Alexander Coal Project

Alexander Coal Project: Groundwater Specialist Study

SLR Project No.: 750.01080.00006
Report No.: 01
Revision No. 01

July 2016

Anglo American Inyosi Coal (Pty) Limited

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ALEXANDER COAL PROJECT: GROUNDWATER SPECIALIST STUDY

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ACRONYMS AND ABBREVIATIONS

Below a list of acronyms and abbreviations used in this report.

Acronyms / Abbreviations	**Definition**
BIC	Bushveld Igneous Complex
BH	Borehole
DWS	Department of Water Affairs and Sanitation
DWAF	Department of Water Affairs and Forestry
EMP	Environmental Monitoring Plan
E.N.	Electro neutrality
H, mamsl	Hydraulic Head, mamsl
K, m/d	Hydraulic Conductivity, m/d
mbgl	Metres below ground level
mamsl	Metres above mean sea level
PEST	Parameter Estimation Routine
QA / QC	Quality Assurance / Quality Control
SANAS	South African National Accreditation System
SANS	South African National Standards
SOP	Standard Operating Procedure
TDS	Total Dissolved Solids
WRD	Waste Rock Dump

ALEXANDER COAL PROJECT: GROUNDWATER SPECIALIST STUDY

1 INTRODUCTION

1.1 BACKGROUND

Anglo American Inyosi Coal (Pty) Ltd (“AAIC”) is proposing to establish a new underground coal mine through the Alexander Coal Project (“the Project Area”), located near Kriel in the Mpumalanga Province. SLR Consulting (Africa) (Pty) Limited (“SLR”) has been commissioned to undertake both groundwater and surface water impact assessments to determine the potential impacts of the mining on the environment. The assessments will support the Environmental Impact Assessment (EIA) for the Project.

1.2 LOCATION AND SITE LAYOUT

The Alexander Project area is in the northern part of the Highveld coalfield, near Kriel, approximately 30 kilometres from Ogies and Bethal in Mpumalanga. There is a network of tarred roads connecting the Alexander mine lease area to the surrounding towns. The road distances to Pretoria and Johannesburg are approximately 140 km, via the Pretoria/Middelburg Highway (N4) and Johannesburg/ Witbank highway (N12) respectively[2]. Figure 1-1 shows the location of the Alexander mine lease area.

The Alexander Project Area covers an area of approximately 7,300 hectares (ha) directly south-east of Kriel and approximately 14 km north-west of Bethal in the Mpumalanga Province.

1.3 PROJECT OBJECTIVES

The Scope of Work defined consists of:

- Hydrocensus of existing groundwater and surface water users in the project area.
- Develop a conceptual groundwater model for Alexander Project
- Develop a numerical groundwater model to determine the impacts of mining activities to the groundwater regime.

1.4 REPORT STRUCTURE

This report aims to present in a systematically concise manner the work conducted and results obtained.

- Section 1 outlines the scope of work in the context of the project background information.
- Section 2 presents an overview of the topography, climate, geology and hydrogeology of the proposed project area and describes the Alexander underground mining development.
- Section 3 details the SLR conducted fieldwork programme describing the baseline groundwater conditions of the site.
- Section 4 represents the 3D Groundwater Numerical Model, and
- Section 5 addresses the Groundwater Impacts Assessment for the Alexander Project.

1.5 DECLARATION

I, ***Mihai Muresan*** hereby declare that I am an independent consultant, who has no interest or personal gains in this proposed project whatsoever, except receiving fair payment for rendering an independent professional service.

I am a hydrogeologist with 25 years' experience conducting hydrogeological assessments for the mining industry. CV attached in Appendix E.

I am an Earth Science professional registered with the South African Council for Natural Scientific Professions. My registration number is 400105/10.

This report complies with the requirements of the NEMA and environmental impact assessment (EIA) regulations (GNR 982 of 2014). The table below provides a summary of the requirements, with cross references to the report sections where these requirements have been addressed.

TABLE 1-1:SPECIALIST REPORT REQUIREMENTS IN TERMS OF APPENDIX 6 OF THE EIA REGULATIONS (2014)

A specialist report prepared in terms of the Environmental Impact Regulations of 2014 must contain:	Relevant section in report
Details of the specialist who prepared the report	Section 1.5
The expertise of that person to compile a specialist report including a curriculum vitae	Appendix E
A declaration that the person is independent in a form as may be specified by the competent authority	Section 1.5
An indication of the scope of, and the purpose for which, the report was prepared	Section 1.3
The date and season of the site investigation and the relevance of the season to the outcome of the assessment	Section 3
A description of the methodology adopted in preparing the report or carrying out the specialised process	Section 1.4
The specific identified sensitivity of the site related to the activity and its associated structures and infrastructure	Section 2
An identification of any areas to be avoided, including buffers	Section 5.2
A map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers;	Section 4
A description of any assumptions made and any uncertainties or gaps in knowledge;	Section 4.6, Section 1
A description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives, on the environment	Section 1
Any mitigation measures for inclusion in the EMPr	Section 5.1.1 and 5.2.1
Any conditions for inclusion in the environmental authorisation	Section 5.1.1 and 5.2.1
Any monitoring requirements for inclusion in the EMPr or environmental authorisation	Section 1
A reasoned opinion as to whether the proposed activity or portions thereof should be authorised and	Section 5
If the opinion is that the proposed activity or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan	Section 1
A description of any consultation process that was undertaken during the course of carrying out the study	Section 3.1
A summary and copies if any comments that were received during any consultation process	N/A
Any other information requested by the competent authority.	N/A

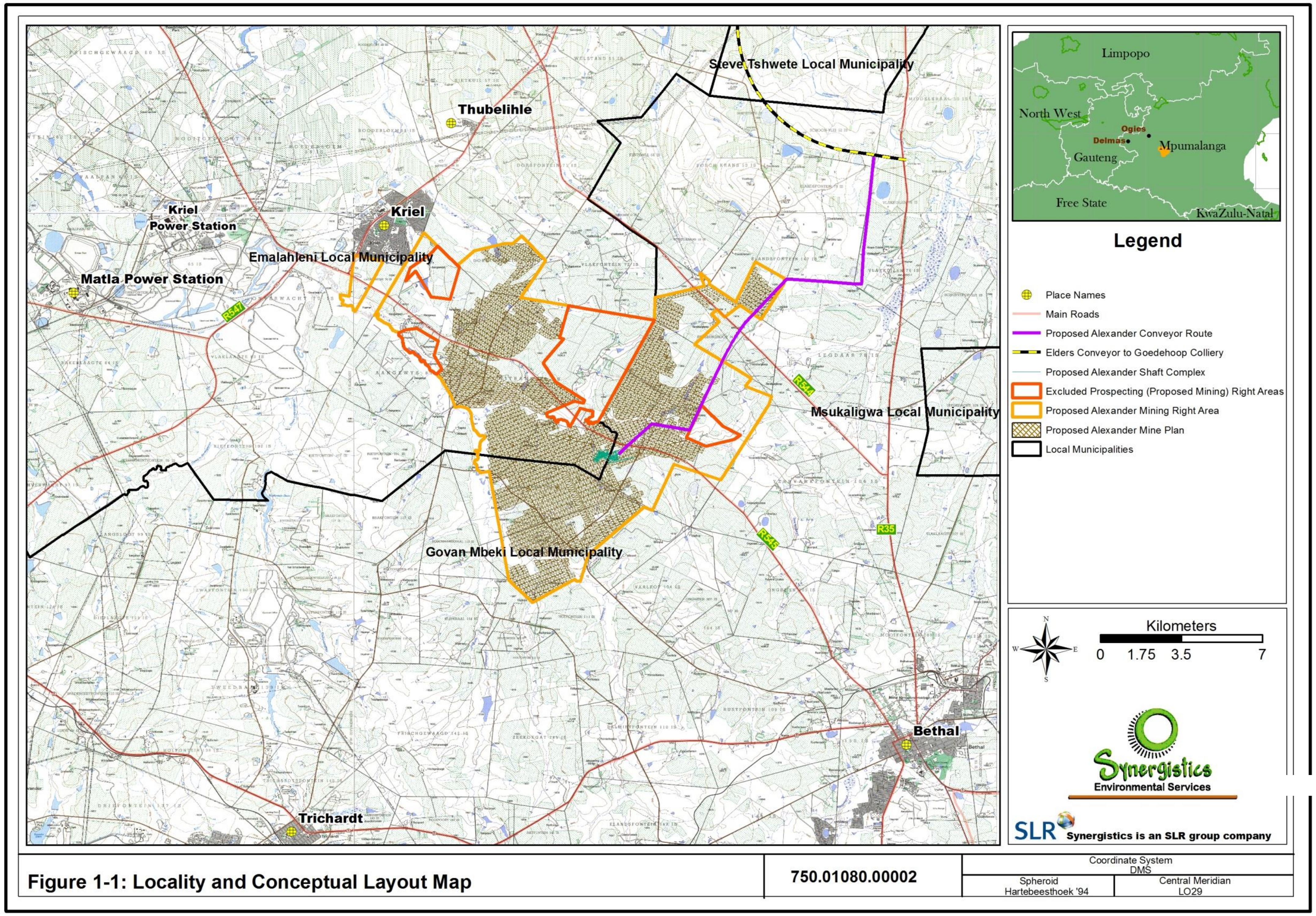


FIGURE 1-1: SITE LOCATION

2 PROJECT SETTINGS

Topography, climate and geology influence the occurrence of groundwater at the proposed project area. This section provides a brief description of these factors.

2.1 GEOMORPHOLOGY

The project area has a low relief with local depressions forming pans. The average height above sea level is between 1560 and 1630m. The gradient of the area decreases in elevation to the northwest of the study area.

Locally, the topography of the project area and surroundings slopes gently to the west and typical gradients are very low 1:250.

The topography of the project area slopes towards the north with a slight catchment divide running through the centre of the site, runoff from the west of the divide flows to the north-west and runoff from the east of the site flows to the north-east.

2.2 HYDROLOGY

The Water Resources of South Africa (WRC, 2012) shows that the project area falls within Olifants water management area (WMA). The Olifants River catchment boundary runs through the South of the project area.

The mining lease area is mainly covered by the B11C quaternary catchment area, formed by the Upper Steenkoolspruit river basin that has the Piekespruit and Debeerspruit as secondary tributaries. Northwards, the groundwater model area extends over the eastern part of the B11D catchment formed by the middle Steenkoolspruit river basin, and the southern and western tips of the B11B and B11A respectively, formed by the middle and upper Olifant River and its tributaries.

2.3 CLIMATE

The climatic conditions generally consist of moderate summers and cold winters. The WR2005 manual shows the project area falls within an area of low mean annual precipitation (MAP) 500-700mm and high mean annual evaporation (MAE) 1373mm and the area has a very low mean annual runoff of 21.55 million cubic metres or 55,974m^3/km.

Figure 2-1 shows the average monthly rainfall considered for the Alexander Project.

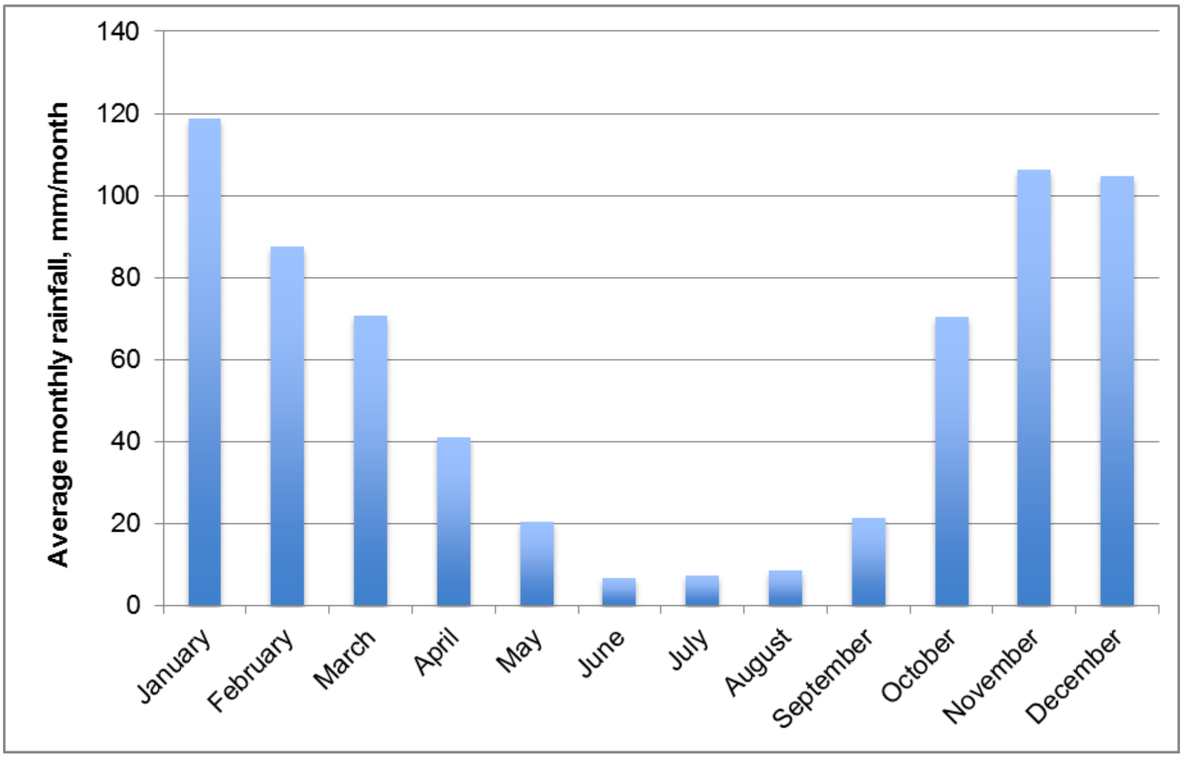


FIGURE 2-1: ALEXANDER - AVERAGE MONTHLY RAINFALL

2.4 GEOLOGY

The proposed Alexander S4 coal seam underground mining development area is situated on the northern margin of the Highveld Coalfields in the vicinity of Kriel town south-easterly adjacent to the Kriel Colliery S5 coal seam opencast operation.

The basement rocks over the area of the Highveld Coalfield range from basement granites, gabbros and norites of the BIC, to Witwatersrand Supergroup metaquartzites, and Transvaal Supergroup metaquartzites and metavolcanics (Figure 2-2).

Whilst being very similar to the stratigraphic succession in the Witbank Coalfield a generalised stratigraphic section for the northernmost Highveld Coalfield is provided in Figure 2-3.

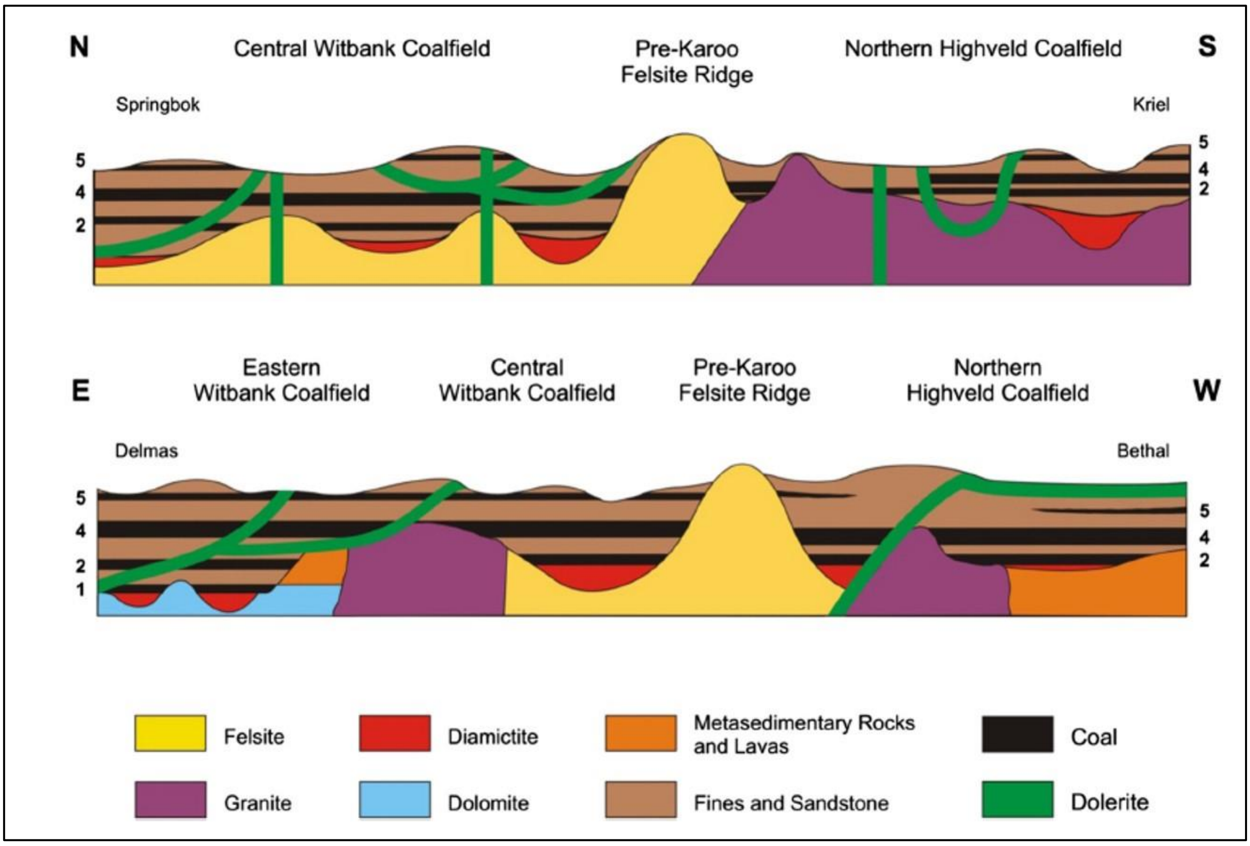


FIGURE 2-2: CROSS SECTIONS - WITBANK AND HIGHVELD COALFIELDS

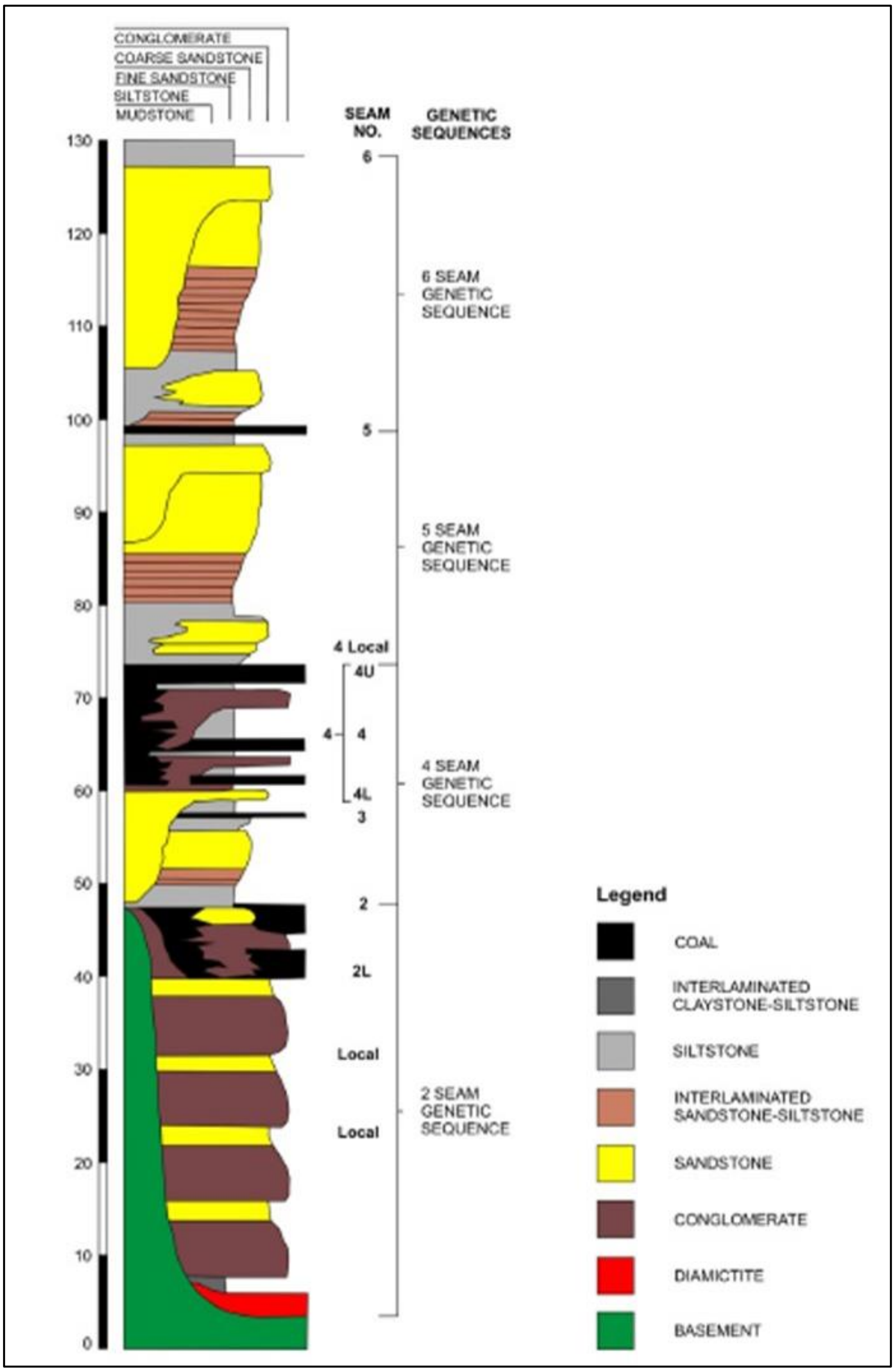


FIGURE 2-3: THE GENERALISED STRATIGRAPHY AND DEPOSITIONAL SEQUENCE OF THE HIGHVELD COALFIELD. (HANCOX AND GOETZ, 2014)

As in the Witbank Coalfield the Pietermaritzburg Formation is absent in the Highveld Coalfield, with the Dwyka Group being overlain directly by rocks assignable to the Vryheid Formation.

The Vryheid formation (Ecca) is essentially an interbedded succession of sandstone with lesser gritstone, siltstone and mudstone, which contains five coal seams of the Highveld coalfield.

The No. 4 seam lithological sequence has most commonly a carbonaceous siltstone overlain by lenticular laminated siltstone interlaminated sandstone-siltstone and cross-laminated to cross-bedded sandstone. This assemblage is intensely bioturbated in places resulting in the intermixing of sandstone and siltstone thereby producing a homogenized sequence. In the study area No 4 seam has an average thickness of 4.5 m ±2m.

2.5 HYDROGEOLOGY

Table 2-1 summarises the regional hydrogeology based on the National Groundwater Maps (Vegter 1995).

TABLE 2-1: HYDROGEOLOGICAL SETTINGS

Hydrogeological parameter	**Estimated value**
Nature of aquifer	Pores in disintegrated/decomposed, partly decomposed rock and fractures, which are principally restricted to a zone directly below groundwater level. Zone is transitional between weathered and fresh rock
Depth to groundwater (m)	10 - 20
Recharge (mm)	25 - 37
Recharge as % MAP	5 - 7
Storage coefficient	0.001 – 0.01
Probability of drilling successful borehole (%)	40 - 60

3 HYDROCENSUS

The objective of the hydrocensus was to identify groundwater users and surface water within the Project Area and to ascertain the current status of existing boreholes and to determine current groundwater and surface water conditions (groundwater elevations and ground-surface water quality).

SLR undertook the hydrocensus between the 13th and 21st of April 2016. The following section describes the monitoring and sampling methodologies and procedures.

3.1 BOREHOLE IDENTIFICATION

Prior to visiting the project area, SLR personnel used the Interested and Affected Parties (IAP) database, established from the social scan, undertaken for the site by SLR, to contact landholders within the Project Area. Landowners were contacted and those farms with boreholes noted. A number of farms were identified as ‘no go areas’.

In addition, the National Groundwater Archive (NGA) database was consulted and boreholes in the vicinity of the Project Area identified, however data for the majority of boreholes were pre-1994.

During the course of the hydrocensus, twenty-one (21) boreholes were identified and inspected. Details of the boreholes inspected are presented in Table 3-1 and Figure 3-1 illustrates the locations of identified boreholes in relation to the Project Area.

For each borehole identified, parameters including the location, groundwater level, water quality, and groundwater usage including extraction volumes and application observations were recorded. In addition, groundwater sampling was conducted at selected sites in order to gather water quality information for the area.

3.2 GROUNDWATER LEVELS

Where possible, the depth to groundwater and the depth to the base of each well were measured, using a Solinst dip meter. Depths were measured against the top of the casing and ground level.

