m, respectively, was achieved. The final root mean square error (RMSE) was 5.36, which was lower than 10% of the dataset head variation (i.e. 8.71 m), thus the steady state model was considered calibrated. Transient state flow model calibration was completed using head observation collected during the project hydrocensus investigation and aquifer testing, using a combination of manual and automated calibration methods. The total head variance across the dataset was 66.41 m, setting a residual head criterion of 6.64 m (after Mandle, 2002). A final mean error (ME) and mean absolute error (MAE) of 4.96 and 5.11 m, respectively, was achieved. The final root mean square error (RMSE) was 6.22, which was lower than 10% of the dataset head variation (i.e. 6.64 m), thus the transient state model was considered calibrated. Recharge and hydraulic conductivity both showed slight sensitivity when decreased with recharge showing the highest sensitivity when increased and hydraulic conductivity showing a high sensitivity when increased by one order of magnitude. Specific storage showed little sensitivity when adjusted.

The calibrated transient state flow and transport models were used to simulate various scenarios at the Site in order to determine the potential impacts on the receiving groundwater environment in terms of both quantity and quality changes.

The hydrogeological impact assessment for the Site considered the construction, operational, closure and post-closure phases of the LoM, with the numerical model scenario results interpreted to determine the hydrogeological impacts in terms of quality and quantity at the Site. The impacts for the construction, operational and closure/post-closure phases of the LoM are summarised in Table 12.2, Table 12.3 and Table 12.4, respectively.

Table 12.2: Construction Phase Impact Summary

Description of Activity	Model Scenario	Impact Description	M	S	D	P	Risk		Mitigation/Management Measures	M	S	D	P	Risk	
Groundwater Quantity															
Vegetation Clearing	All Model Scenarios	Clearing of vegetation and topsoil may result in increased runoff and reduced recharge to the groundwater system.	2	5	1	3	24	Low	Areas to be cleared should be limited as far as possible.	2	5	1	3	24	Low
Groundwater Dewatering	All Model Scenarios	Groundwater abstraction at the Site borehole may result in localised dewatering.	2	2	1	2	10	Low	Water levels and abstraction volumes should be monitored and recorded. Borehole pump schedules should always be adhered to and water reclaimed within the system where possible to reduce usage.	2	2	1	1	5	Low
Groundwater Quality															
Hydrocarbon Spills	All Model Scenarios	Hydrocarbon spills from construction vehicles and/or laydown areas and workshops may enter the groundwater system.	6	2	1	4	36	Medium	Workshop and Laydown areas should be properly compacted and bunded. Appropriate spill kits should always be available and contaminated soil should be removed as soon as possible and disposed of at an accredited facility.	2	2	1	2	10	Low
Domestic Waste Generation	All Model Scenarios	During construction domestic waste will be generated by contractors and staff.	2	2	3	4	28	Low	Domestic waste should be disposed of at a dedicated, suitable landfill site and managed appropriately.	2	1	3	2	12	Low

Table 12.3: Operational Phase Impact Summary

Description of Activity	Model Scenario	Impact Description	M	S	D	P	Risk		Mitigation/Management Measures	M	S	D	P	Risk	
Groundwater Quantity															
Groundwater Dewatering	Base Case Scenario	Groundwater inflows to the active mining area may result in dewatering of the surrounding aquifer system(s).	4	3	2	4	36	Medium	No Mitigation Possible. Groundwater levels at the Site and surroundings should be monitored on a quarterly basis in order to determine any negative trends that may occur due to dewatering of the mining area. Should mining activities negatively impact any surrounding groundwater users, the mine should compensate the affected parties accordingly and provide alternative water supply for the duration of mining operations.	4	2	2	3	24	Low
	Scenario 1		8	3	4	5	75	High		6	3	4	4	52	Medium
	Scenario 2		4	3	2	4	36	Medium		3	2	2	3	21	Low
	Scenario 3		4	3	2	4	36	Medium		4	2	2	3	24	Low
	Scenario 4		4	3	2	4	36	Medium		3	2	2	3	21	Low
	Scenario 5		2	2	2	3	18	Low		2	2	2	3	18	Low
	Scenario 6		2	2	2	3	18	Low		2	2	2	3	18	Low
Groundwater Quality															
Backfill Material Leachate	All Model Scenarios	Poor quality leachate generated within the backfill material used at the Site during concurrent rehabilitation may enter the groundwater system.	6	1	4	4	44	Medium	Sulphide-bearing material should be placed at the base of the backfilling and covered as soon as possible with more neutral material to prevent oxidation. A 200 mm clay layer should be placed on top of the backfill material to limit water ingress.	4	1	4	3	27	Low
Poor Quality Seepage from the PCD	All Model Scenarios	Poor quality water stored at the Site PCD may seep into the groundwater system at the Site.	4	1	4	2	18	Low	The liner at the PCD should be maintained and regularly inspected for any tears and/or leakage. The freeboard at the PCD should be maintained at all times to avoid overflow and water quality sampling should be taken regularly at the PCD.	2	1	4	2	14	Low
Waste Rock/Coal Stockpile Leachate	All Model Scenarios	Poor quality leachate from the Site waste rock dump and coal stockpile areas may enter the groundwater system.	4	1	4	3	27	Low	Carbonaceous material stored at the waste rock dumps should be covered where possible to limit the oxidation of sulphide-bearing materials, with the dumps contoured, where possible, to encourage runoff. Material stored at the coal stockpiles should be removed as soon as possible to prevent oxidation of the material and sufficient surface water management infrastructure put in place to limit standing water at the stockpiles. Groundwater monitoring boreholes should be installed at the dump and stockpile areas and water quality samples taken regularly.	2	1	4	2	14	Low