3.3 GROUNDWATER QUALITY

3.3.1 SAMPLE LOCATIONS AND METHODOLOGY

Groundwater sampling was performed at fifteen (15) of the boreholes visited by SLR. Sampled boreholes were selected based on location, in order to gather a spread of data across the area, and also based on operational status. Boreholes with installed and frequently operational pumps were selected as preferred sampling points to ensure water within the boreholes was representative of the intersected aquifer.

Where possible, water samples were obtained directly from an outlet with close proximity to the borehole head-works. A number of samples were taken from storage dams in which the borehole pumped to. Field parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS) and temperature (°C) were measured using a calibrated multi-meter. The locations of sampled boreholes are listed in Table 3-1

3.3.2 SAMPLE PREPARATION, PRESERVATION AND TRANSPORT

In accordance with the Water Research Commission's (WRC) Groundwater Sampling report (Weaver, et al, 2007), sample filtration for dissolved heavy metals was undertaken in the field using 0.45µm in-line filter to prevent precipitation of metal species. One 250mL plastic bottle, containing nitric acid as a preservative, was filled with filtered water. A second unfiltered, unpreserved sample was collected in a one litre plastic bottle for all other analysis.

Once collected, samples were labelled appropriately, placed in a cool box with ice blocks, and delivered to the laboratory with the relevant completed chain of custody form.

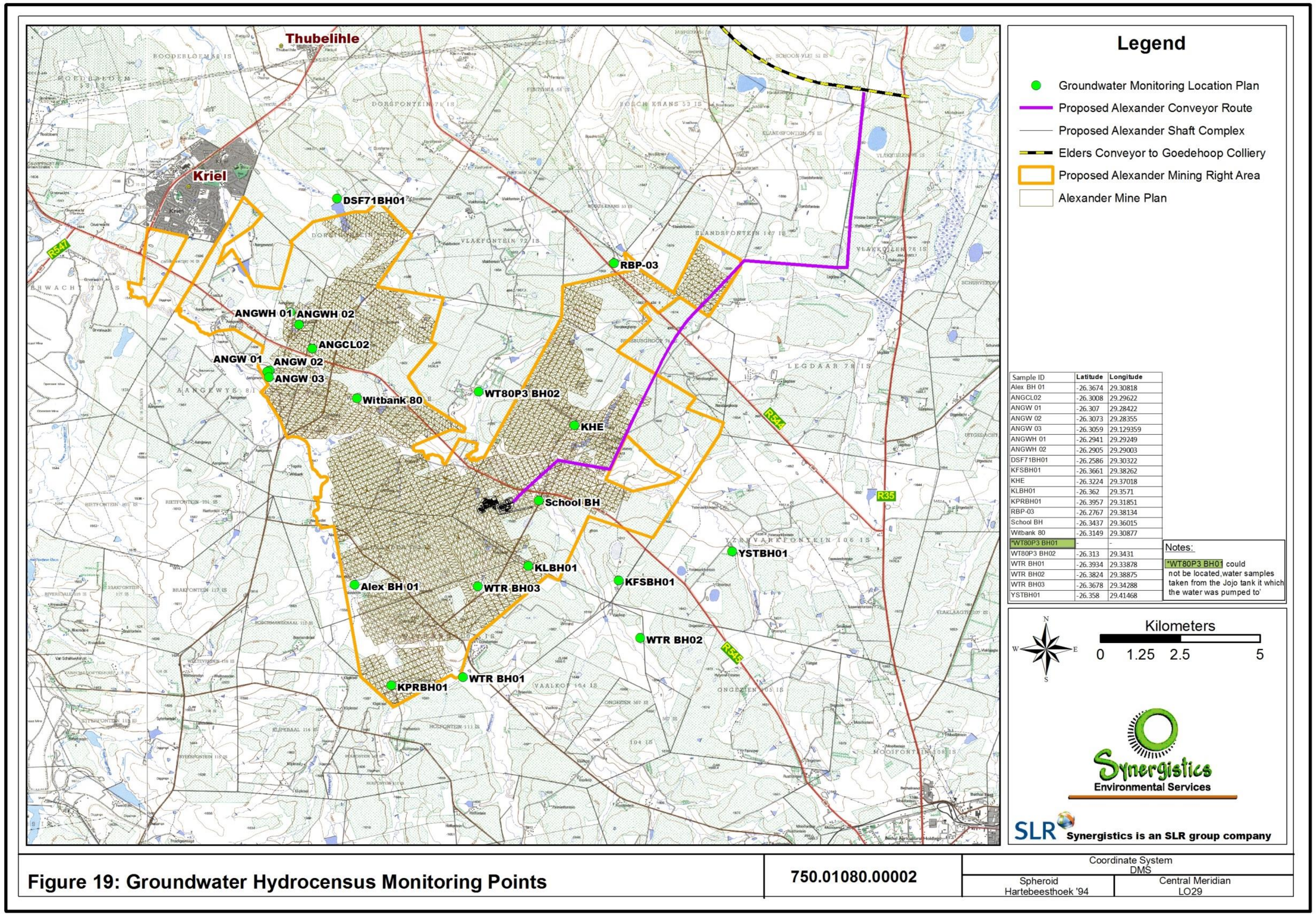
3.3.3 ANALYTICAL SUITE

All samples were sent to Waterlab (Pty) Limited, in Pretoria, South Africa, for laboratory analysis. Waterlab is a SANAS (South African National Accreditation System) accredited laboratory according to ISO/IEC 17025:2005 standards. Samples were submitted for the following analytical suite:

- Physio-chemical parameters: pH, total dissolved solids (TDS), electrical conductivity (EC), alkalinity titration.
- Major anions: fluoride, chloride, sulphate and nitrate.
- Major and trace element ICP Scan (dissolved metals).

TABLE 3-1: SUMMARY OF THE GROUNDWATER MONITORING POINTS FOR THE 2016 HYDROCENSUS

Borehole ID	Farm Name	Borehole Coordinates (WGS84)		Borehole Status	Water Application	Pump type	Water Sample Collected	Comment
		Latitude	Longitude					
Alex BH01	Alexander	-26.36735	29.30818	In use	Domestic	Submersible pump	Yes	
ANGCL02	Aangewys CL2	-26.300805	29.29622	In use	Stock Watering	Windmill	Yes	Sampled from dam in which water is pumped into.
ANGW01	Aangewys	-26.30699	29.28422	In use	Domestic, workshop, irrigation	Submersible pump	Yes	Sample from tap.
ANGW02	Aangewys	-26.30732	29.28355	Not in use	-	No equipment	Yes	
ANGW03	Aangewys CL1	-26.30593	29.129359	In use	Domestic - not consumptions	Submersible pump	Yes	Used only for bathing. Borehole is contaminated according to Farmer.
ANGWH01	Angewya H0	-26.29405	29.29249	In use	Domestic	Submersible pump	Yes	
ANGWH02	Aangewys	-26.29053	29.29003	Not in use	Washing	Submersible pump	No	Not in use, pump currently broken.
DSF71BH01	Doorfontein 71	-26.25858	29.30322	Not in use	None	No equipment	No	
KFSBH01	Kaffestad S	-26.36609	29.38262	Not in use	-	Windmill	No	Not operational.
KHE	Kaffestad HE	-26.3224	29.37018	In use	Irrigation, domestic	Submersible pump	Yes	Sample from tap.
KLBH01	Kuil 77	-26.36203	29.3571	In use	Domestic	Handpump	Yes	
KPRBH01	Klipkraal	-26.3957	29.31851	In use	Domestic	Submersible pump	Yes	
RBP-03	Rensburghoop	-26.27674	29.38134	In use	Domestic	Submersible pump	Yes	
School BH	Kaffestad Portion 19	-26.343656	29.36015	In use - Broken	Domestic	Hand pump	No	School borehole. Pump broken.
Witbank 80	Witbank 80	-26.31487	29.30877	In use	Domestic	Submersible pump	Yes	
WT80P3 BH01	Witbank 80	-	-	In use	Domestic	Unknown	Yes	Borehole not located. Sampled from jojo tank where the borehole pumps to.
WT80P3 BH02	Witbank 80 Portion 5	-26.31296	29.3431	In use	Domestic	Submersible pump	Yes	Production BH. Sample taken from the storage tank in which the borehole pumps to.
WTRBH01	Witrand 103 Portion 4	-26.39335	29.33878	In use	Domestic, cattle, irrigation	Submersible pump	Yes	Sample collected from dam in which water from borehole is pumped into. Water sample taken from dam - blend of water from WTR BH01, WTR BH02 and WTR BH03
WTRBH02	Witrand 103 Portion 4	-26.38237	29.38875	In use	Domestic, cattle, irrigation	Submersible pump	Combined with WTR BH01	
WTRBH03	Witrand Portion 4	-26.36781	29.34288	In use	Domestic, cattle, irrigation	Windmill	Combined with WTR BH01	
YSTBH01	Ystervarkfontein	-26.35799	29.41468	In use	Domestic	Submersible pump	Yes	



Sample ID	Latitude	Longitude
Alex BH 01	-26.3674	29.30818
ANGCL02	-26.3008	29.29622
ANGW 01	-26.307	29.28422
ANGW 02	-26.3073	29.28355
ANGW 03	-26.3059	29.129359
ANGWH 01	-26.2941	29.29249
ANGWH 02	-26.2905	29.29003
DSF71BH01	-26.2586	29.30322
KFSBH01	-26.3661	29.38262
KHE	-26.3224	29.37018
KLBH01	-26.362	29.3571
KPRBH01	-26.3957	29.31851
RBP-03	-26.2767	29.38134
School BH	-26.3437	29.36015
Witbank 80	-26.3149	29.30877
*WT80P3 BH01	-	-
WT80P3 BH02	-26.313	29.3431
WTR BH01	-26.3934	29.33878
WTR BH02	-26.3824	29.38875
WTR BH03	-26.3678	29.34288
YSTBH01	-26.358	29.41468

Notes:

*WT80P3 BH01 could not be located,water samples taken from the Jojo tank it which the water was pumped to'

FIGURE 3-1: LOCATIONS OF THE GROUNDWATER MONITORING POINTS FOR THE 2016 HYDROCENSUS

3.4 RESULTS

3.4.1 BOREHOLE OBSERVATIONS

SLR identified twenty-one (21) boreholes during the hydrocensus. Full details of all boreholes are presented in Appendix A.

Observations were made regarding borehole construction details, current status, and water application and usage estimates.

Key findings include:

- A total of five (5) water levels were recorded, while the remaining water levels were unable to be measured due to the presence of installed pumps or other obstructions within the boreholes.
- Primary groundwater water uses at identified sites include domestic use, drinking water for cattle and irrigation.
- The depth of borehole for the majority of sites could not be recorded due to the presence of installed pumps or other obstructions within the boreholes. The aquifer being monitored can therefore only be assumed.
- Electric, submersible pumps were the primary method for water abstraction on the majority of operational boreholes. Wind pumps, solar and hand pumps were also noted.
- The majority of boreholes were pumping at the time of monitoring, therefore boreholes were considered ‘purged’.

3.4.2 GROUNDWATER LEVELS

Groundwater levels were recorded in five (5) of the boreholes. Due to the borehole construction and casing, the water level in borehole DSF71BH01 (65.05 mbgl) is questionably and not considered further in the report. Recorded groundwater levels are presented in Table 3-2.

Ground surface levels at the borehole locations were extracted from geographic information systems (GIS) and used to convert the groundwater observations to metres above mean sea level (mamsl) datum.

TABLE 3-2: GROUNDWATER LEVELS

Borehole ID	Water level (mbgl)	Status	Water Elevation (mamsl)	Coordinates (WGS84)	
				Latitude	Longitude
Alex BH 01	-	Pump obstructing	-	-26.36735	29.30818
ANGCL02	-	Borehole pumping	-	-26.300805	29.29622
ANGW 01	-	No access	-	-26.30699	29.28422

Borehole ID	Water level (mbgl)	Status	Water Elevation	Coordinates (WGS84)	
ANGW 02	7.7	Static	1580	-26.30732	29.28355
ANGW 03	5.72	Static	1613	-26.30593	29.29359
ANGWH 01	-	Borehole pumping	-	-26.29405	29.29249
ANGWH 02	28.86	Static	1573	-26.29053	29.29003
DSF71BH01	65.05*	Static	-	-26.25858	29.30322
KFSBH01	-	Pump obstructing	-	-26.36609	29.38262
KHE	-	Pump obstructing	-	-26.3224	29.37018
KLBH01	-	Pump obstructing	-	-26.36203	29.3571
KPRBH01	-	Pump obstructing	-	-26.3957	29.31851
RBP-03	-	Pump obstructing	-	-26.27674	29.38134
School BH	-	Pump obstructing	-	-26.343656	29.36015
Witbank 80	14.02	Affected by pumping	1577	-26.31487	29.30877
WT80P3 BH01	-	Borehole not located	-	-	-
WT80P3 BH02	-	Pump obstructing	-	-26.31296	29.3431
WTR BH01	-	No access	-	-26.39335	29.33878
WTR BH02	-	Pump obstructing	-	-26.38237	29.38875
WTR BH03	-	Pump obstructing	-	-26.36781	29.34288
YSTBH01	-	Pump obstructing	-	-26.35799	29.41468

Note: * borehole construction suggests water level is questionable

3.4.3 GROUNDWATER QUALITY

This section presents the results of groundwater quality analysis.

Data Validation

The E.N. calculation was applied to the groundwater samples. All samples showed an acceptable level of accuracy of below 10%. The laboratory results are considered acceptable for the purposes of this assessment.

Data Review

The results of the fifteen (15) groundwater water samples are presented in Table 3-3. Analytical reports received from Waterlab are included in Appendix B.

Significant findings include:

- Concentrations of the majority of elements were low and recorded at concentrations below relevant water quality standards.
- **pH** values ranged from pH7.4 in RPB03 to pH8.7 in ANGCL02. The pH recorded in RPB03 was above the upper limit of the DWAF Target Water Quality Range (TWQR) for Irrigation (pH8.4).

- **Electrical conductivity (EC)** concentrations ranged from 19.3 mS/m in ANGCL02 to 77.5 mS/m in ANGW03. Concentrations in 13 of the 15 samples exceeded the DWAF TWQR for Irrigation but remained below the SANS 241: 2015 DWS of 170 mg/L (Aesthetics). There is no DWAF TWQR for Livestock Watering.
- Concentrations of barium (Ba), iron (Fe), manganese (Mn), sodium (Na), zinc (Zn), and nitrate (NO_3) were reported at concentrations in excess of one of the stipulated water quality standards (Section 3.4.3) in at least one sample.
- From the aforementioned elements, the key chemicals of concern (CoCs) are considered to be Mn and NO_3. These three elements are discussed below:
    - **Mn** concentrations ranged from bellow the laboratory detection limit of 0.025 mg/L in 11 boreholes to 0.1 mg/L in RB03. Concentrations in 4 of the 15 samples exceeded the DWAF TWQR for Irrigation (0.02 mg/L), with the concentrations recorded in RB03 also exceeding the SANS 241:2015 DWS for Aesthetics (0.1 mg/L).
    - **NO_3** concentrations ranged from below the laboratory detection limit of 0.1 mg/L in 5 boreholes to 18 mg/L in ANGW03. Concentrations in 3 of the 15 samples exceeded the SANS 241: 2015 DWS for Acute Health (11 mg/L) but remained below the DWAF TWQR for Livestock Watering. There is no DWAF TWQR for Irrigation.

TABLE 3-3: GROUNDWATER QUALITY RESULTS COMPARED TO WATER QUALITY GUIDELINES

BH ID	Al (mg/L)	As (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	Ca (mg/L)	Co (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	K (mg/L)	Li (mg/L)	Mg (mg/L)	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	Ni (mg/L)	P (mg/L)	Pb (mg/L)
DWAF LW	**5.00**	**1.00**	**5.00**				**1000**	**1.00**		**0.50**	**10**			**500**	**10**	**0.01**	**2000**	**1.00**	**1.00**	**0.10**
DWAF IR	**5.00**	**0.10**	**0.50**		**0.10**			**0.05**	**0.10**	**0.20**	**5**		**2.50**		**0.02**	**0.01**	**70**	**0.20**	**0.05**	**0.20**
SANS 241: OP	**0.3**																			
SANS 241: AS											**0.3**				**0.1**		**200**			
SANS 241: AH																				
SANS 241: CH		**0.01**	**2.4**	**0.7**				**0.5**	**0.05**	**2**	**2**				**0.4**			**0.07**	**0.5**	**0.01**
Alex BH01	< 0.100	< 0.010	0.146	0.409	< 0.010	< 0.010	62	< 0.010	< 0.010	0.016	< 0.025	2.0	0.027	21	< 0.025	< 0.010	70	< 0.010	0.082	< 0.010
ANGCL02	< 0.100	< 0.010	0.020	0.208	< 0.010	< 0.010	16	< 0.010	< 0.010	< 0.010	0.069	4.3	0.022	7	< 0.025	< 0.010	16	< 0.010	0.064	< 0.010
ANGW01	< 0.100	< 0.010	< 0.010	0.181	< 0.010	< 0.010	54	< 0.010	< 0.010	< 0.010	< 0.025	7.4	0.023	11	< 0.025	< 0.010	32	< 0.010	0.095	< 0.010
ANGW02	< 0.100	< 0.010	< 0.010	0.147	< 0.010	< 0.010	61	< 0.010	< 0.010	< 0.010	< 0.025	7.4	0.017	11	< 0.025	< 0.010	33	< 0.010	0.097	< 0.010
ANGW03	< 0.100	< 0.010	< 0.010	0.718	< 0.010	< 0.010	106	< 0.010	< 0.010	< 0.010	< 0.025	12.5	0.021	20	< 0.025	< 0.010	25	< 0.010	0.016	< 0.010
ANGWH01	< 0.100	< 0.010	0.063	0.141	< 0.010	< 0.010	40	< 0.010	< 0.010	< 0.010	< 0.025	7.2	0.047	20	< 0.025	< 0.010	41	< 0.010	0.111	< 0.010
KHE	< 0.100	< 0.010	0.027	0.244	< 0.010	< 0.010	42	< 0.010	< 0.010	< 0.010	0.052	4.8	0.024	18	< 0.025	< 0.010	20	< 0.010	0.028	< 0.010
KLBH01	< 0.100	< 0.010	0.018	0.116	< 0.010	< 0.010	14	< 0.010	< 0.010	< 0.010	0.203	6.5	0.013	6	< 0.025	< 0.010	21	< 0.010	0.077	< 0.010
KPRBH01	< 0.100	< 0.010	0.150	0.229	< 0.010	< 0.010	45	< 0.010	< 0.010	< 0.010	0.401	4.3	0.027	14	0.075	< 0.010	54	< 0.010	0.052	< 0.010
RBP-03	< 0.100	< 0.010	0.016	0.156	< 0.010	< 0.010	86	< 0.010	< 0.010	< 0.010	0.053	3.2	0.047	32	0.104	< 0.010	31	0.022	< 0.010	< 0.010
Witbank 80	< 0.100	< 0.010	0.073	0.313	< 0.010	< 0.010	47	< 0.010	< 0.010	< 0.010	0.067	5.2	0.038	17	0.057	< 0.010	54	< 0.010	0.012	< 0.010
WT80P3 BH01	< 0.100	< 0.010	0.022	0.168	< 0.010	< 0.010	91	< 0.010	< 0.010	< 0.010	< 0.025	10.2	0.037	21	< 0.025	< 0.010	40	< 0.010	0.030	< 0.010
WT80P3 BH02	< 0.100	< 0.010	0.119	0.350	< 0.010	< 0.010	47	< 0.010	< 0.010	< 0.010	< 0.025	7.5	0.033	14	< 0.025	< 0.010	75	< 0.010	0.058	< 0.010
WTRBH01	0.202	< 0.010	0.042	0.065	< 0.010	< 0.010	78	< 0.010	< 0.010	< 0.010	0.049	6.6	0.037	30	< 0.025	< 0.010	41	< 0.010	0.046	< 0.010
YstBH01	< 0.100	< 0.010	0.038	0.179	< 0.010	< 0.010	45	< 0.010	< 0.010	< 0.010	< 0.025	3.3	0.022	18	0.034	< 0.010	53	< 0.010	0.039	< 0.010

BH ID	S (mg/L)	Sb (mg/L)	Se (mg/L)	Si (mg/L)	Sn (mg/L)	Sr (mg/L)	Ti (mg/L)	V (mg/L)	Zn (mg/L)	pH	Electrical Conductivity (mS/m)	Total Dissolved Solids (mg/L)	Total Alkalinity as $CaCO_3$ (mg/L)	Chloride as Cl (mg/L)	Sulphate as SO_4 (mg/L)	Fluoride as F (mg/L)	Nitrate as N (mg/L)	Nitrite as N (mg/L)	Free & Saline Ammonia as N (mg/L)
DWAF LW			**50**					**1.00**	**20**					**1500**	**1000**		**50**		
DWAF IR			**0.02**					**0.10**	**1**	**6.5 - 8.4**	**40**			**100**		**2.00**			
SANS 241: OP										**5 - 9.7**									
SANS 241: AS									**5**		**170**	**1200**		**300**	**250**				**1.5**
SANS 241: AH															**500**		**11**	**0.9**	
SANS 241: CH		**0.02**	**0.04**					**0.2**								**1.5**			
Alex BH01	71	< 0.010	0.015	14.8	< 0.010	0.785	0.101	< 0.010	2.920	7.8	69.3	448	324	34	29	0.6	<0.1	<0.05	<0.1
ANGCL02	< 0.010	< 0.010	< 0.010	20	< 0.010	0.135	0.027	< 0.010	0.025	8.7	19.3	162	96	5	<2	0.2	<0.1	<0.05	0.1
ANGW01	77	< 0.010	< 0.010	19.9	< 0.010	0.245	0.087	< 0.010	0.337	7.7	46.7	330	184	14	34	<0.2	5.2	<0.05	0.1
ANGW02	29	< 0.010	0.011	19.2	< 0.010	0.237	0.099	< 0.010	0.040	7.8	47.7	350	128	21	72	<0.2	7.1	<0.05	0.1
ANGW03	15	< 0.010	0.012	15.6	< 0.010	0.396	0.178	< 0.010	0.121	7.8	77.5	514	248	52	39	0.2	18	<0.05	0.1
ANGWH01	23	< 0.010	0.013	16.4	< 0.010	0.556	0.060	< 0.010	0.015	8.1	51.5	342	152	50	50	<0.2	0.3	<0.05	0.1
KHE	185	< 0.010	< 0.010	12.8	< 0.010	0.509	0.069	< 0.010	0.040	7.7	41.9	276	176	21	30	<0.2	<0.1	<0.05	0.1
KLBH01	< 0.010	< 0.010	< 0.010	20	< 0.010	0.130	0.023	< 0.010	0.059	7.8	20.1	164	96	4	2	<0.2	0.9	<0.05	0.1
KPRBH01	2.80	< 0.010	< 0.010	14.8	< 0.010	0.590	0.071	< 0.010	< 0.010	7.8	53.4	342	252	25	11	0.5	<0.1	<0.05	0.3
RBP-03	1344	< 0.010	< 0.010	15.2	< 0.010	0.475	0.143	< 0.010	0.071	7.4	70.9	510	220	25	142	<0.2	0.4	<0.05	<0.1
Witbank 80	12	< 0.010	0.012	10.9	< 0.010	0.973	0.078	< 0.010	< 0.010	8.1	54.4	348	260	18	24	0.4	<0.1	<0.05	0.2
WT80P3 BH01	41	< 0.010	0.019	20	< 0.010	0.589	0.144	< 0.010	0.025	7.7	74.5	506	244	39	74	0.2	12	<0.05	0.1
WT80P3 BH02	6	< 0.010	0.010	17.1	< 0.010	0.967	0.082	< 0.010	0.038	8.1	63.1	408	300	28	17	1.1	1.2	0.4	0.3
WTRBH01	39	< 0.010	0.011	21	< 0.010	0.489	0.128	< 0.010	0.137	7.8	73.2	502	232	36	84	0.3	12	<0.05	0.1
YstBH01	24	< 0.010	< 0.010	18.9	< 0.010	0.515	0.070	< 0.010	0.022	7.6	54.3	378	212	35	44	0.3	0.3	<0.05	<0.1

Note: Coloured cells refer to the relevant water quality standard that has been exceeded

DWAF: LW - Livestock watering. IR – Irrigation

SANS 241: OP – Operational. AS – Aesthetics. AH – Acute Heath. CH – Chronic Health. 2015 Standards

3.4.4 HYDROCHEMICAL FACIES

As water flows through an aquifer it assumes a diagnostic chemical composite as a result of interaction with the lithologic framework. The term hydrochemical facies refers to bodies of groundwater, within an aquifer, that differ in their chemical composition. The facies are a function of the lithology, solution kinetics and flow patterns of the aquifer (Back, 1960 and 1966 as cited in Fetter, 2001) and can assist in determining whether water has been impacted by anthropogenic activities

Hydrochemical facies are classified based on the dominant ions. The hydrochemical facies for the 15 groundwater samples are presented in Table 3-4 and presented graphically as a piper diagram in Figure 3-2. Stiff diagrams, an alternative type of graphical presentation of chemical analyse, were also generated for the samples and are presented in Appendix C.

The data show that the majority of samples are dominated by the bicarbonate anion which indicates relatively young or fresh groundwater.

The dominance of calcium (Ca) and magnesium (Mg) in the majority of samples indicates dissolution of calcite / gypsum and dolomite respectively.

TABLE 3-4: HYDROCHEMCIAL FACIES FO THE 15 GROUNDWATER SAMPLES

Borehole ID	Hydrochemical Facies	Description
ANGW 03	Ca-Mg-HCO_3	Due to dissolution of calcite and dolomite. HCO_3 indicates relatively young or fresh groundwater
KHE	Ca-Mg-HCO_3	
RBP-03	Ca-Mg-HCO3-SO4	Due to dissolution of calcite and dolomite. HCO_3 indicates relatively young or fresh groundwater High SO_4, may be due to SO_4 fertiliser (ammonium sulphate), oxidation of sulphide minerals, H_2S oxidation.
WTR BH01	Ca-Mg-Na-HCO3-SO_4	High SO_4, may be due to SO_4 fertiliser (ammonium sulphate), oxidation of sulphide minerals, H_2S oxidation.
ANGW 01	Ca-Na-HCO_3	
ANGW 02	Ca-Na-HCO3-SO_4	
Alex BH 01	Ca-Na-Mg-HCO_3	Surface dominated, young, oxidised groundwater, unconfined aquifer. HCO_3 indicates relatively young or fresh groundwater
ANGCL02	Ca-Na-Mg-HCO_3	
WT80P3 BH01	Ca-Na-Mg-HCO_3	
ANGWH 01	Ca-Na-Mg-HCO3-Cl	Surface dominated, young, oxidised groundwater, unconfined aquifer. Cl indicates moderate human impact OR carbonate clastic aquifer. Addition of NaCl to the system and mixing with Ca-Mg-HCO_3 waters
KPRBH01	Na-Ca-HCO_3	Surface dominated, young, oxidised groundwater, unconfined aquifer. Carbonate or Clastic Aquifer. Dissolution of sodium rich sandstones or shales
WT80P3 BH02	Na-Ca-HCO_3	
KLBH01	Na-Ca-Mg-HCO_3	Surface dominated, young, oxidised groundwater, unconfined aquifer
Witbank 80	Na-Ca-Mg-HCO_3	
YSTBH01	Na-Ca-Mg-HCO_3	

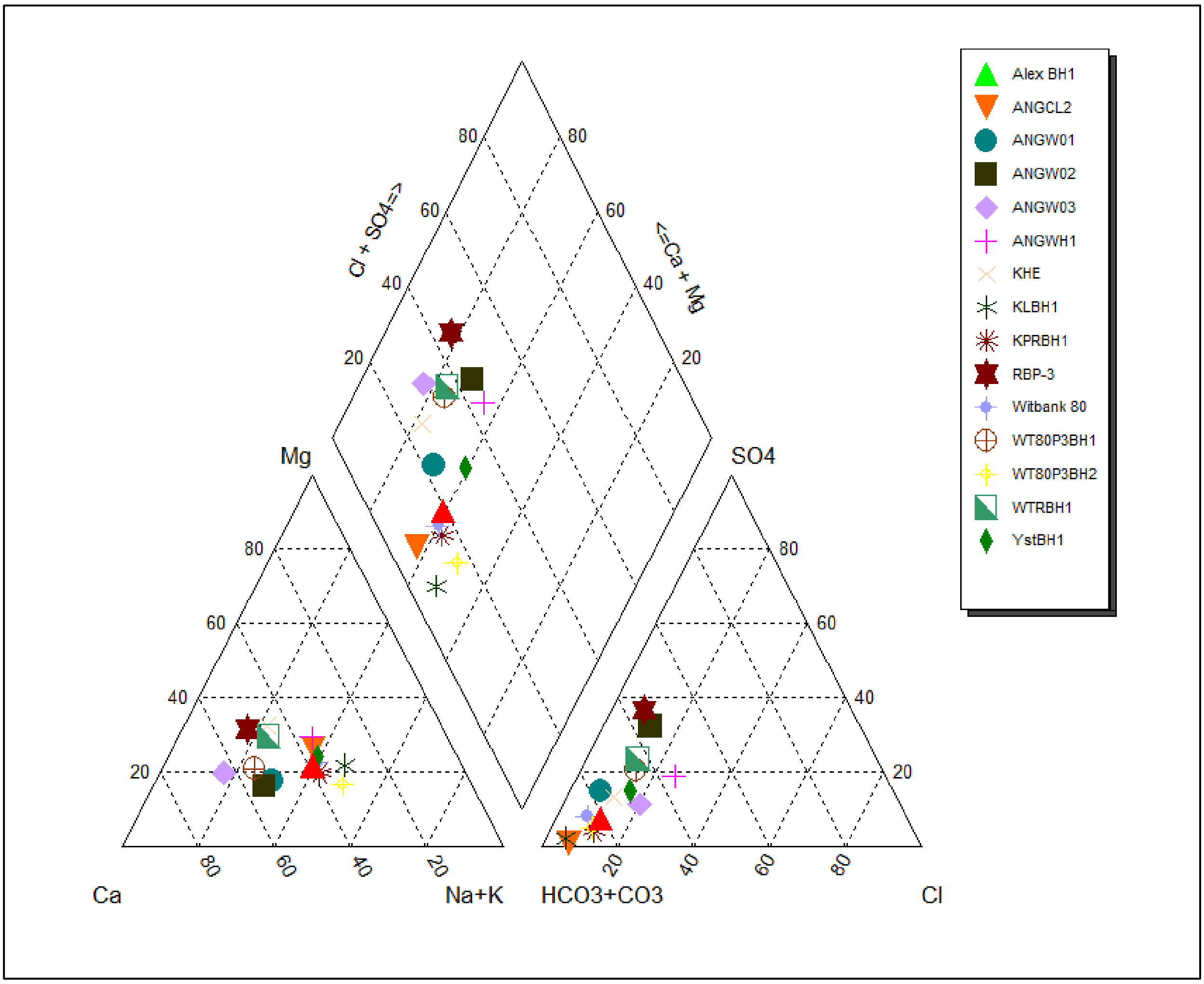


FIGURE 3-2: PIPER DIAGRAM FOR GROUNDWATER SAMPLES TAKEN DURING THE 2016 HYDROCENSUS

The hydrocensus results for the Surface Water point are detailed in the Surface Water Specialist Study.

4 NUMERICAL GROUNDWATER MODEL

To assess the potential impact of the proposed mining development on the local groundwater system, SLR developed a numerical groundwater flow model to simulate underground mining and the possible contaminant flow.

The groundwater flow model constructed for this investigation utilised the numerical code FEFLOW developed by DHI-WASY, that solves three-dimensional ground-water flow problems using the finite-element method.

FEFLOW is a widely used, commercially available groundwater numerical code. The recent developments of FEFLOW are focussing on specific mining applications and the code is fully suitable for the Alexander numerical simulations of the hydrogeology.

The numerical code selection has been made in terms of suitability to provide the answers required from the groundwater model:

- Determine the distribution of hydraulic heads during and post-mining, as response to modifications occurring in the system during and post-mining,
- Predict the possible groundwater passive inflow volumes into the underground mine during and post-mining
- Predict the extent and magnitude of a possible contaminant plume during and post-mining and operation of facilities.

The model domain is split into 3-dimensional triangular prisms, constituting the 3D finite elements containing the material (hydraulic) properties. The elements are connected to each other at corners – constituting nodes, where the hydraulic heads are assigned and flow equations are calculated for each node during the model run.

4.1 HYDROGEOLOGICAL CONCEPTUAL MODEL

The conceptual model is the base of the numerical model.
The Hydrogeological Conceptual model for the Alexander underground mine is illustrated in Figure 4-1.
It incorporates the main hydrogeological units and describes their hydraulic properties. The main hydrogeological units are represented by:

- Ecca Formation: an alternating suite of sandstones, siltstones and mudstones; from a hydrogeological point of view, this can be divided into 2 units. The top Ecca presents a moderate (in some places high) hydraulic conductivity and represents the main aquifer; The lower part of Ecca has poor hydraulic conductivities and is considered an aquitard.

- S4 coal seam: the general hydraulic conductivity for coal is approximately 1 x 10^{-3} m/d; the important component in the groundwater model is represented by the underground mine, which is expected to act as a sink, therefore a cone of drawdown is expected to develop.
- Dwyka tillite: the unit is considered to be an aquitard.
- Pre-Karoo basement: practically impermeable
- Dolerite dykes: generally they are considered as impermeable; however, locally these can present enhanced hydraulic properties; for the Alexander model, we assume that the constitute hydraulic barriers; the nature of the dolerite dykes can be update when more information becomes available.

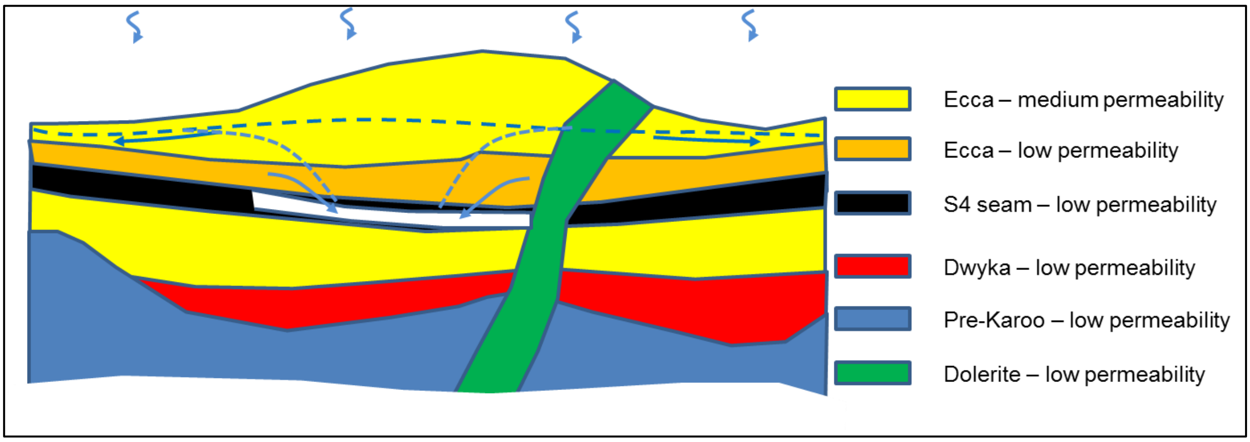


FIGURE 4-1: ALEXANDER - HYDROGEOLOGICAL CONCEPTUAL MODEL

4.2 MODELLING DOMAIN AND BOUNDARY CONDITIONS

The selection of a groundwater model domain is usually done based on the larger catchment areas, presence of hydrographic features and known geological features and their hydraulic behaviour.

In the case of S4 Alexander Underground Mining Development Project, the model domain was selected purely on catchment areas and divides between the catchments, and in such a way that the boundaries are sufficiently far to avoid any boundary condition interference with the future mine, considered in the groundwater model as a stress component. The model domain is shown in Figure 4-2, together with the main elements incorporated into the groundwater model.

The boundary conditions of the Alexander Groundwater Model are set as following (Figure 4-2):

1) No-flow boundaries:
   a. A **no-flow boundary** considers that no fluid exchange (in- or out- the groundwater system) takes place along this section of the model boundaries. The no-flow boundary was selected at the southern, eastern and western sides of the model domain, along the lines of high elevations representing watershed lines;

b. **Specified head boundaries** consider that fluid exchange occurs along in- and out- the model domain, in such a way that the hydraulic head boundaries are maintained at their initial values.
   1. External boundaries: along the low elevation streams on the northern half of the model domain boundaries.
   2. Internal boundaries included in the groundwater domain are set along the rivers included in the model domain.

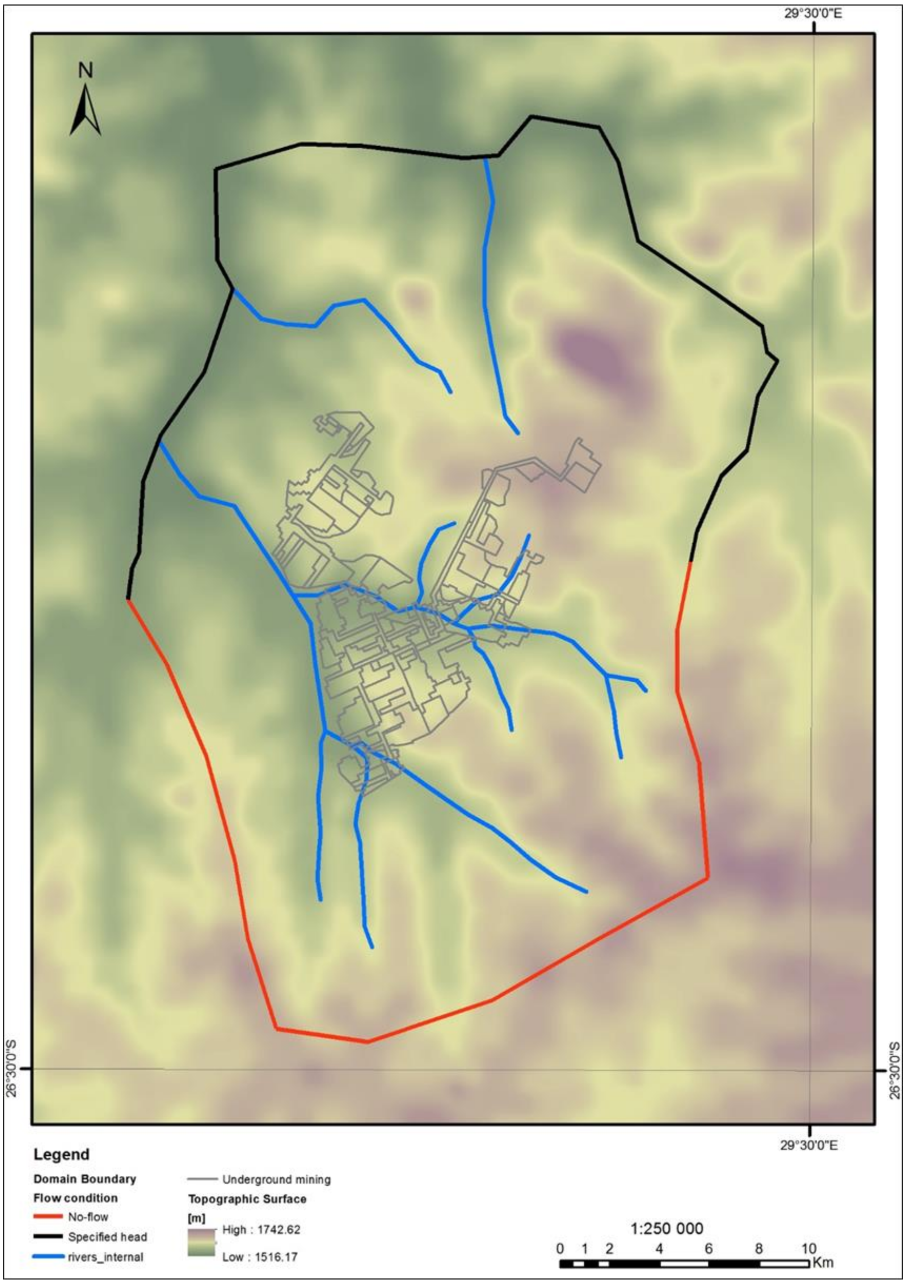


FIGURE 4-2: GROUNDWATER MODEL DOMAIN

4.3 MODEL SET-UP AND DISCRETIZATION

The development of the model consisted of discretising the model domain into individual elements for which changes would be computed during simulations, setting of boundary conditions, and calibration. These are described in the following sections.

4.3.1 HYDROGEOLOGICAL UNITS

The framework for the 3D numerical simulations consists of the geology and structure present in the S4 Alexander Underground Mining Development immediate License Area, extended through reasonable approximation towards the model domain boundaries. Figure 4-4 shows the S4 Alexander Underground Mining Development model domain and the simplified geological units incorporated.

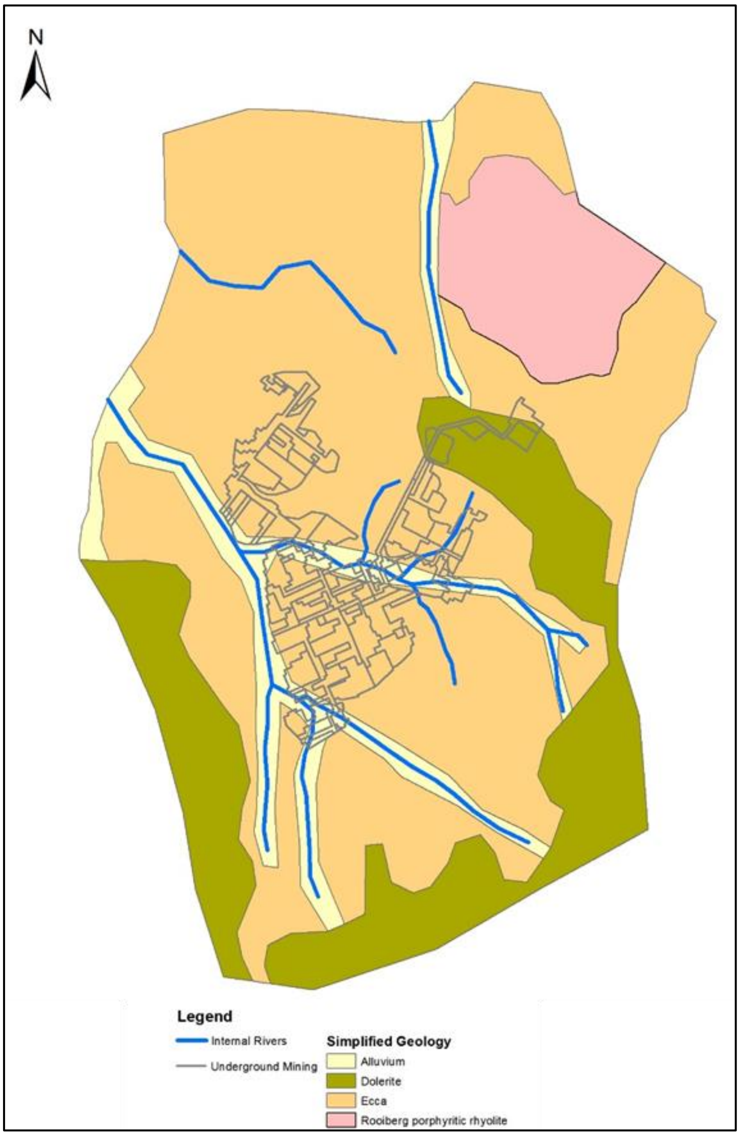


FIGURE 4-4: ALEXANDER - SIMPLIFIED GEOLOGY

The main hydrogeological units derived from the simplified geology map are:

- Ecca
- Dwyka
- Pre-Karoo Basement
- Dolerites

These will be discussed later in the model Construction Section.

4.3.2 HORIZONTAL DISCRETIZATION

The horizontal discretization was achieved taking into consideration the following elements:

- The stratigraphy within the model domain (hydrogeological units),
- The footprint of the future underground mine,
- The position and footprint of the Waste Rock Dump (WRD).

The horizontal discretization is achieved by a mesh definition to contour the boundaries of the required mining elements.

The future mine and all surface facilities are critical components for the groundwater impact assessment, and therefore the model will have to account for these. Although these elements will be simulated during the post-calibration stage of the model, provisions must be made for these during the model setup phase, for both horizontal and vertical dimensions.

Figure 4-5 shows the horizontal discretization of the Alexander model domain. The elements sizes within the Alexander model vary from 5000m at the edge (boundaries) of the model to 10m elements in the areas where better hydraulic resolution is required. The model is finely refined in the mine and WRD areas (areas of hydraulic and geochemical stresses), and less refined outside the stress areas.

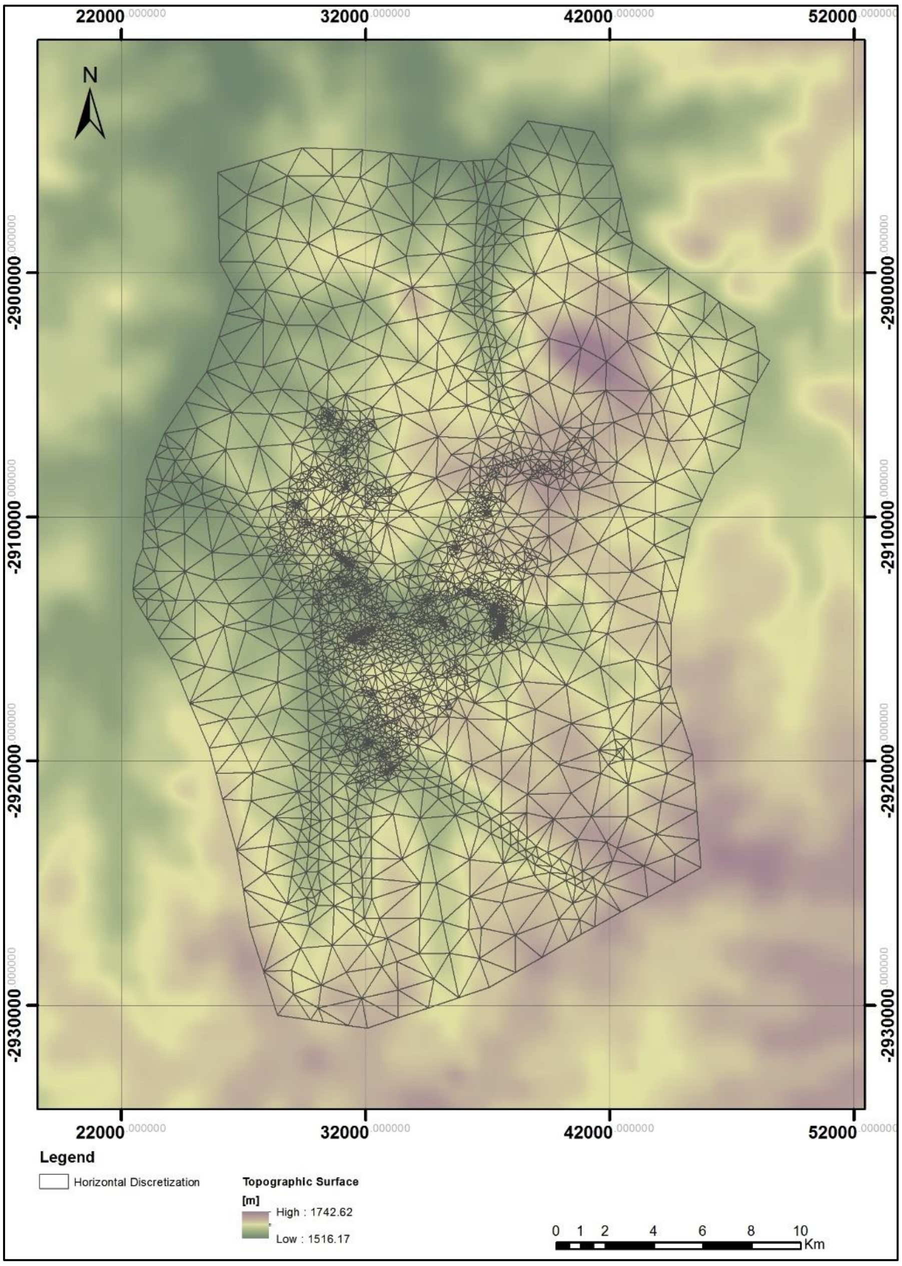


FIGURE 4-5: ALEXANDER GROUNDWATER MODEL - HORIZONTAL DISCRETIZATION

4.3.3 VERTICAL DISCRETIZATION

Generally, the stratigraphy and future mining constitute the two major components which determine the vertical discretization.

In the case of Alexander, the stratigraphy will be represented as zones of different hydraulic properties on the various layers inside the model domain, in such a way that it represents best the local geology and hydro-stratigraphic units. The vertical layering of the model is achieved by splitting the 3D model into eight vertical layers to represent the succession of layers representing the local stratigraphy.

4-1 details the model layers considered for the Alexander groundwater model.