Table 12.4: Closure/Post-Closure Phase Impact Summary

Description of Activity	Model Scenario	Impact Description	M	S	D	P	Risk		Mitigation/Management Measures	M	S	D	P	Risk	
Groundwater Quantity															
Groundwater Level Rebound	All Scenarios	Following the end of mining operations at the Site groundwater levels will rebound to pre-mining water levels.	2	1	4	3	21	Low	No Mitigation Required. Groundwater levels at the Site should be measured quarterly to identify groundwater level trends.	2	1	4	2	14	Low
Decant	All Scenarios	Decant may occur at the Site during the rebound of water levels.	8	3	5	2	32	Medium	Should decant occur at the Site, a suitable capture and treat system should be implemented and the water treated to levels suitable for discharge to the environment.	6	2	5	2	26	Low
Groundwater Quality															
Poor Quality Leachate	All Scenarios	Poor quality leachate generated within the backfill material used at the Site during concurrent rehabilitation may enter the groundwater system.	6	2	4	3	36	Medium	Sulphide-bearing material should be placed at the base of the backfilling and covered as soon as possible with more neutral material to prevent oxidation and a 200 mm clay layer should be placed on top of the backfill material to limit washout of material through water ingress. If possible, the material should be covered/inundated as soon as possible to limit oxidation potential.	4	2	3	3	27	Low

12.1. Recommendations

Monitoring Network

A total of nineteen (19) new monitoring boreholes (excluding the existing DBR01 and DBR03 boreholes) are recommended to be drilled comprised of 6 multi-level borehole sets drilled between mine workings and wetland features, 7 monitoring boreholes installed during the operational phase and 6 monitoring boreholes installed at rehabilitated mine workings following closure.

The multi-level boreholes should be installed to intersect the deeper aquifer zone, intermediate weathered zone and upper interflow/unsaturated zone, with the deepest borehole installed closest to the mining area and the shallowest installed toward the wetland/surface water feature being considered for baseflow monitoring.

Geochemical Assessment

It is recommended that a geochemical model assessment is completed during the life of the mine in order to calibrate and validate its results and to construct an effective closure plan. Monitoring of mine water is critical in order to validate the geochemical assessment. A geochemical model should be constructed that assess the effectiveness of potential mitigation measures and the evolution of water qualities during the operational phase so that mitigation measures could be implemented proactively.

AMD Management

During backfilling of completed cuts at the Site it is recommended that the materials are placed in such a manner that sulphide-bearing materials are placed at the base of the pit and covered with more neutral overburden material, with the material being compacted suitably to mimic the surrounding hydrogeological environment as far as possible. The backfill material should be capped with a 200 mm clay layer to limit the ingress of water into the material during operations. It is recommended that topsoil placement is only done once the final landform has been created at the open pit area.

Any groundwater ingress into the opencast pit during the operational phase should be collected in a central sump area and discharged to the PCD complex as soon as possible, thus limiting contact time with exposed material within the pit area. During mining operations, a surface water berm should always be maintained at the limits of the pit area to prevent clean runoff entering the pit area. The Site water management plan should aim to keep clean and dirty water separate during all phases of LoM, with all water encountering mining activities being considered dirty and disposed of at the PCD complex as soon as possible.

Once mining has been completed at the Site, the final mining cut will be backfilled, and a topsoil horizon placed above the 200 mm clay layer for the establishment of vegetation. During the placement of the topsoil layer it is important to avoid compaction of the soil as this will lead to destruction of the soil horizons.

During topsoil placement the following steps should be taken:

1. Assuming soils were stripped according to form, the soils should be placed according to the existing plan for the Site;
2. A soil reserve should be maintained at the Site to allow for the repair of localised subsidence (if any);
3. The replacement of soils should be done using appropriate equipment to avoid compaction and the greatest possible thickness achieved with a single lift;
4. In order to minimize compaction, it is recommended that soils are moved when they are dry;
5. Should soil layering be implemented, running over lower soil layers with heavy machinery should be minimized to avoid compaction;
6. It is recommended that soil smoothing is done using dozers as opposed to graders; and
7. Once in place, soils should be ripped to full rooting depth and where natural vegetation is not possible tilling should be done to allow for seeding of pre-selected plant species.

Simulated groundwater rebound at the Site indicated that decant is possible, although limited, at the central region of Opencast 1, with no decant expected at Opencast 2. The predicted decant volume at Opencast 1 was in the order of 250-300 m^3/day, with expected sulphate concentrations of ~400-500 mg/l.

Based on the geochemical, groundwater level and groundwater quality data available for the Site currently and the simulated groundwater impacts for the Site during the operational, closure and post-closure LoM phases several potential AMD management/treatment solutions were evaluated for the Site. The potential solutions considered were pump-and-treat (ion exchange), neutralisation of backfill material and constructed wetlands. Each of the potential solutions were evaluated based on their efficiencies, overall environmental footprint (incl. space requirements, power requirements, by-product generation etc.).

The constructed wetland treatment solution would be the preferred solution at the Site, offering benefits such as wetland reclamation and low operational costs. However, the final solution for the management of AMD (if any) at the Site will be determined, designed and implemented (where possible) during the operational phase of the LoM following further geochemical testing and numerical groundwater modelling refinement at the Site.

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Appendix A: Hydrocensus Sheets

Appendix B: Hydrocensus Laboratory Certificates

Appendix C: Geophysical Survey Results

Appendix D: Aquifer Testing Data Sheets

Appendix E: Aquifer Testing Interpretation Graphs

Appendix F: Aquifer Testing Laboratory Certificates

Appendix G: Geochemical Laboratory Certificates