TABLE 4-1: ALEXANDER GROUNDWATER MODEL LAYERS

Surface	Layer	Layer Name	K_h [m/d]	K_v [m/d]
1	L1	Weathering	0.5	0.5
2	L2	Ecca1	0.01	0.005
3	L3	Ecca2	0.0001	0.0001
4	L4	S4	0.003	0.003
5	L5	Ecca3	0.005	0.005
7	L6	Dwyka	0.001	0.001
8	L7	PreKaroo	0.0005	0.0005

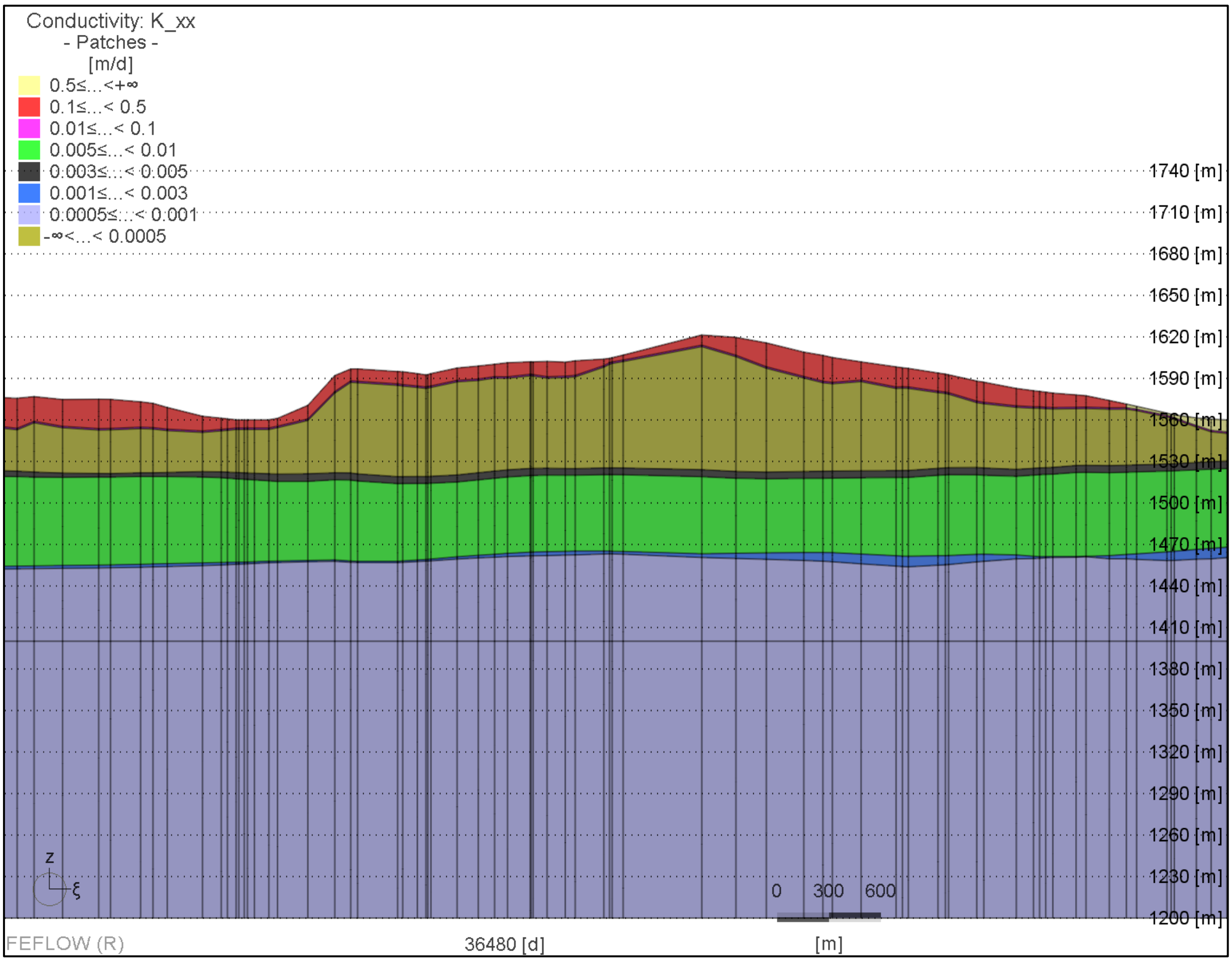


FIGURE 4-6: ALEXANDER GROUNDWATER MODEL - VERTICAL DISCRETIZATION

Figure 4-6 shows the vertical layers selected to cross S4 coal seam and the underground workings to allow simulation of mining vs. time, on a South West –North East cross section.

The final Alexander model contains 8 layers to a final depth of -1400 mamsl, as following:

The resulting 3-dimensional finite element grid for the Alexander model contains:

- 1197984 elements, and
- 74923 nodes.

4.3.4 TIME DISCRETIZATION – TIME SERIES

The Alexander groundwater model is susceptible to changes occurring in time – mining, operation of waste rock dump. These have an influence on groundwater levels and groundwater quality.

To realize a reasonable time discretization, the model was setup to run as transient flow and transport at constant time.

The simulation period was selected to include both mining and post-mining stages; mining at Alexander takes place for a period of 35 years; the post-mining stage is run for a further 65 years (more than double than mining stage) to ensure that long term impact on groundwater are captured.

The time step was defined to 1 month; this is considered in the model code as a constant 30.4 days per month.

4.4 GROUNDWATER MODEL INITIALS

4.4.1 GROUNDWATER RECHARGE

The groundwater recharge represents a percentage of the rainfall (Figure 2-1) which will reach and contribute to the fluid mass balance within the model domain. The initial groundwater recharge values for the Alexander steady-state calibration run was assigned at 5% of M.A.P (Table 2-1).

The average annual rainfall value is 540 mm/yr. The groundwater recharge considered pre-calibration estimated at 5% of M.A.P. is 5.4 mm/year (7.5 x 10^{-2} m/d).
Transient values for recharge at monthly time-steps will be determined after the steady-state calibration.

4.4.2 HYDRAULIC HEAD

The initial hydraulic head distribution over the whole groundwater model domain was computed based on a combination of several measurements during the hydrocensus, historical water levels extracted from the National Groundwater Database (DWS) and the general difference between the measured water levels and the topography.

The initial groundwater levels (pre-calibration) are shown in Figure 4-7.

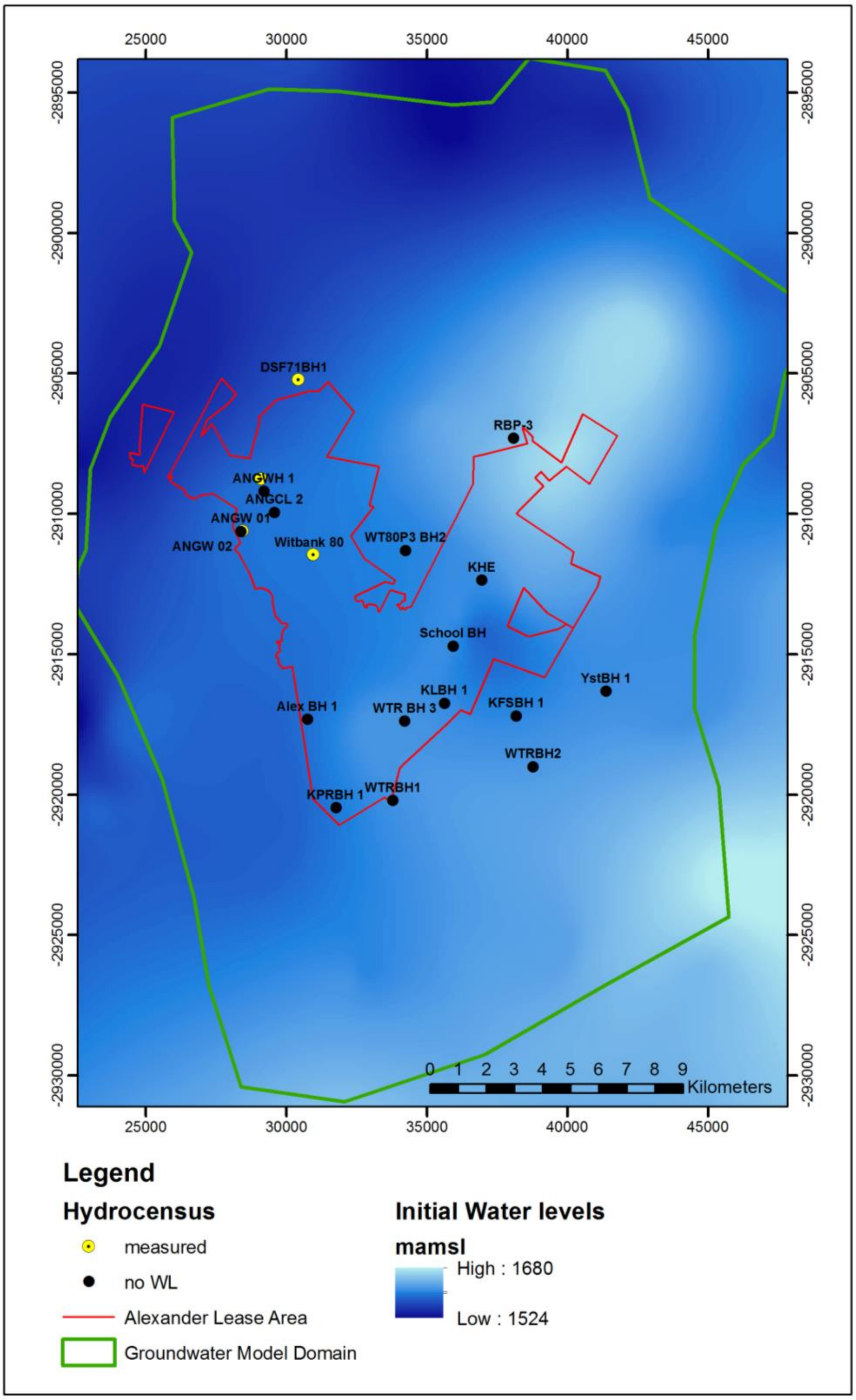


FIGURE 4-7: ALEXANDER PROJECT - INITIAL HYDRAULIC HEAD

4.4.3 HYDRAULIC PROPERTIES

The initial hydraulic properties for the Alexander groundwater numerical model are shown in Table 4-2.

TABLE 4-2: INITIAL HYDRAULIC PROPERTIES

Surface	Layer	Layer Name	K_h [m/d]	K_v [m/d]
1	L1	Weathering	0.5	0.5
2	L2	Ecca1	0.01	0.005
3	L3	Ecca2	0.0001	0.0001
4	L4	Seam 4	0.003	0.003
5	L5	Ecca3	0.005	0.005
7	L6	Dwyka	0.001	0.001
8	L7	PreKaroo	0.0005	0.0005

The initial hydraulic properties for the model, together with the initial hydraulic heads represent the start of the calibration process.

4.5 MODEL CALIBRATION

The calibration of a groundwater model consists in comparing the measured water levels and the water levels computed during the calibration run. The initial steady-state calibration of the Alexander groundwater model was run using the initial hydraulic properties assigned together with the hydraulic head values and average groundwater recharge values computed from the average rainfall data throughout the model domain.

The first step in the calibration process was the run of the *PEST* (parameter estimation) routine on the Alexander model.

The second step was to run the PEST model in steady-state model, until suitable calibration is obtained. Table 4-3 shows the comparison between the steady-state computed hydraulic head vs. the measured hydraulic head for the 4 boreholes considered (Table 3-2).

TABLE 4-3: HYDRAULIC - STEADY-STATE CALIBRATION

Borehole ID	Computed head, mamsl	Measured head, mamsl	Head difference, m
ANGW 02	1579.1	1580	-0.90
ANGW 03	1614.3	1613	1.30
ANGWH 02	1571.2	1573	-1.80
Witbank 80	1575.6	1577	-1.40
		RMSE	**1.39**
		NRMSE	**3%**

The differences between the measured hydraulic head and computed hydraulic head are very small, and the calibration was considered satisfactory. The RMSE and NRMSE, which represent the quantitative measure of the model calibration are within the prescribe groundwater modelling guidelines (ASTM).

4.6 TRANSIENT SIMULATIONS

4.6.1 SIMULATION OF MINING

The future mine and all surface facilities are critical components for the groundwater impact assessment, and therefore the model will have to account for these.

Figure 4-8 shows the annual schedule of the Alexander underground mine.

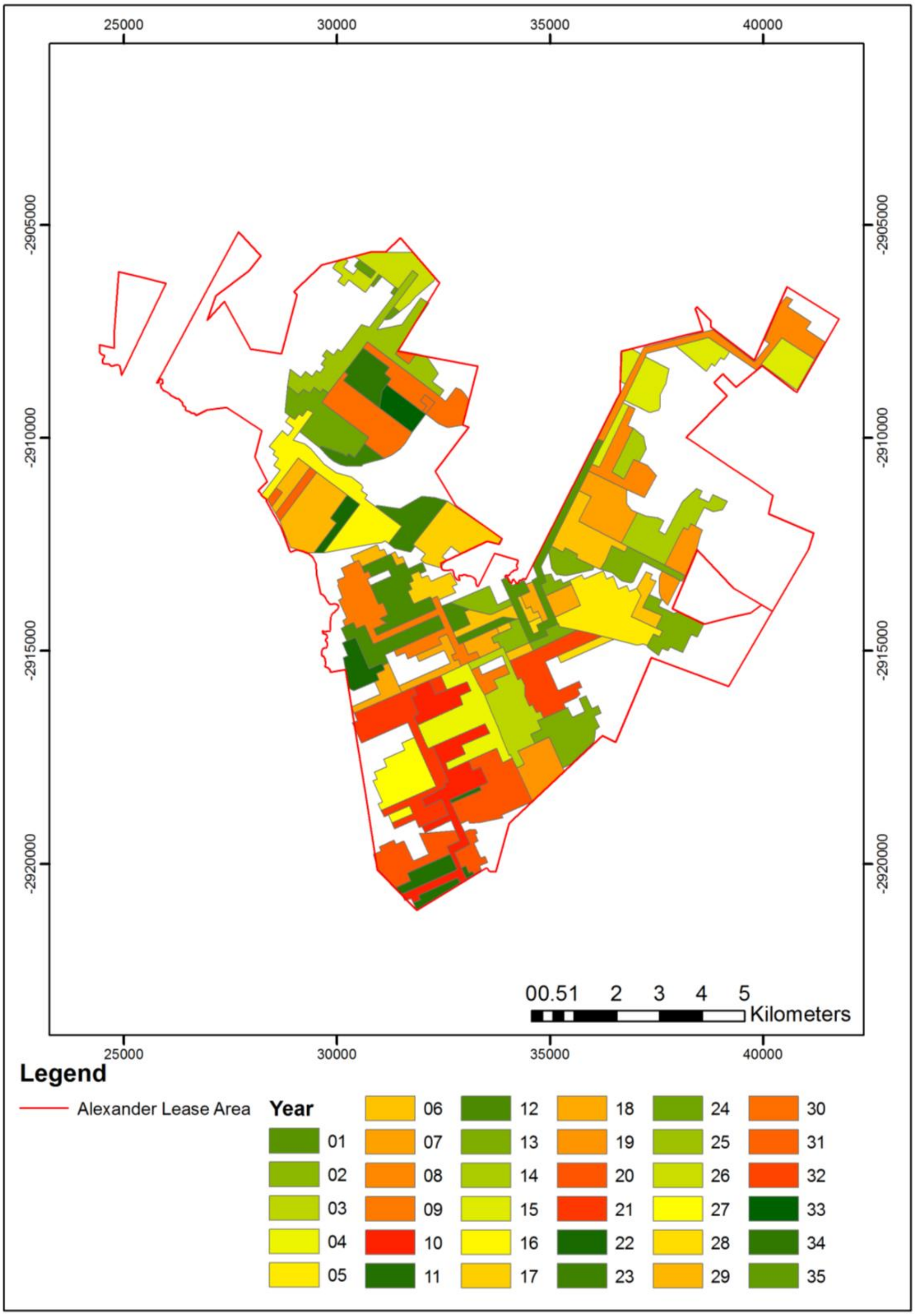


FIGURE 4-8:ALEXANDER UNDERGROUND MINE - ANNUAL MINING PLANS

4.6.2 SOURCE TERM

4.6.2.1 Scenario 1: Unmitigated Scenario

The source term considered for the Alexander Project waste rock dump was determined by the Geochemistry Study. As much water as possible will be left underground in old mining panels, closed and converted to water storage dams. Only excess water that cannot be stored underground will be pumped to the surface. However, the worst case scenario of all the underground mine water being pumped out of the mine and therefore not contributing to any underground contaminant sources, has been included in the numerical groundwater model. The recovery of the water levels are quite slow, with the hydraulic gradients driving the groundwater flow towards the mine until the end of the simulation period (100 years), and therefore unlikely that and possible contaminated water will migrate outside the underground mine. Nevertheless, this will confirmed after the transient simulations.

As informed by the Geochemistry Study, the main contaminant exceeding the prescribed groundwater quality limits and identified as per the water contact quality statement was Fe (iron). All other contaminants were negligible and/or within the prescribed limits.

The main assumption is that the waste rock dump will be in operation only for the life of mine (35 years). Post-mining commitment is that the waste rock dump material will be removed for the WRD location.

During the operation of the mine and WRD, the Fe concentration determined by the Source Term study is of 1.47 mg/l.

The groundwater model incorporates this as concentration boundary condition on the WRD location for a period of 35 years. After that, until the end of the simulation, the concentration boundary condition is removed, allowing the contaminant transport model to determine the evolution of the contaminant plume with the residual Fe present at year 35.

The groundwater recharge considered for the WRD area is 0.0006 m/d (Alexander Shaft Waste Rock Dump Design, SLR, 2016)

4.6.2.2 Scenario 2: Mitigated Scenario

A second scenario was constructed and run for the WRD possible Fe plume development to reflect mitigation measures, as following:

- The WRD will be lined with a Class C liner; this will be simulated as a local layer of 0.5m thickness and 10^{-9} m/s (10^{-4} m/d) vertical hydraulic conductivity;
- The WRD will be covered with soil, to restrict vertical seepage and recharge to groundwater from the WRD; as determined by the modelling described in the Alexander Shaft Waste Rock Dump Design, the local recharge considered for Scenario 2 from the WRD was 0.00003 m/d.

4.7 SIMULATIONS RESULTS

4.7.1 GROUNDWATER PASSIVE INFLOWS

The groundwater passive inflows represent the inflows of groundwater into the mining works, without any active dewatering (dewatering boreholes, galleries, etc.).

These were calculated by the groundwater model, as the groundwater model drains are activated according to the mining schedule. When the drains are activated (assigned as seepage face) it is considered that all inflows taking place through these nodes are pumped out of the system (underground pumping to surface).

Figure 4-9 shows the predicted inflows into the Alexander underground mine as the mining is advancing. The inflows are directly influenced by the mining area open at any given time step.

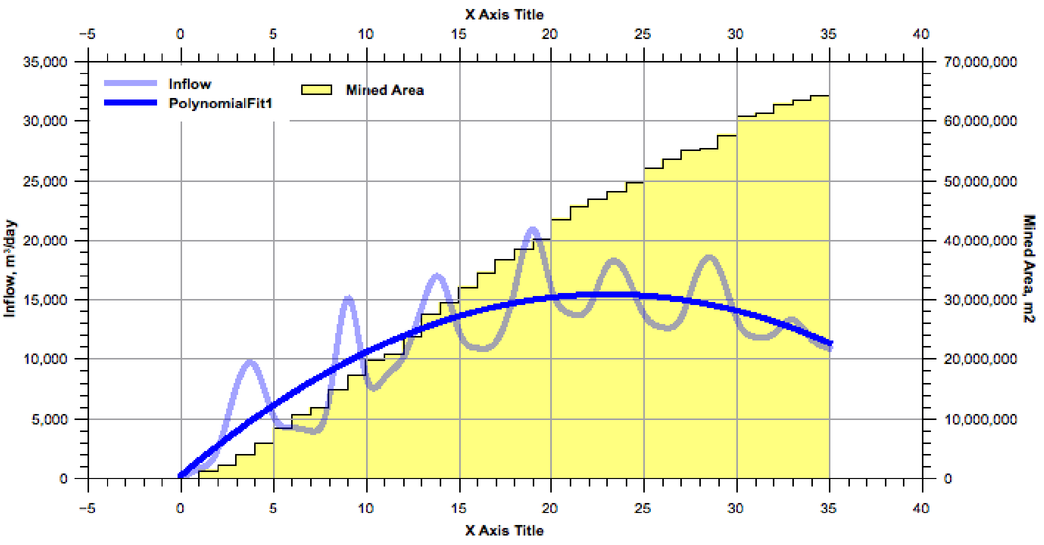


FIGURE 4-9: ALEXANDER UNDERGROUND MINE - PREDICTED GROUNDWATER PASSIVE INFLOWS

The groundwater passive inflows show an increasing trend until year 23 as more mining area is developed. After year 23, although the mining continues, the passive inflows show a decrease, due to the lower hydraulic heads (and gradients) around the underground mine.

The polynomial fit (2nd degree) trend curve shows a square mean of the annual inflows rates predicted by the numerical model. However, for safe operation of the mine, we recommend that the maximum values predicted to be used for designing the underground pumping system.

The maximum inflow predicted is 21,000 m^3/day.

4.7.2 HYDRAULIC HEADS

The distribution of the hydraulic heads predicted for the first 35 years of the numerical simulation represent the groundwater flow conditions as a response to underground mining and groundwater passive inflows into the underground mine.

The following time-steps were selected to illustrate the evolution of the hydraulic heads during the run of the Alexander groundwater model:

- Year 0: pre-mining – Figure 4-10
- Year 10 of mining – Figure 4-11
- Year 20 of mining –Figure 4-12
- Year 30 of mining – Figure 4-13
- Year 35 of mining: end of mining – Figure 4-14
- Year 50: 15 years post closure -Figure 4-15
- Year 70: closure period equal to mining period – Figure 4-16
- Year 100: end of simulation – Figure 4-17

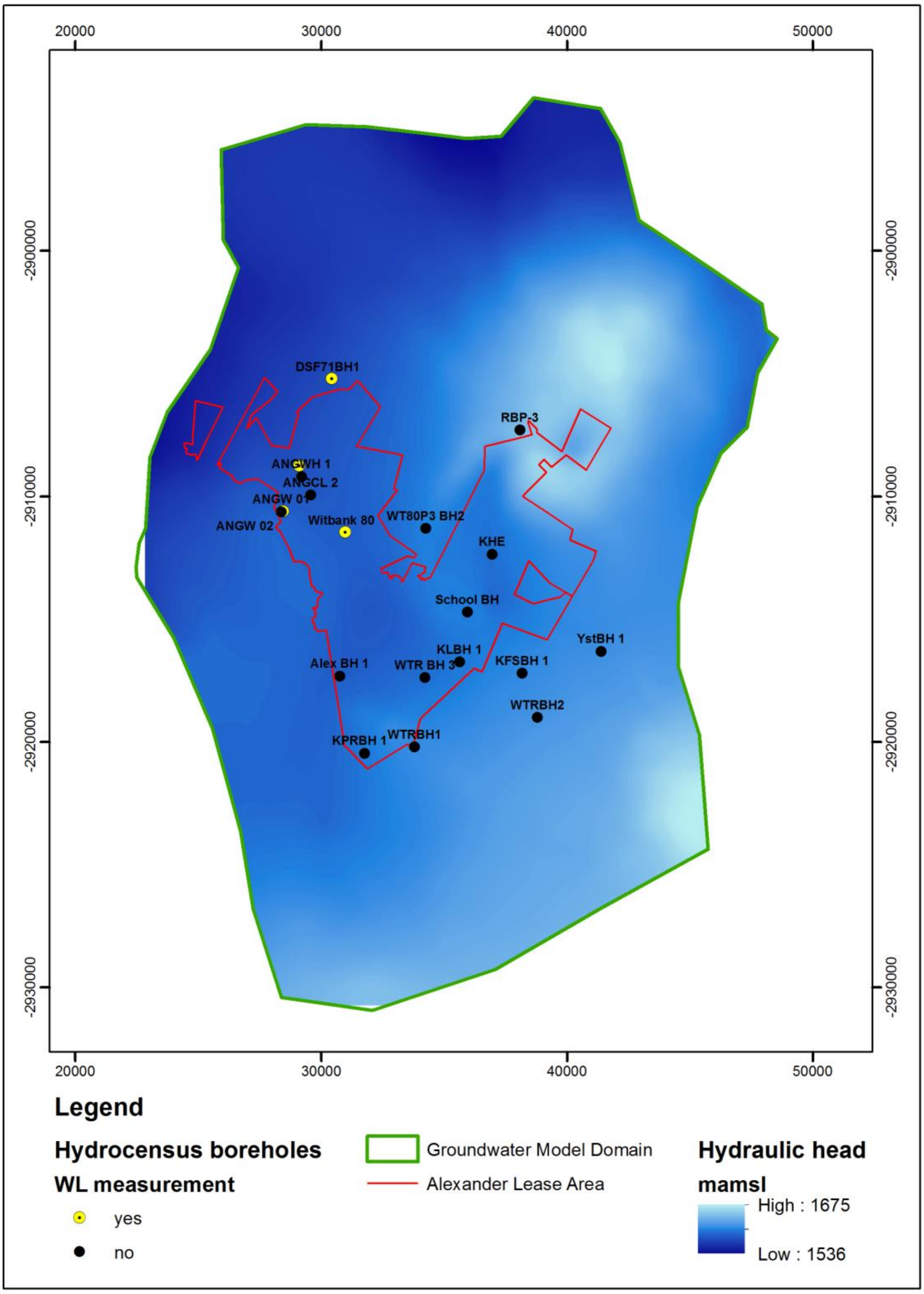


FIGURE 4-10: PRE-MINING HYDRAULIC HEAD DISTRIBUTION

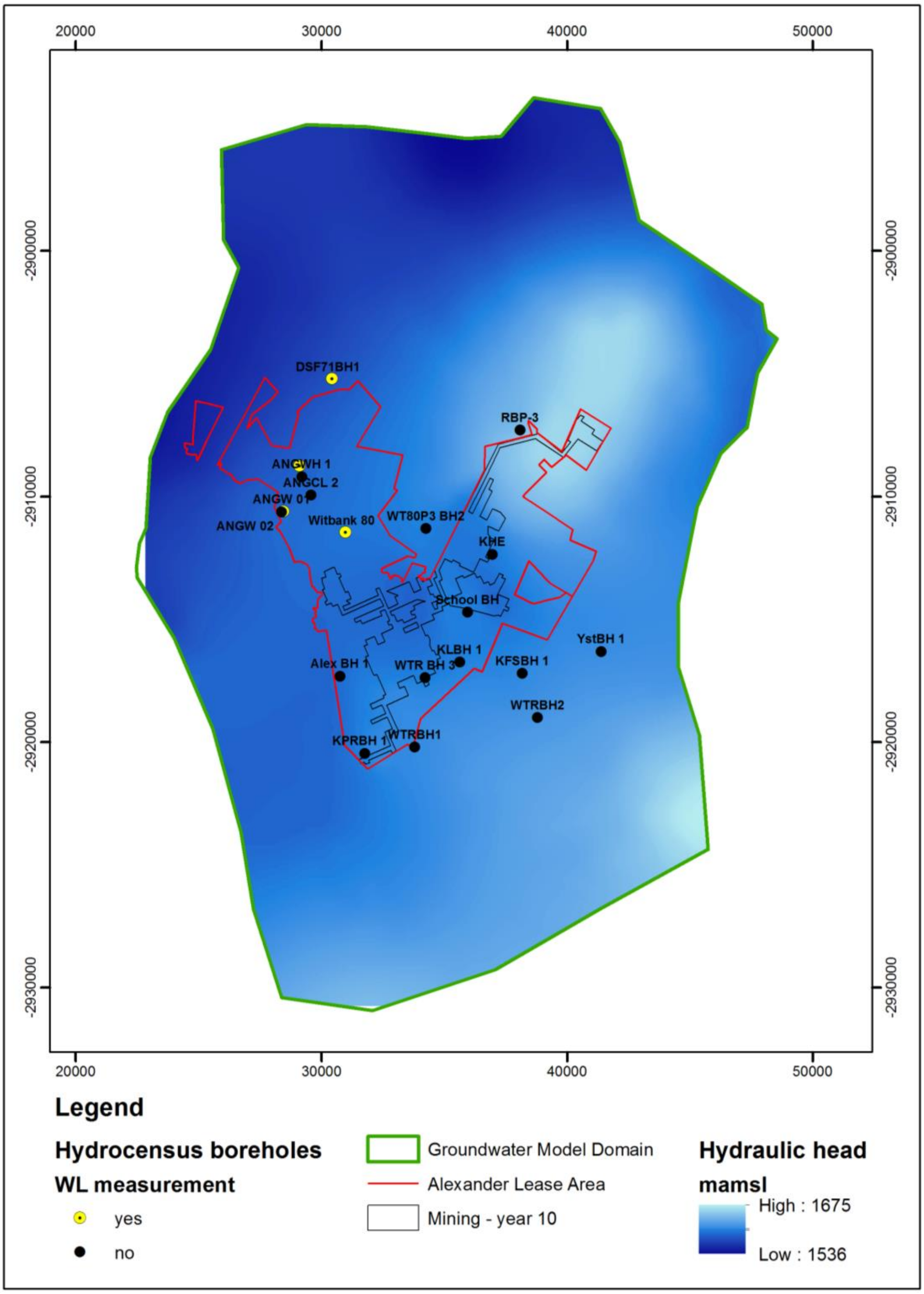


Figure 4-11: Hydraulic head distribution - year 10 of mining

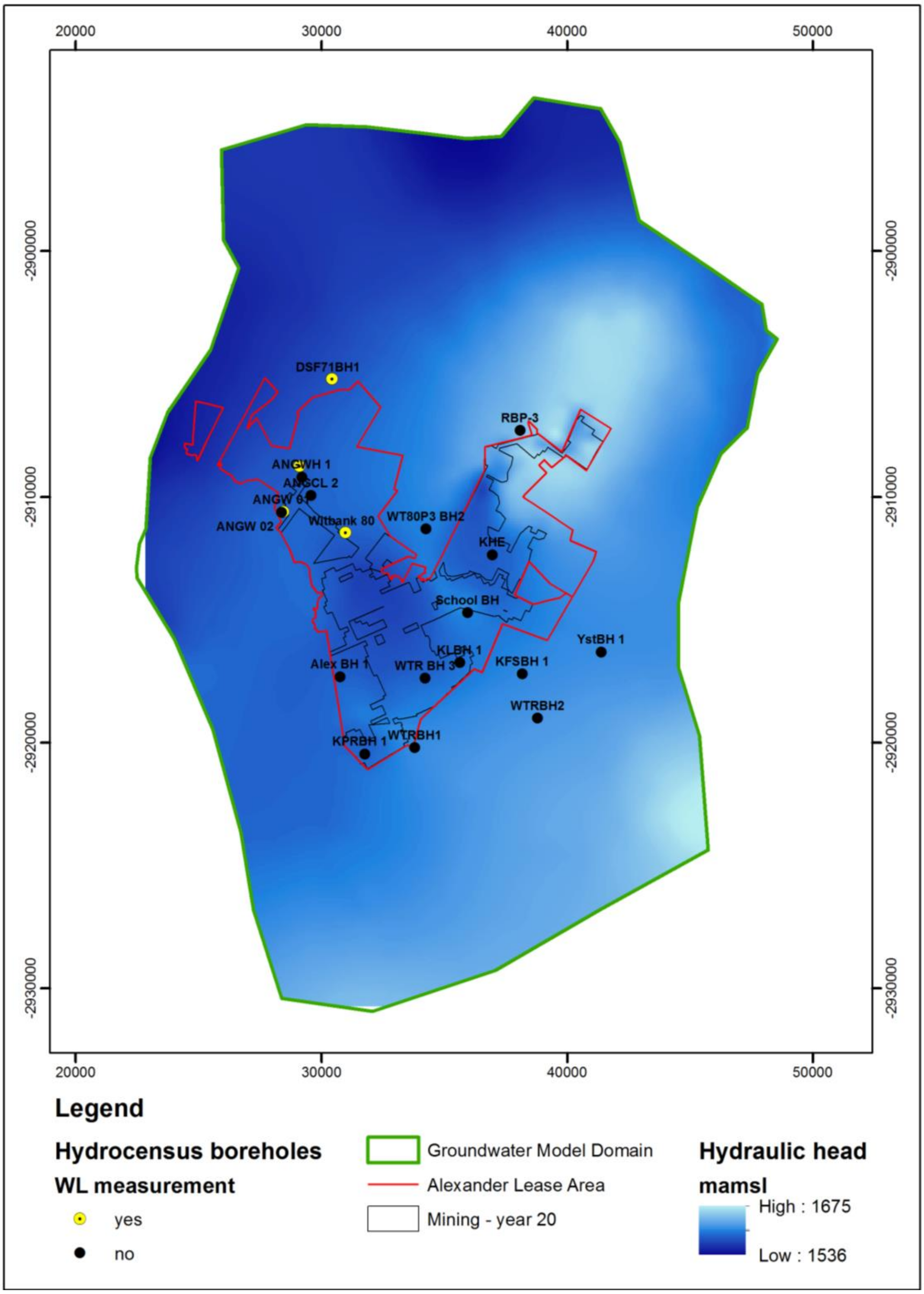


FIGURE 4-12: HYDRAULIC HEAD DISTRIBUTION - YEAR 20 OF MINING

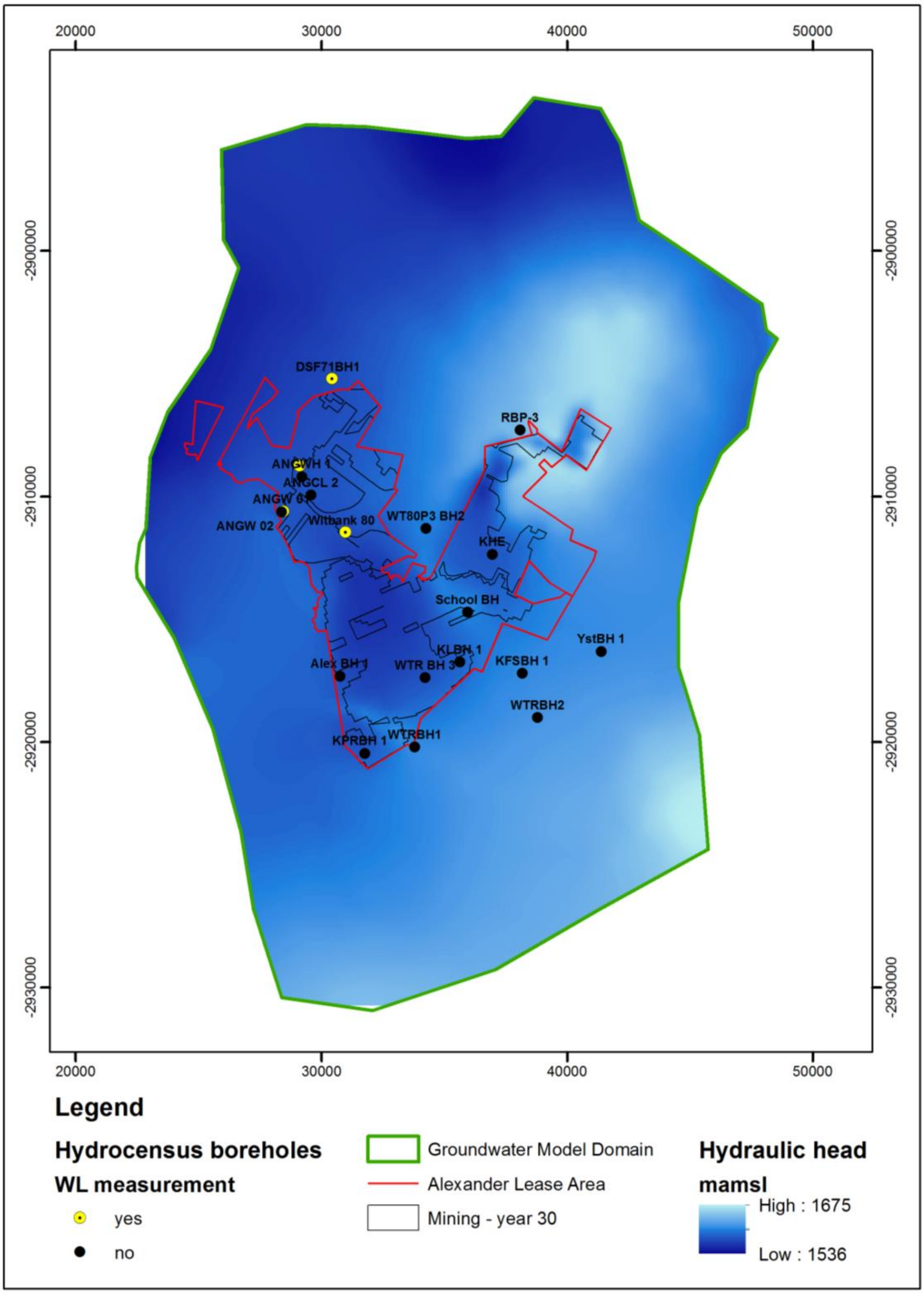


FIGURE 4-13: HYDRAULIC HEAD DISTRIBUTION - YEAR 30 OF MINING

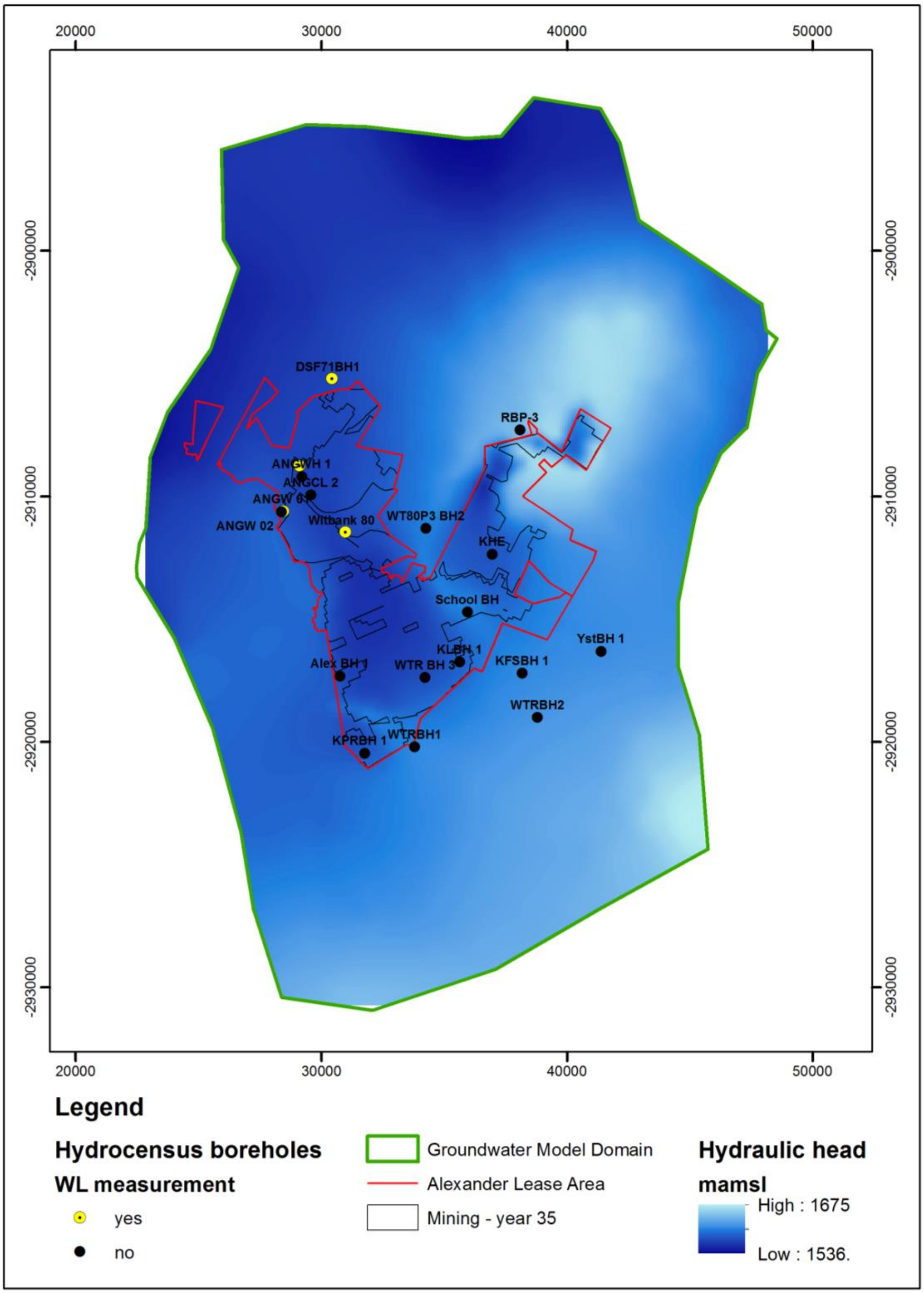


FIGURE 4-14: HYDRAULIC HEAD DISTRIBUTION - YEAR 35 (END OF MINING)

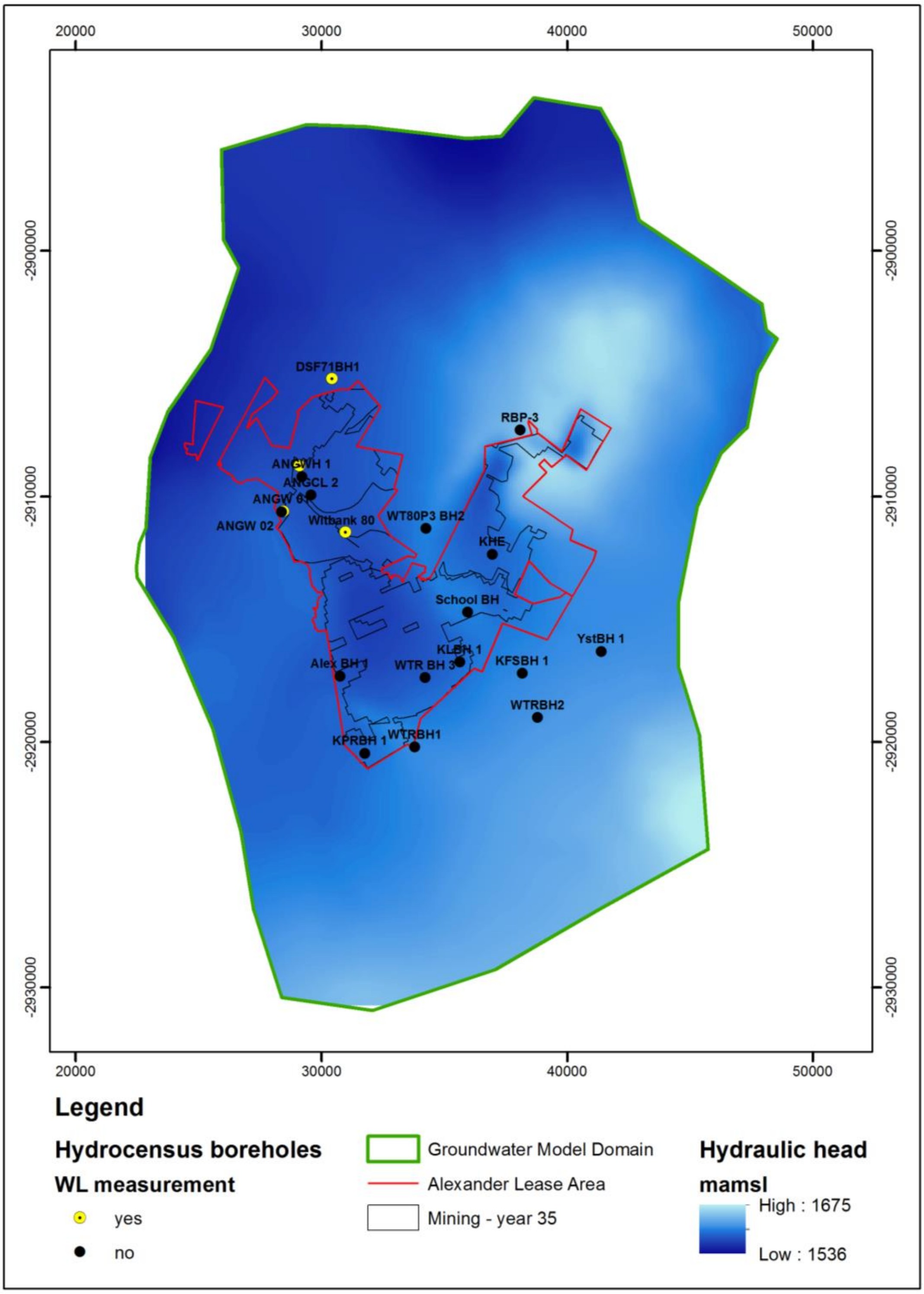


FIGURE 4-15: HYDRAULIC HEAD DISTRIBUTION - YEAR 50 (15 YRS POST-MINING)

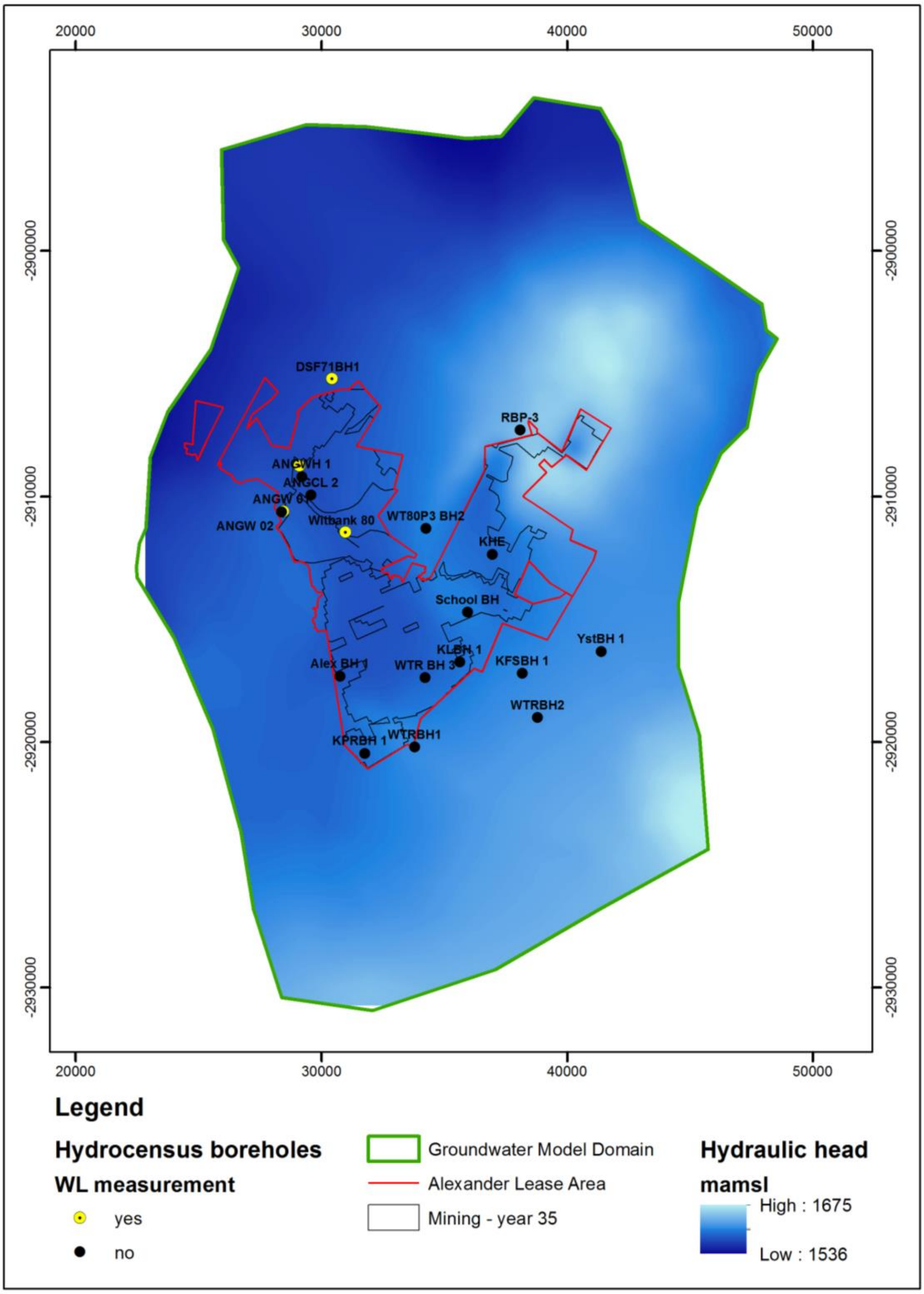


FIGURE 4-16: HYDRAULIC HEAD DISTRIBUTION - YEAR 70 (35 YRS POST-MINING)

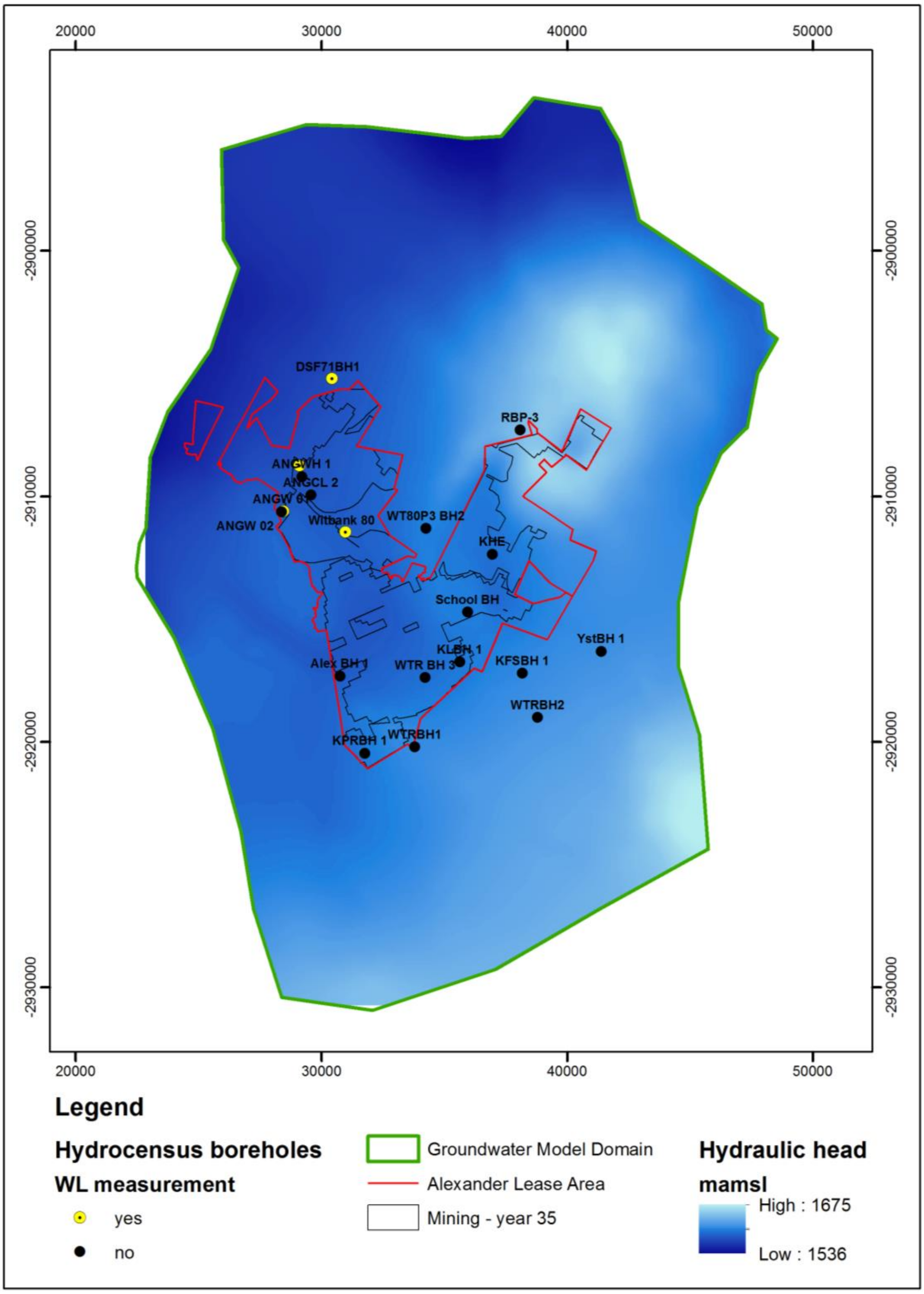


FIGURE 4-17: HYDRAULIC HEAD DISTRIBUTION - YEAR 100 (END OF SIMULATION)

The predicted hydraulic heads were further processed to determine the development of the cone of drawdown during the 100 years simulation for the Alexander Project.

Figure 4-18 shows the cone of drawdown developed at year 10 of mining. The maximum drawdown at end of year 10 is of 8 mbgl.

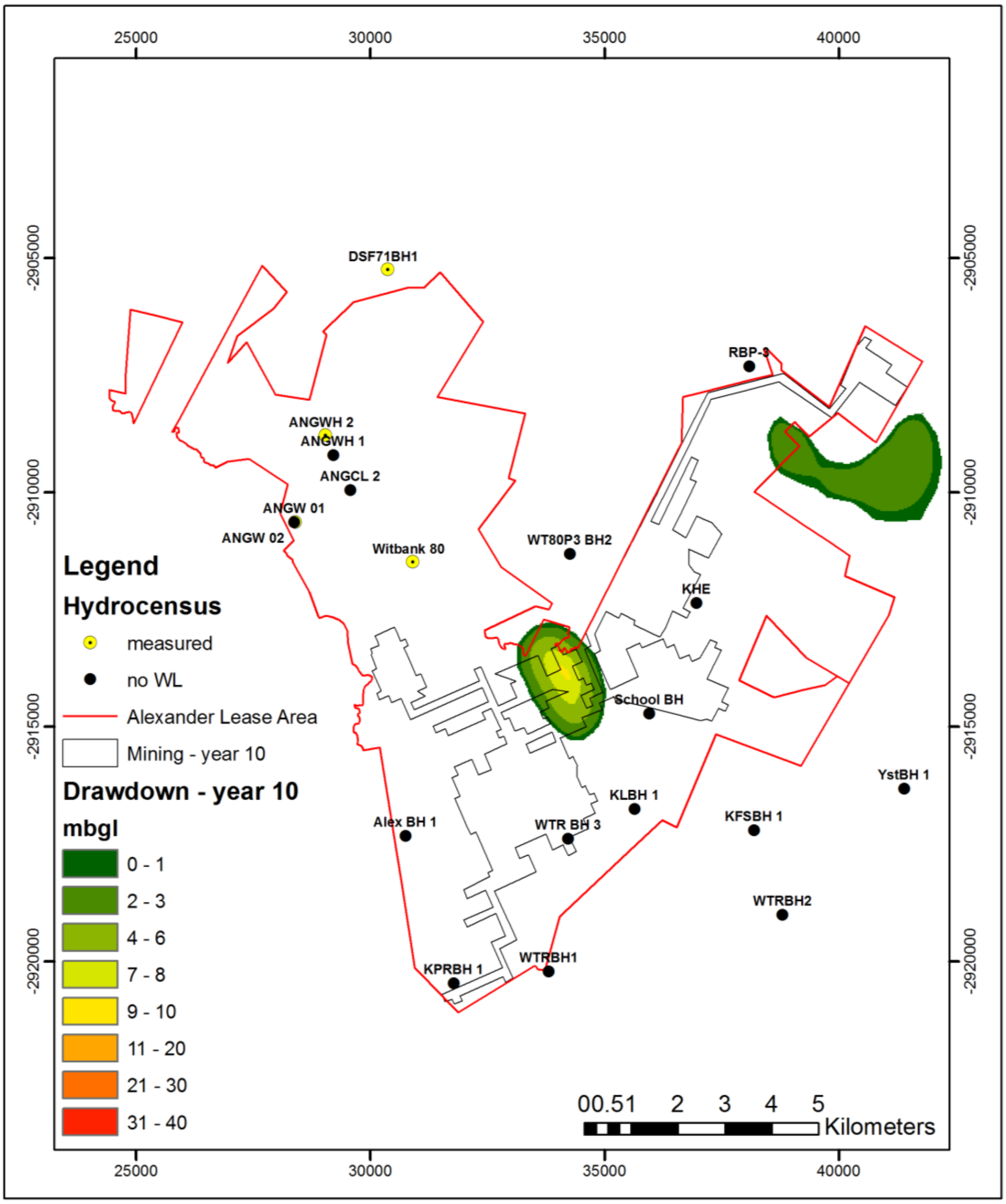


FIGURE 4-18: ALEXANDER UNDERGROUND MINE - CONE OF DRAWDOWN AT YEAR 10

The drawdown at the end of year 20 is illustrated in Figure 4-19. The cone of drawdown extends as mining progresses – greater areal extent. The depth of the cone of drawdown is increasing due to longer drainage into the underground workings.

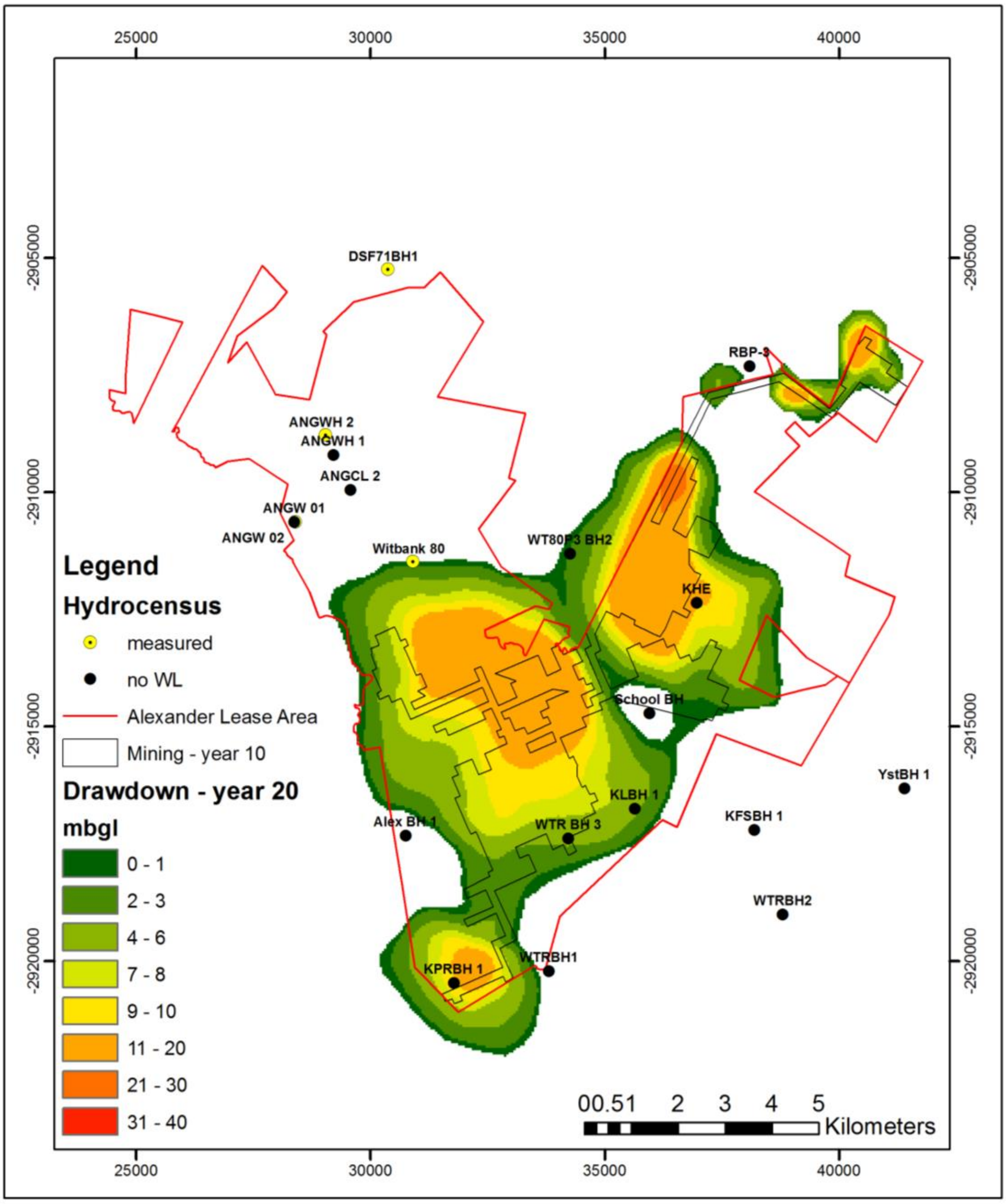


FIGURE 4-19: ALEXANDER UNDERGROUND MINE CONE OF DRAWDOWN AT YEAR 20

The cone of drawdown is becoming near maximum extent at depth at end of year 30 when mining is near the end (Figure 4-20).

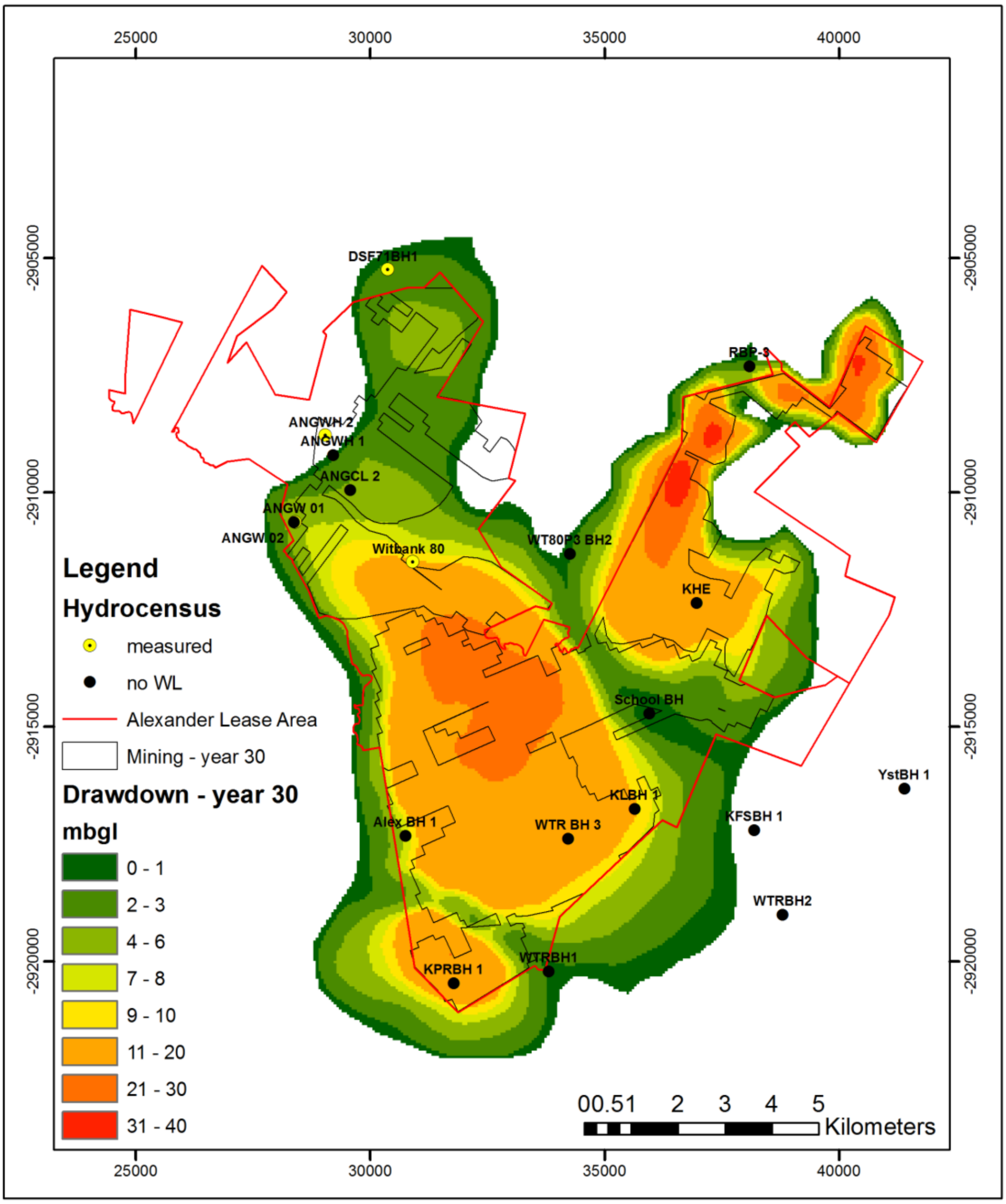


FIGURE 4-20:ALEXANDER UNDERGROUND MINE - CONE OF DRAWDOWN AT YEAR 30

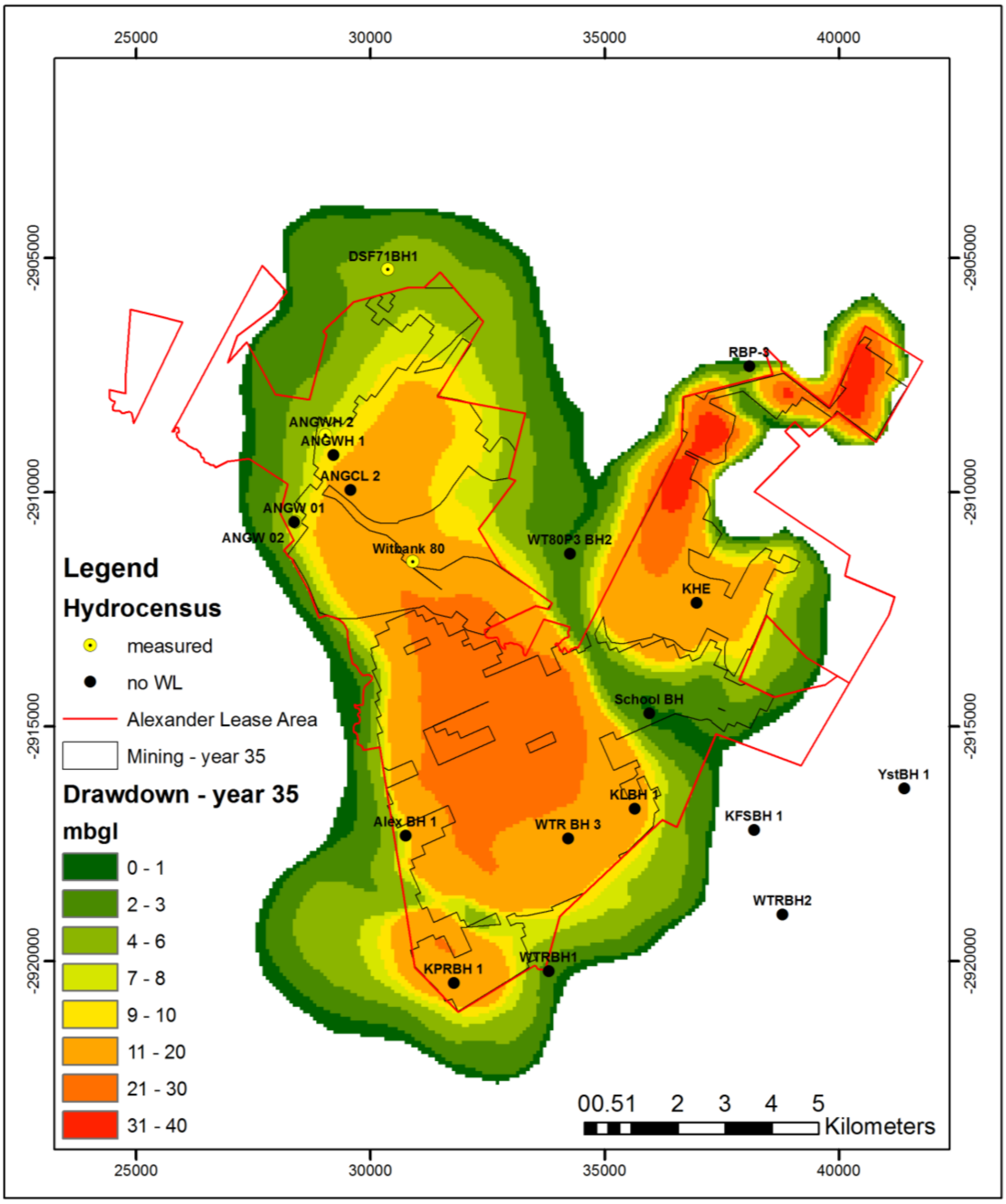


FIGURE 4-21: ALEXANDER UNDERGROUND MINE - CONE OF DRAWDOWN YEAR 35 (END OF MINING)

At year 35 of simulation (end of mining) the cone of drawdown is at maximum extent. This is expected as the underground mine is at full development. A depth of maximum 30m in the central underground mine zone is developed for a larger extent.

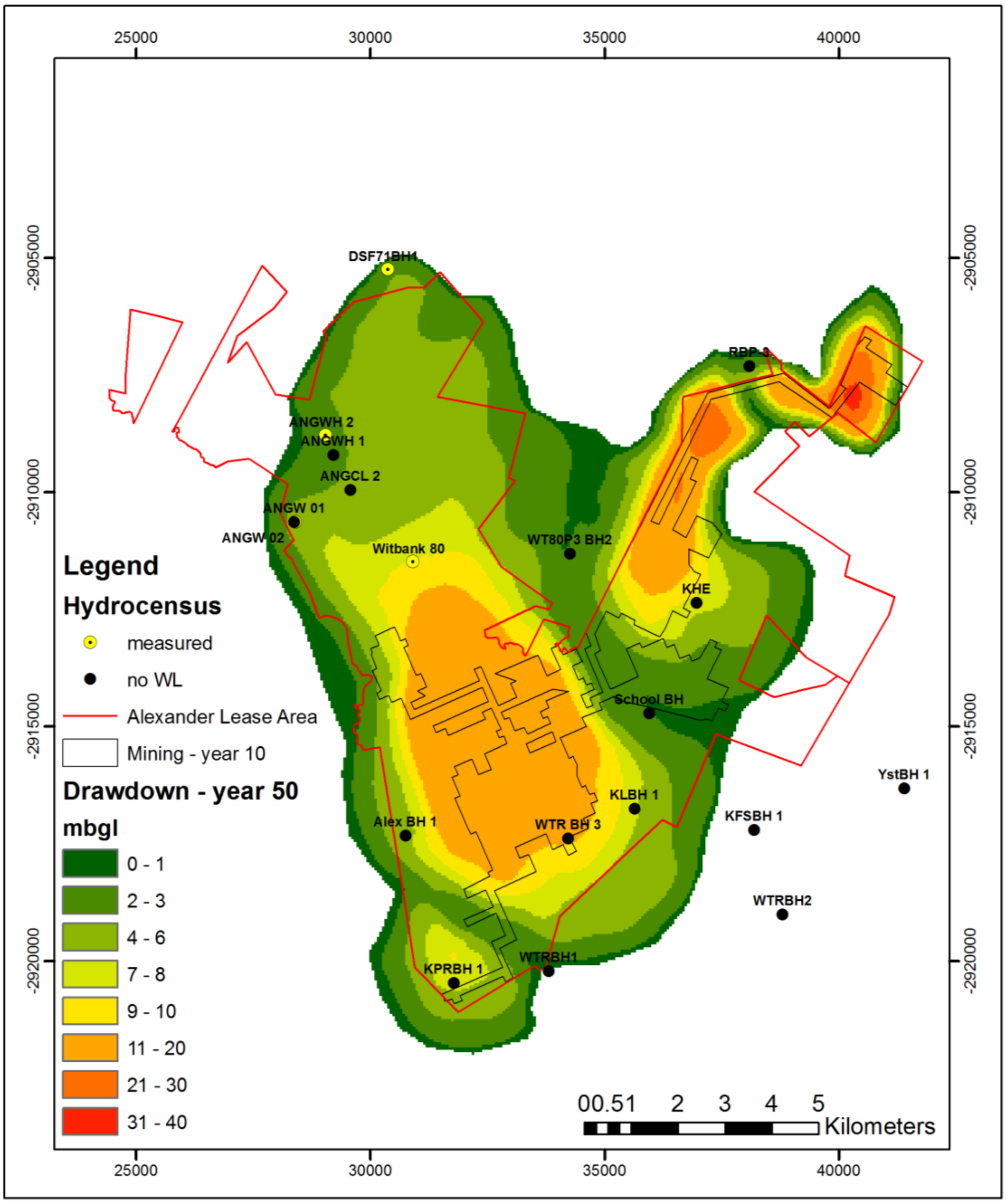


FIGURE 4-22: ALEXANDER UNDERGROUND MINE – CONE OF DRAWDOWN YEAR 50 (15 YEARS POST-MINING)

The cone of drawdown starts to recover as shown in Figure 4-22 at year 50 of simulation (15 years post-mining). The extent of the cone of drawdown is slightly smaller than the extent at year 35, however the depth of the cone of drawdown is less than at year 35 (Figure 4-20).

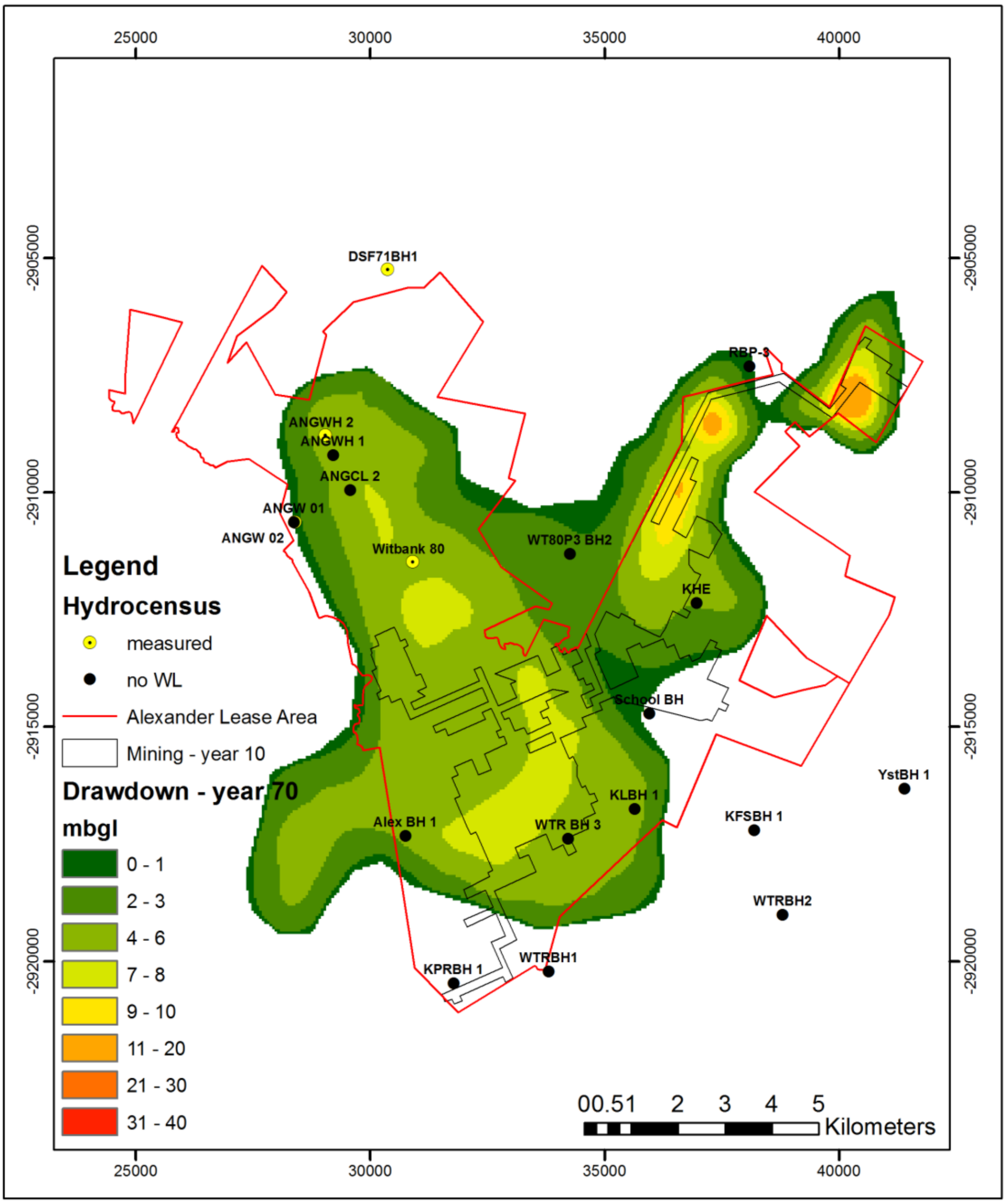


FIGURE 4-23: ALEXANDER UNDERGROUND MINE - CONE OF DRAWDOWN YEAR 70 (35 YEARS POST-MINING)

The cone of drawdown is recovering in extent and depth. The depth of the cone of drawdown at year 70 recovers to 8m in the central mining area, and to 20m in the north-eastern sector of the underground mine.

At year 100 of simulation (65 years post mining) the cone of drawdown recovered completely. No cone of drawdown map can be showed for 0m drawdown.

One point to be clarified consists in groundwater/surface water interaction. For the Alexander project this will not be an issue, as we consider that there is no hydraulic connection between the surface water bodies and the groundwater, for the following reasons:

- The wetlands occur generally in localized areas, where quasi-impermeable lenses of clays and silty-clays occur; these will allow the water to be stored and maintained in restricted “pockets”.
- The general groundwater level is between 15 and 20 mbgl, therefore if any hydraulic connectivity exists then there will be no water bodies to maintain the wetlands; at Alexander, there is no such evidence of hydraulic connectivity.
- The cone of drawdown depicted in the hydraulic head and cone of drawdown maps represent the distribution of the hydraulic heads and extent of cone of drawdown predicted at highest groundwater level (15-20mbgl).

There will be no decant occurring from the underground mine to surface. The general piezometric surface is approximately 15-20m below surface. This will not be exceeded during recovery and no artesian flow will occur

4.7.3 CONTAMINANT FLOW

The contaminant plume of the Fe considered for the WRD in the mass transport simulation is developing as the mining is progressing and waste material is deposited on WRD.

There is no contaminant flow expected to migrate from the underground workings. During mining the cone of depression and the hydraulic gradients created are the main drivers of groundwater flow towards the underground voids. At full recovery (year 100) is unlikely that underground flow will mobilize any contaminant from the underground mine due to low hydraulic gradients and high difference in hydraulic properties between the voids and the host rock.

The following figures illustrate the extent of the Fe contaminant plume at same time steps used to illustrate the hydraulic heads and cone of drawdown, for both unmitigated and mitigated scenarios:

- Year 10 of mining – Figure 4-24
- Year 20 of mining – Figure 4-25
- Year 30 of mining – Figure 4-26
- Year 35 of mining: end of mining – Figure 4-27
- Year 50: 15 years post closure - Figure 4-28
- Year 70: closure period equal to mining period – Figure 4-29
- Year 100: end of simulation – Figure 4-30

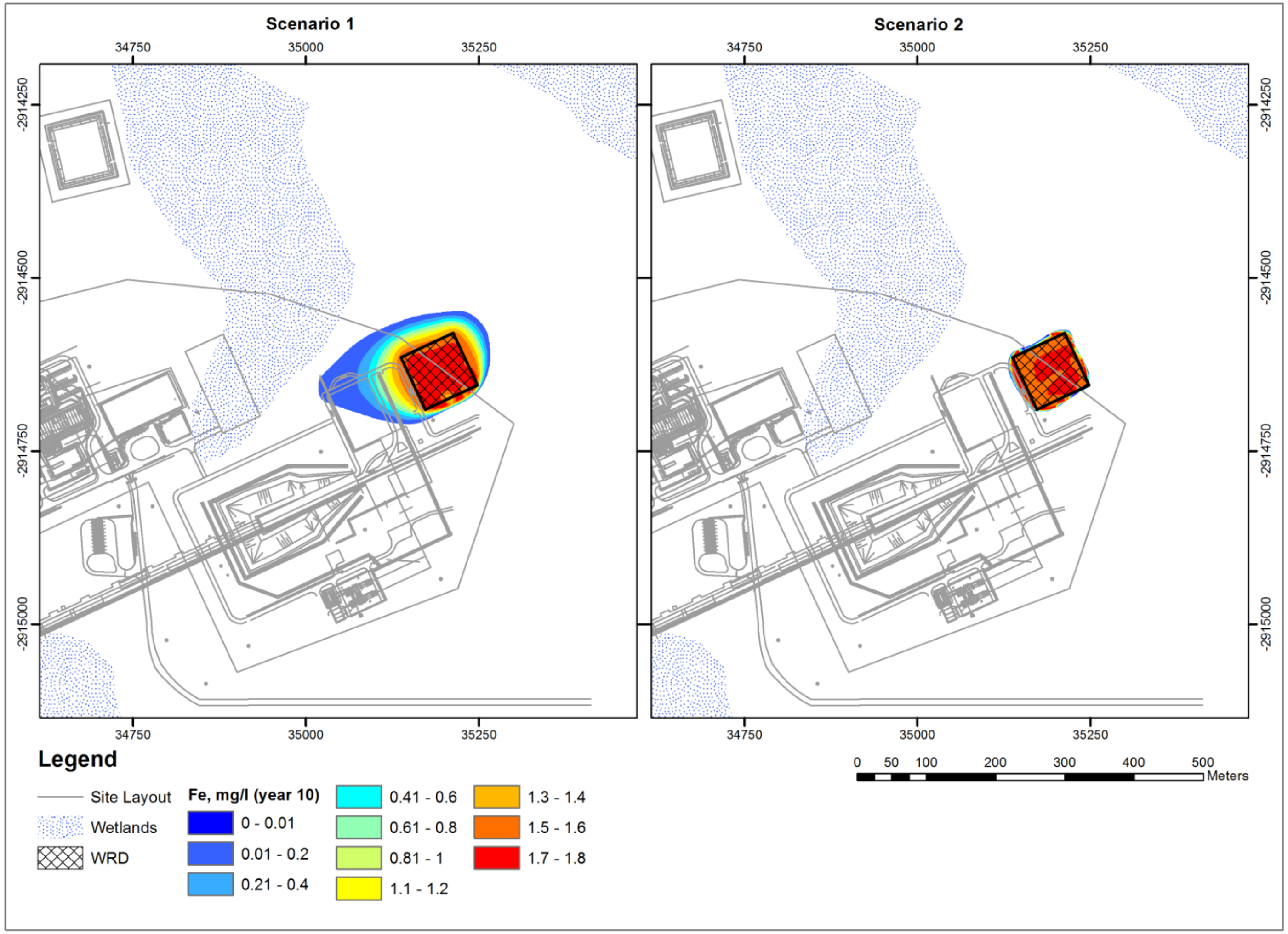


FIGURE 4-24: FE PLUME - YEAR 10: MITIGATED AND UNMITIGATED SCENARIOS

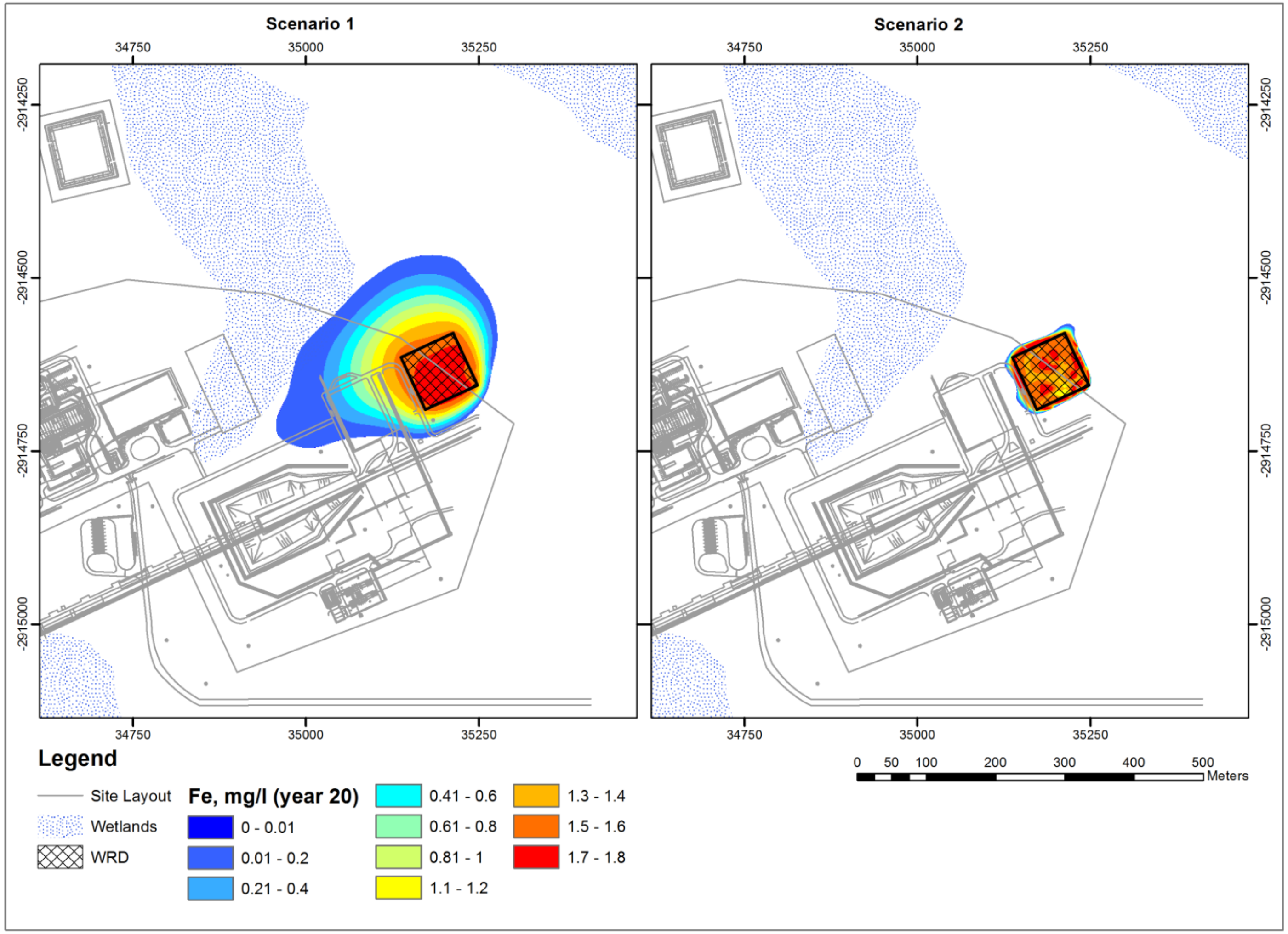


FIGURE 4-25: FE PLUME - YEAR 20: MITIGATED AND UNMITIGATED SCENARIOS

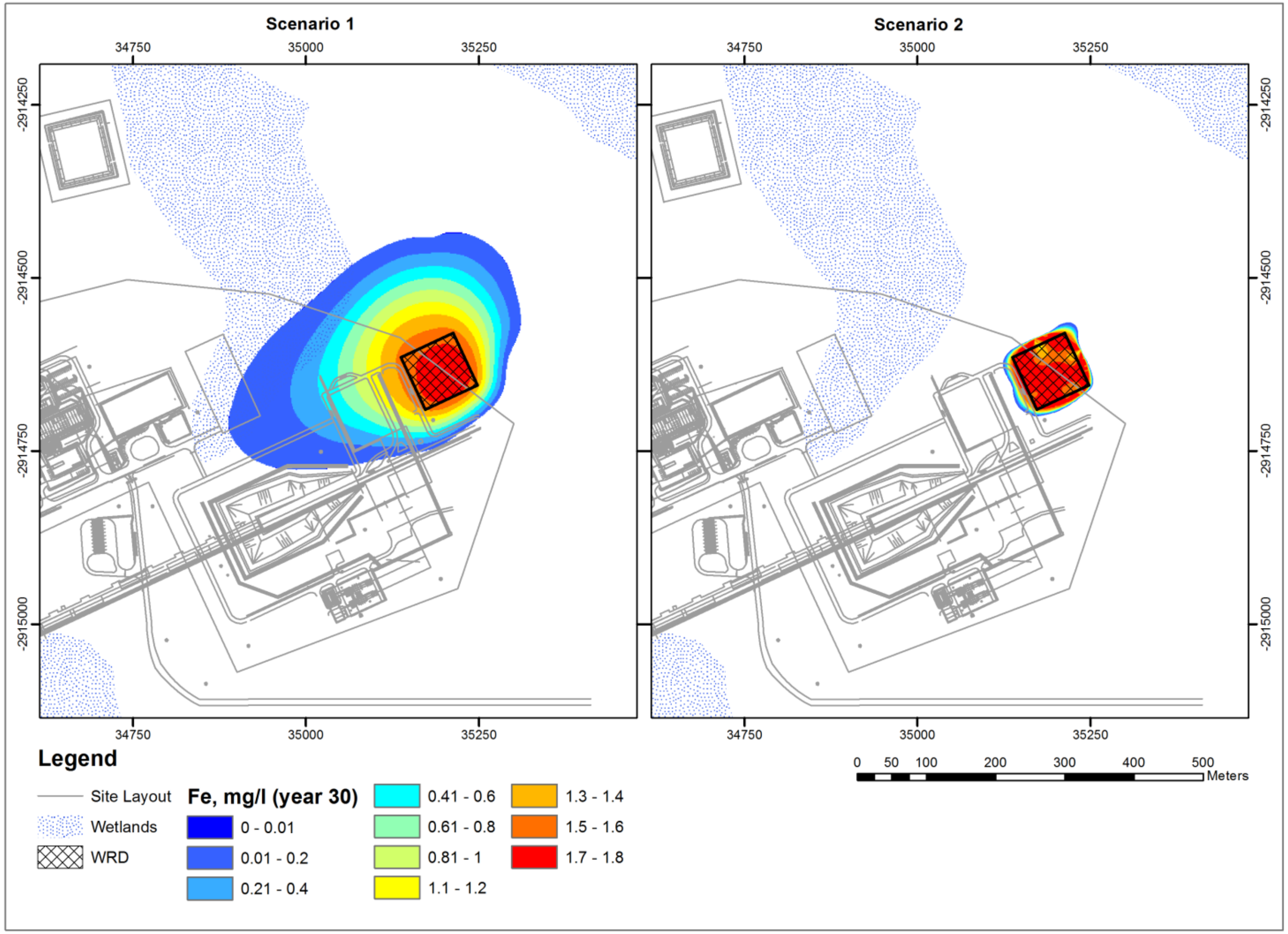


FIGURE 4-26: FE PLUME - YEAR 30: MITIGATED AND UNMITIGATED SCENARIOS

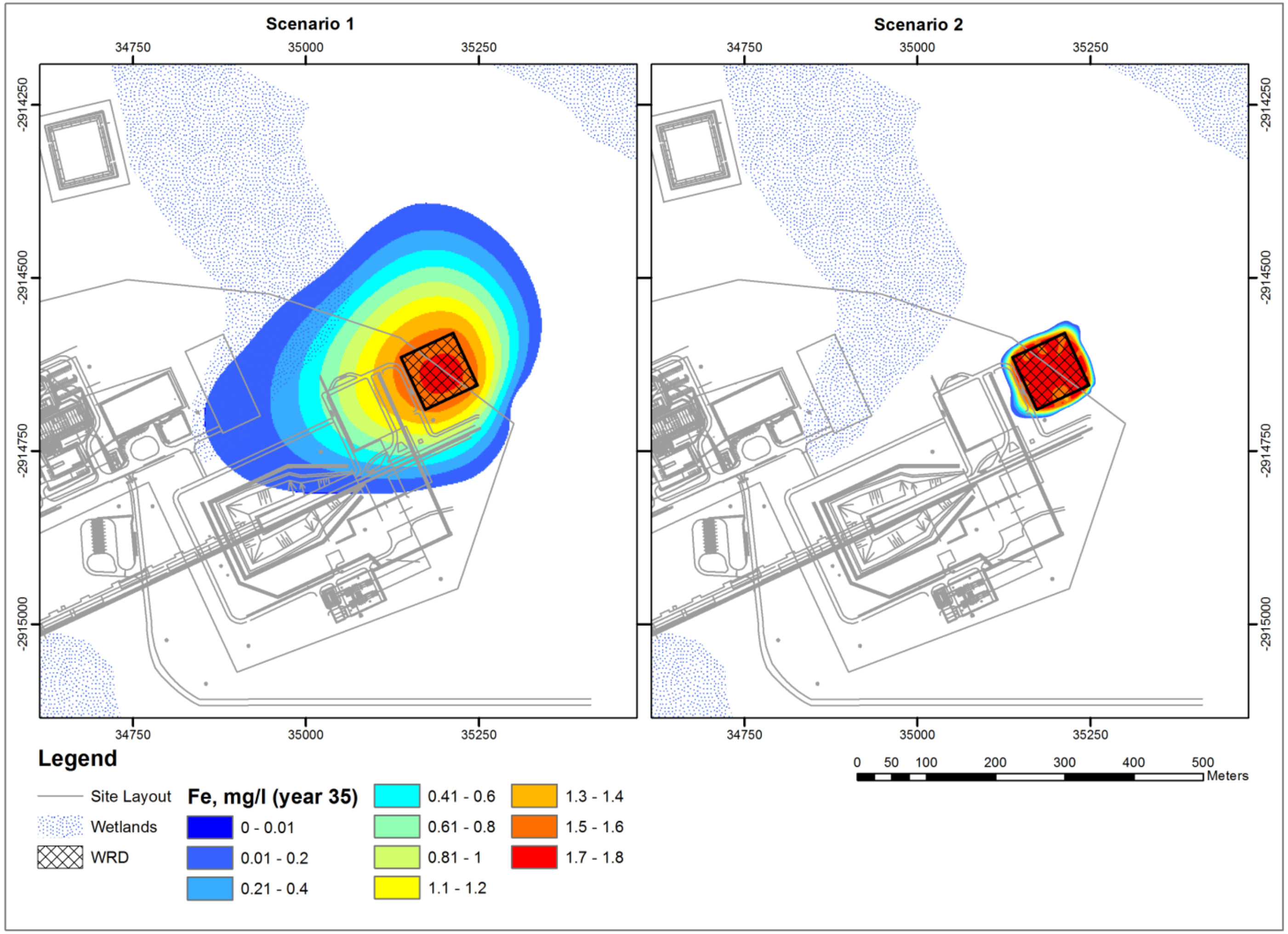


FIGURE 4-27: FE PLUME - YEAR 35 (END OF OPERATION): MITIGATED AND UNMITIGTED SCENARIOS

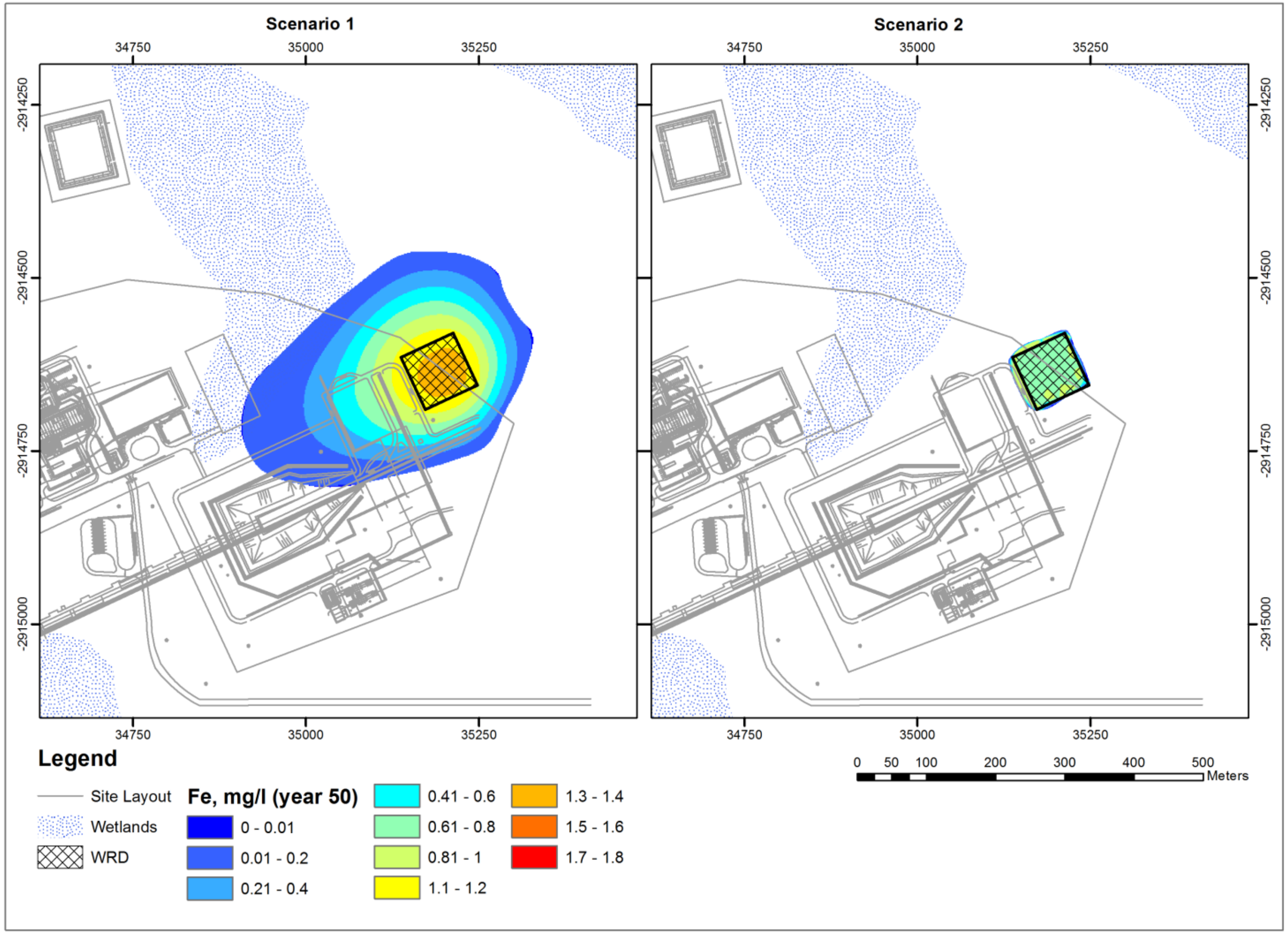


FIGURE 4-28: FE PLUME - YEAR 50 (15 YEARS POST-OPERATIONAL): MITIGATED AND UNMITIGATED SCENARIOS

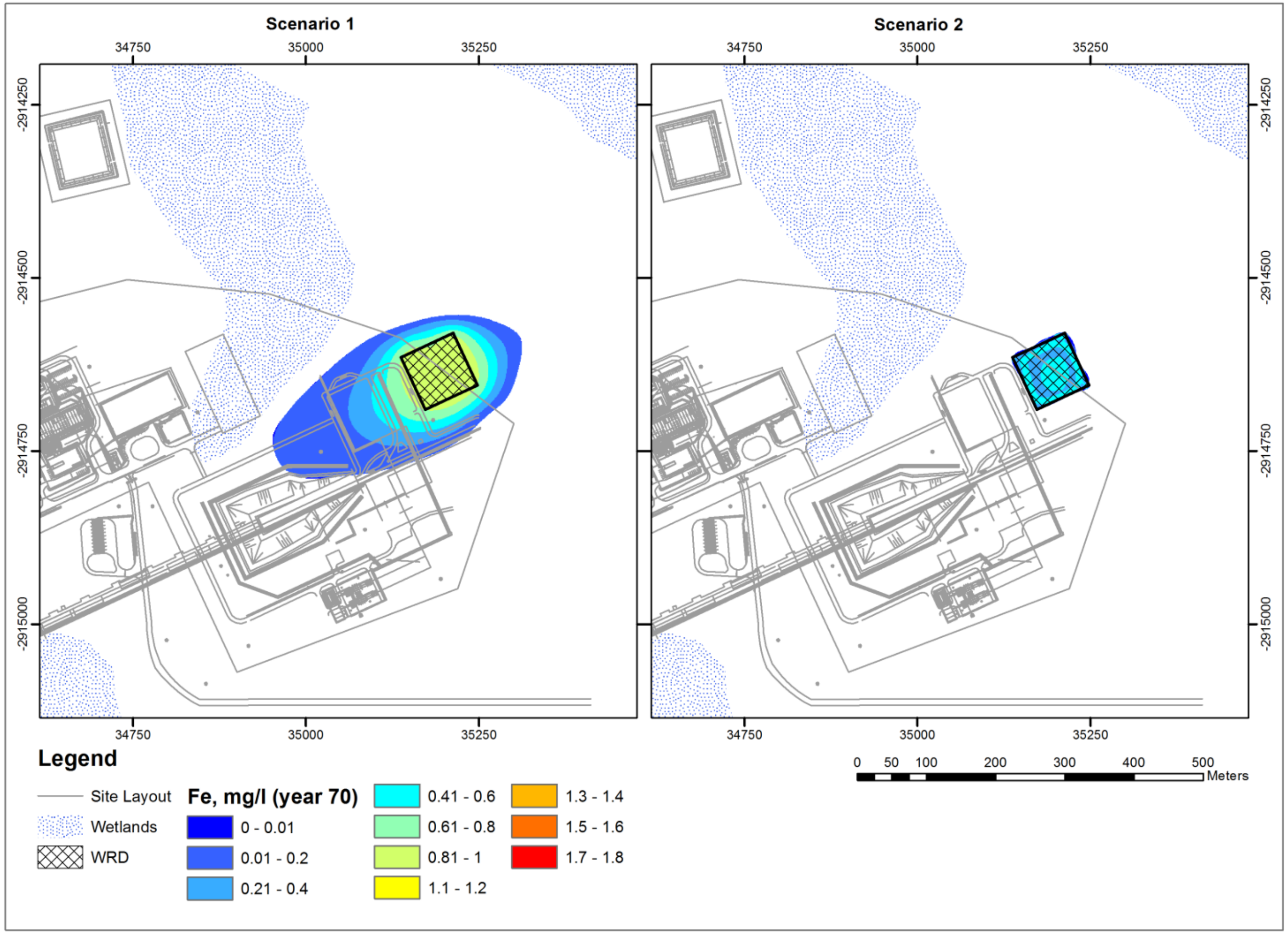


FIGURE 4-29: FE PLUME - YEAR 70 (35 YEARS POST-OPERATIONAL): MITIGATED AND UNMITIGATED SCENARIOS

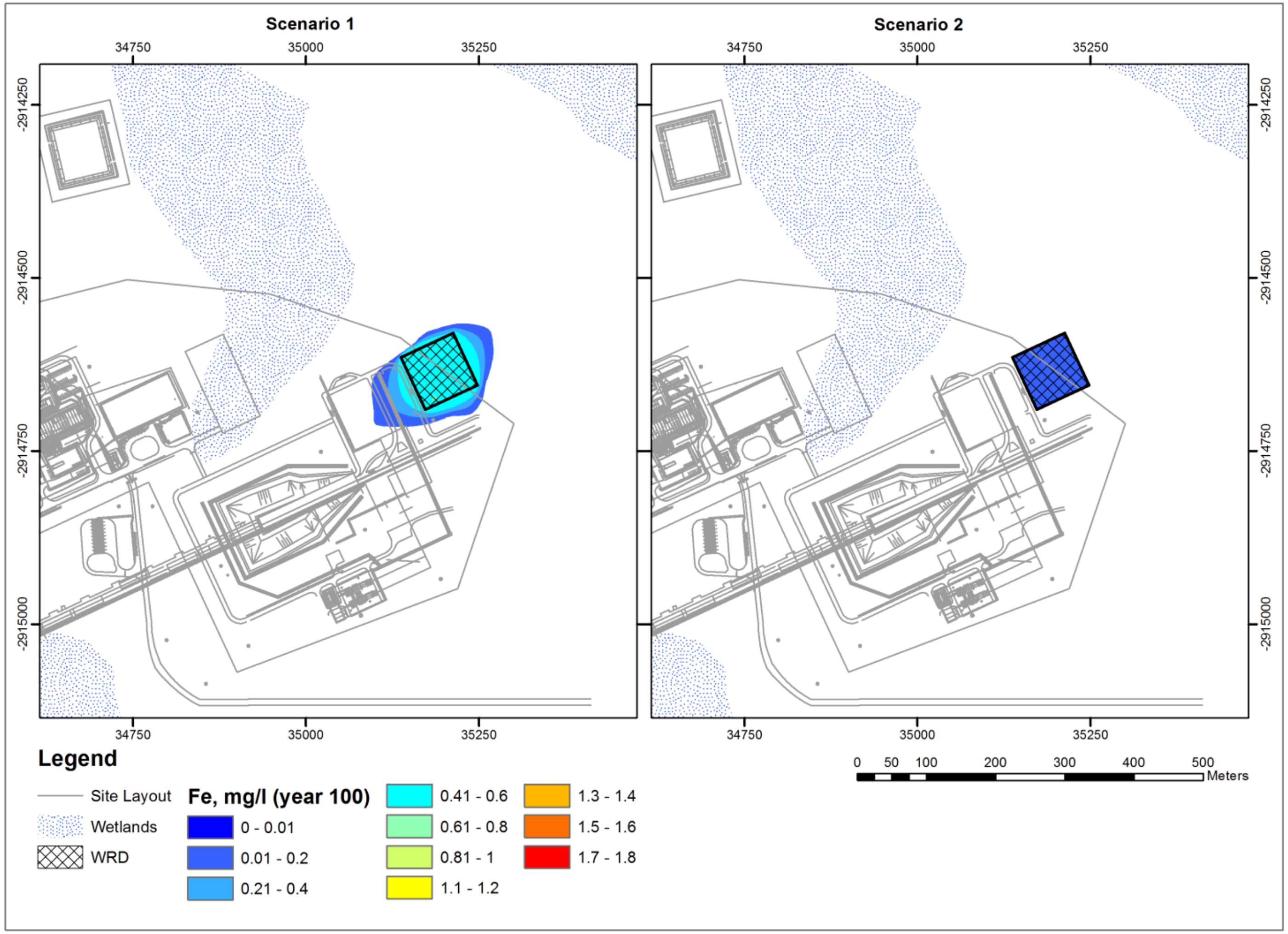


FIGURE 4-30: FE PLUME - YEAR 100 (END OF SIMULATION): MITIGATED AND UNMITIGATED SCENARIOS

The Fe plume is constantly increasing in areal extent until end of simulation (year 100). However, the Fe concentrations migrating from the WRD decrease in the post-operational stage. However, the extent of Fe plume is much decreased in the mitigated Scenario 2. Table 4-4 shows the maximum extent of the Fe plume developed for both unmitigated and mitigated scenarios.

TABLE 4-4: MAXIMUM FE PLUME EXTENT

Simulation/Mining Year	Scenario 1 (unmitigated), Fe plume extent, m	Scenario 2 (mitigated), Fe plume extent, m
10	130	11
20	205	21
30	274	23
35	302	35
50	259	11
70	224	5
100	75	0

From the surface water bodies (rivers, wetlands) only the wetlands are affected by the contaminant plume (West of WRD), in the unmitigated scenario, where the plume reached a distance of 302m from the WRD. The mitigated scenario indicated that no contaminant plume will reach the wetlands. No river will be impacted by the migration of the contaminant plume.

4.8 CONCLUSIONS

4.8.1 GROUNDWATER INFLOWS

The maximum groundwater inflows into the underground mine occur at year 10 of mining. The maximum inflow rate predicted is 21,000 m^3/day. This is expected, considering that the footprint of the underground mine is approximately 68,000,000 m^2 at full development.

4.8.2 CONE OF DRAWDOWN

The cone of drawdown created by the groundwater passive inflows into the underground mine is at full development at year 35 (end of mining). The depth of the cone of drawdown is approximately 80 m in the deepest areas.

Table 4-5 shows the number of boreholes affected by the cone of drawdown.

TABLE 4-5: BOREHOLES IMPACTED BY THE CONE OF DRAWDOWN

Year	Number of boreholes affected by cone of drawdown
10	0
20	6
30	15
35	16

Year	Number of boreholes affected by cone of drawdown
50	15
70	10
100	0

There will be no surface decant from the underground mine to surface.

4.8.3 FE CONTAMINANT PLUME

The Fe migrate from the WRD into the groundwater system as the waste is deposited. It should however be noted that waste will only be deposited on the WRD during the construction phase of the mine until the shaft sinking activities have ended. However, the high concentrations (1.47 mg/l) maintained in the WRD will be for the duration of the operational phase. As mining stops, the WRD source term will be terminated. This will reduce considerably the Fe maximum concentration and the plume is still reducing in size and concentration during post-operations.

As predicted by the contaminant transport mitigated scenario, there will be no impact on quality of the surface water bodies, or on groundwater from the underground voids.

5 IMPACT ASSESSMENT

Predictive simulations were run using the calibrated numerical groundwater model. The simulation results indicate the potential impacts of mine dewatering and contaminant transport scenarios. Relevant assumptions and limitations are detailed in the specific sections.

The impacts on groundwater have been assessed in terms of possible impacts on existing and/or future groundwater users.

There are a number of sources in all mine phases that have the potential to pollute groundwater. In the construction and decommissioning phases some of these potential pollution sources are temporary and diffuse in nature. Even though the sources are temporary in nature, related potential pollution can be long term. The operational phase will present more long term potential sources (waste rock dump).

5.1 MINE DEWATERING IMPACT

Dewatering activities has the potential to cause a lowering of groundwater levels which may cause a loss in water supply to surrounding borehole users in the impact zone.

Severity / nature

Based on the results of the groundwater study, the cone of depression is predicted to impact 16 identified boreholes, with a maximum drawdown of 40 m. It is however important to note that the drawdown decreases with an increase in distance away from the underground mine. Unfortunately the depth of the boreholes is unknown (equipment installed). A more detailed assessment of the water levels impact on the water supply boreholes can be done in the conditions that the existing equipment will be removed and the depth and water levels in the of the boreholes will be measured.

The severity in the unmitigated scenario is medium to high.

Duration

The duration of the impacts is linked to the duration of the dewatering/abstraction and the recharge time thereafter. Based on groundwater model predictions, it is expected that groundwater levels in the main water supply aquifer will recover after a period greater than double the mining period (more than 70 years) but not longer than 100 years.

Spatial scale / extent

The spatial scale of the predicted dewatering cone will extend beyond the mine lease area which is a medium spatial scale.

Consequence

In the unmitigated scenario the consequence is high and reduces to low with mitigation.

Probability

Predicted modelling results indicate that 16 boreholes are located within the cone of depression zone in year 35, when the depression cone is at maximum extent. It follows that the unmitigated probability is high.

Significance

The unmitigated significance is high and is reduced to low with mitigation.

5.1.1 MANAGEMENT MEASURES

During the mining phase the following need to be implemented:

- All potentially affected third party boreholes will be included in the Alexander Project groundwater monitoring program to ensure that changes in water depths can be identified.
- Where Alexander Project dewatering causes a loss of water supply to third parties, appropriate compensation will be provided until such time as the dewatering impacts cease.
- Groundwater quantity as per the monitoring programme must be monitored.

5.1.2 ASSUMPTIONS AND LIMITATIONS

It is important to note that the Conclusions and the Impact Assessments take into consideration only the boreholes identified and visited during the hydrocensus (Table 3-1). It is possible that other boreholes exist within the Leas Area. However, these could not be visited as the farm owner did not grant access to the hydrocensus team. Under these circumstances, the unknown boreholes could not be included in the Impact Assessment.

Three assumptions were made when assessing the mine dewatering and development of a cone of drawdown:

1) The groundwater entering the mine voids during mining will be pumped out to surface,
2) No intersecting faults were considered, as the hydraulic nature of possible faults and structures is unknown at this stage,
3) The shafts will be grouted as water is intersected during sinking and enlarging operations and therefore eliminating groundwater inflows.

5.2 GROUNDWATER CONTAMINATION IMPACT

Two types of pollution sources are broadly considered. The one type is diffused pollution which includes ad hoc spills and discharges of polluting substances. The other type is point source pollution which includes more long term pollution associated with sources such as the waste rock dump.

Based on modelled results the drainage water quality and run-off from the side slopes of the waste rock dump have a neutral pH and trace elements are generally at or below the model reporting limits. It is however, important to note that the contaminant transport modelling the identified high concentrations and specific seepage rates only for Fe for the waste rock dump.

The groundwater model (Scenario 1- unmitigated), assuming no lining or base preparation of waste rock dump location predicts that a contamination plume could migrate maximum 302 m in a south West-South-West direction, as indicated in Table 4-4.

At closure the waste rock will be removed from surface and the only remaining Fe concentrations which are present at the time of closure slowly decrease.

In the unmitigated scenario the severity is medium, due to relatively low extent, however, possibly impacting the nearby wetlands.

The mitigated scenario run (Scenario 2) assumes a Class C liner which will be applied on surface before the waste material will be dumped, as well as a soil cover maintained for the duration of the operations. At the end of mining, the waste material will be removed and the soil cover will be re-applied.

The severity of the impact in the mitigated scenario is low.

Duration

Groundwater contamination is long term in nature, occurring for periods longer than the life of proposed project.

Spatial scale / extent

The pollution plume will extend beyond the shaft complex area, however, there is no identified third party user. The results of the contaminant transport (Scenario1 – unmitigated) however, indicate that the plume will reach the wetland situated on the North-Western side.

The mitigated scenario (Scenario 2) model runs show a minimum spatial extent of maximum 35m.

Consequence

The consequence is medium in the unmitigated scenario, and low in the mitigated scenario.

Probability

The probability of the impact occurring relies on a causal chain that comprises three main elements:

- Does contamination reach groundwater resources?
- Will people and animals utilise this contaminated water?
- Is the contamination level harmful?

The first element is that contamination reaches the groundwater resources underneath or adjacent to the proposed project area. Due to the proximity of the sources to groundwater, the TDS will reach groundwater resources.

The second element is that third parties and/or livestock use this contaminated water for drinking purposes. The nearest third party borehole identified during the hydrocensus is located approximately 700m to the east of the waste rock dump. It follows, that no third party borehole identified during the hydrocensus is located within the contamination plume zone.

However, it must be noted that there may be other third party boreholes which could be impacted. However these could not be identified and recorded, as the farm owners responded negatively to the hydrocensus.

The third element is whether contamination is at concentrations which are harmful to users. Based on predicted groundwater modelling, mine related contamination will significantly worsen the existing water quality.

As a combination, the unmitigated and mitigated probability is medium.

Significance

The unmitigated significance is low.

5.2.1 MANAGEMENT MEASURES

- Anglo American will comply with both the National Water Act (36 of 1998) and Regulation 704 (4 June 1999) during all project phases.
- Infrastructure that has the potential to pollute groundwater resources will be designed and implemented in a manner that pollution is addressed in all mine phases. In this regard, as part of detailed design of the waste rock dump the required soil cap and appropriate risk based liner selection will be determined and incorporated A site specific geochemistry study will assist in the liner determination.

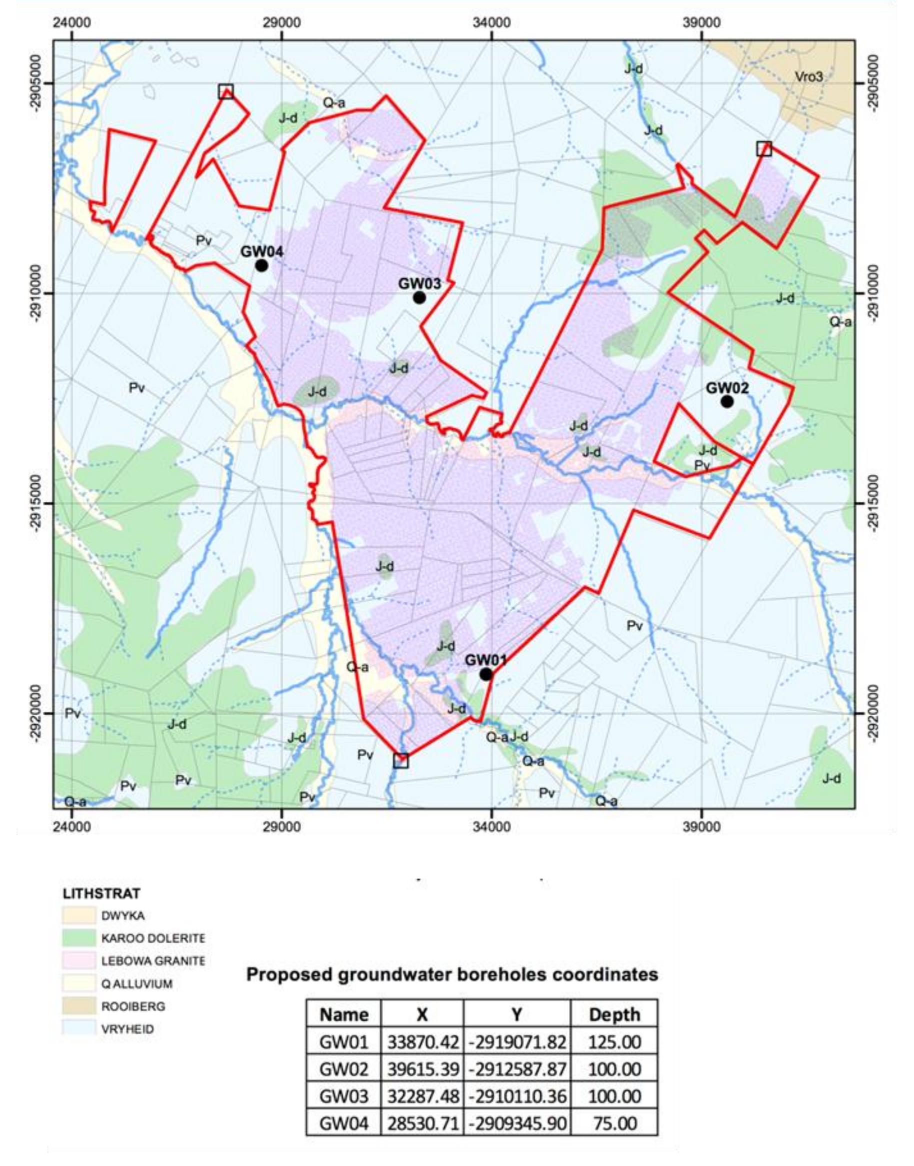
- Planned infrastructure that has the potential to pollute groundwater (waste rock dump) will be identified and included into the groundwater pollution management plan which will be implemented on an ongoing basis. The plan includes:
    - Identify potential pollution sources
    - Determine the extent of the pollution plume
    - Design and implement intervention measures to prevent, eliminate and/or control the pollution plume.
    - Limit unauthorized access to waste rock dump.
    - Monitoring all potential impact zones to track pollution and mitigation impacts
    - Where monitoring results indicates that third party water supply has been polluted by Alexander Project will ensure that appropriate compensation will be provided.
    - At closure no waste rock will remain on surface.
- For the unmitigated scenario:
    - At least a 302 m buffer zone needs to be established around the perimeter of the waste rock dump. These buffers should be adjusted if future monitoring information indicates that the zone of influence is different than the modelled prediction. These buffers will ensure that no third parties are able to abstract groundwater within the contamination plume extent. Beyond 620 m distance the TDS concentrations added to the baseline groundwater will be within the prescribed limits.
    - If third party users are within the 302m buffer zone, then these should be identified and advised of the potential risks; alternative water supply should be provided.

In conclusion, the Alexander Coal Project is a feasible project, with the provision that mitigation measures (as per Scenario 2) are in place in order to have a minimum/low impact on the groundwater resources in the Project area.

6 GROUNDWATER MONITORING PLAN

SLR recommends that Anglo American implement a monitoring plan to monitor the groundwater levels and groundwater quality, as follows:

1) Monitoring plan to include all hydrocensus boreholes together with the possible existing third party users boreholes which were not identified during the hydrocensus, and also 4 (four) new monitoring boreholes which will need to be drilled as per Figure 6-1.
2) Monitoring protocol:
    a. Monitoring frequency: it is recommended that the monitoring must be performed on a quarterly basis,
    b. The water levels must be recorded during each monitoring event and included in a mine groundwater database,
    c. Water samples must be collected according to the South African best practice guideline (boreholes purging, preservation) for each monitoring event and the samples must be analysed by an accredited laboratory in South Africa,
    d. The usual inorganics suite (anions, cations, metals) must be analysed at each monitoring event to determine changes or no changes in groundwater quality (Table 6-1); the results should be incorporated in the mine groundwater database.



Proposed groundwater boreholes coordinates

Name	X	Y	Depth
GW01	33870.42	-2919071.82	125.00
GW02	39615.39	-2912587.87	100.00
GW03	32287.48	-2910110.36	100.00
GW04	28530.71	-2909345.90	75.00

FIGURE 6-1: ALEXANDER - PROPOSED NEW MONITORING BOREHOLES

TABLE 6-1: GROUNDWATER QUALITY RECOMMENDED ANALYSES

No.	Analysis
1	P
2	Pb
3	Sb
4	Se
5	Si
6	Sn
7	Sr
8	U
9	V

No.	Analysis
10	W
11	Y
12	Zn
13	Zr
14	pH
15	EC
16	TDS
17	TSS
18	Total Alkalinity as $CaCO_3$
19	Bicarbonate as HCO_3
20	Chloride as Cl
21	Sulphate as SO_4
22	Fluoride as F
23	Nitrate as N

REFERENCES

Department of Water Affairs and Forestry (1996). *South African Water Quality Guidelines (second edition). Volume 4: Agricultural Use: Irrigation.*

Department of Water Affairs and Forestry (1996). *South African Water Quality Guidelines (second edition). Volume 5: Agricultural Use: Livestock Watering.*

Fetter, C.W (2001) *Applied Hydrogeology*. 4th Edition. Pearson Prentice Hall

Hancox P.J., Goetz, A.E, South Africa's coalfields — *A 2014 perspective, International Journal of Coal Geology 132* (2014) 170–254

Jones and Wagner Engineering and Environmental Consultants (2014) *Baseline Surface Water Report for the Anglo American Inyosi Coal Alexander Project*. Report No.: JW87/14/D715 – Rev 2 DRAFT

South African National; Standard (2015) SANS 241-1, 2015 Edition 1, Drinking water Standards

Weaver, J.M.C, Cave, L and Talma, A.S (2007). *Groundwater Sampling* (Second Edition) Water Research Commission (WRC) Report Number TT 303/07

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(Report Author)	**(Project Manager)**	**(Project Reviewer)**

APPENDIX A: FULL DETAILS OF MONITORING POINTS VISITED

APPENDIX B: LABORATORY CERTIFICATES

APPENDIX C: STIFF DIAGRAMS FOR GROUNDWATER

APPENDIX D: FULL SET OF RESULTS FOR SURFACE WATER

Appendix E: Specialist CV

SLR Consulting (Africa) (Pty) Ltd

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