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GEOHYDROLOGICAL ASSESSMENT FOR CEMENT PLANT, LICHTENBURG, NORTH WEST PROVINCE

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LAFARGE

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SYNOPSIS

Specialist geohydrological assessment in support of water use authorisation for Cement Plant in Lichtenburg, North West Province

KEY WORDS:

Geology, geohydrology, hydrocensus, groundwater use, boreholes, groundwater abstraction, groundwater model, risk and impact

QUALITY VERIFICATION

This report has been prepared under the controls established by a quality management system that meets the requirements of ISO9001: 2015 which has been independently certified by DEKRA Certification

Verification	Capacity	Name	Signature	Date
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1 INTRODUCTION

This report presents the results of a detailed geohydrological assessment carried out for the Cement Plant site located in Lichtenburg in the North West Province. The geohydrological report has been prepared as a specialist study in support of the water use authorisation for the following water uses as per Section 21 of the National Water Act (Act No. 36 of 1998).

Section 21 (a) - taking water from a water resource
Section 21 (g) - disposing of waste in a manner which may detrimentally impact on a water resource
Section 21 (h) - disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process removing.

The scope of services is to prepare a geohydrological report to include the following:

- Geology and geohydrology of the area
- Hydrocensus, groundwater flow and recharge
- All water resources in the plant and surrounding areas must be indicated
- A groundwater model for the pit and area, which must show contaminant transport and impact prediction
- A groundwater monitoring programme indicating monitoring points upstream and downstream of all the waste facilities and the pit
- An impact assessment
- Yield testing of production boreholes to be used in the application and the test data must be shown in the report
- An assessment of ingress water from underground if it fills the pit at any point in time.

We refer to our proposal reference 005752 2117004, titled “Proposal for Detailed Geohydrological Assessments for Tswana Lime and Lichtenburg Cement Factory Plant Sites, North West Province”, dated 10 November 2021. JG Afrika were appointed to proceed with the assessment under purchase order 4501873093, dated 26 April 2022.

2 INFORMATION SUPPLIED

The following information has been used in the preparation of this report:

<u>Reports, Documents and Guidelines</u>

- Letter reference 27/2/2/C131/8/1 of the Department Water and Sanitation, titled “Water Use Licence Application in Terms of Section 40 of the National Water Act, 1998 (Act 36 of 1998): Lafarge Industries South Africa (Pty) Ltd: For an old Cement Plant Situated on Portions 1, 27, 30, 32, 61, 71 of the Farm Lichtenburg 27 IP and Erf 1024 of the Farm Lichtenburg Extension 1 IP, in Lichtenburg Town, within the Ditsobotla Local Municipality, North West Province”, dated 21 February 2022
- Report reference 5707 of JG Afrika (Pty) Ltd, titled “Lichtenburg Lafarge Cement Plant Water Balance Study”, draft, dated March 2022
- Report reference LI/MR9/2021/DS of Aquatico Scientific (Pty) Ltd, titled “Lafarge Industries Monthly Water Quality Assessment Report, October 2021”, dated October 2021

- Report reference LI/AR1/2021/DS of Aquatico Scientific (Pty) Ltd, titled "Lafarge Industries Annual Water Quality Assessment Report, February 2021 – January 2022", dated 9 May 2022
- Report reference GW-16-09-CV414B of Tucana Solutions, titled "Lafarge Lichtenburg Cement Plant and Tswana Quarry – Geohydrological Report", version 1.4, dated February 2017
- Government Notice R267 of March 2017. National Water Act, 1998 (Act No. 36 of 1998). Regulations Regarding the Procedural Requirements for Water Use Licence Applications and Appeals
- The Department of Water Affairs, First Edition, February 2010. Operational Guideline: Integrated Water and Waste Management Plan
- Water Research Commission and Institute for Groundwater Studies, University of the Free State, January 2001. Manual on Pumping Test Analysis in Fractured-Rock Aquifers
- South African National Standard SANS10299-4:2003 – Part 4: Test Pumping of Water Boreholes
- South African National Standard, SANS241: 2015, Edition 2. Drinking Water.
- Aller L, Bennett T, Lehr JH, Petty, RJ and Hackett G (1987). *DRASTIC: A Standardized System for Evaluating Groundwater Pollution Potential using Hydrogeologic Settings*. NWWA/EPA Series, EPA-600/2-87-035
- Bredenkamp D, Botha LJ, van Tonder G and Janse van Rensberg H (1995). *Manual on Qualitative Estimation of Groundwater Recharge and Aquifer Storativity, Based on Practical Hydro-Logical Methods*. Water Research Commission, TT 73/95
- Parsons RP (1995). *A South African Aquifer System Management Classification*. WRC Report No. 77/95, Water Research Commission, Pretoria
- Taylor CJ (1983). *A Geohydrological Investigation of the Lichtenburg Area, Bo- Molopo Subterranean Water Control Area*. Division of Geohydrology, Department of Environment Affairs, Pretoria
- Vegter, J.R. (1995). *An Explanation of a Set of National Groundwater Maps*. WRC Report No. TT 74/95, Water Research Commission, Pretoria, South Africa
- JMC Weaver et al, 2007. Groundwater sampling, A Comprehensive Guide for Sampling Methods. Water Research Commission (TT303/07).

<u>Maps and Drawings</u>

- Map Sheet titled "2626 West Rand", at a scale of 1:250000, dated 1986, of the Geological Map Series, supplied by the Geological Survey, Pretoria
- Map sheet titled, "2526 Johannesburg", at a scale of 1:500 000, first edition, dated 1999, of the Hydrogeological Map Series of the Republic of South Africa, supplied by the Directorate: Geohydrology, of the Department of Water Affairs and Forestry
- Map Sheet titled "2626AA Lichtenburg", at a scale of 1:50 000, dated 2006, digital version, of the Topocadastral Map Series, supplied by the Surveyor General

<u>Data</u>

- National Groundwater Archive (NGA) digital information, as supplied by The Department of Water and Sanitation (DWS) as at August 2022
- DWAF (2003a). Groundwater Resources Assessment Phase II Database. Website: www.dwaf.gov.za/Groundwater/GRAII.aspx
- DWAF (2003b). Groundwater Resources Assessment Phase II Database. Website: www.dwaf.gov.za/Groundwater/GRAII.aspx
- World Aerial Imagery obtained via Global Mapper as at August 2022
- SRTM30 Digital Elevation Model

- DRASTIC Aquifer Vulnerability dataset of South Africa
- Aerial magnetometer data (1km x 1km resolution) for South Africa
- SANBI Wetlands Coverage for South Africa (2010)
- Geohydrological yield map of South Africa (2009)
- Google Earth Pro version 7.3.3 of July 2020.

3 SITE DESCRIPTION

The Cement Plant site is located on farm Lichtenburg Town and Townlands 27 IP in the Ditsobotla Local Municipality of the North West Province. The site is located immediately north east of the town of Lichtenburg and can be accessed from Lichtenburg via the R53 followed by the D379. The location of the site is shown in Figure 1.

Figure 1: Site Locality

4 APPLICABLE WATER USE APPLICATIONS

The water use applications specific to the geohydrological assessment for the Cement Plant site are summarised in Table 1 and shown in Figure 2.

Table 1: Summary Water Uses

Water Use	Description	Latitude	Longitude
CEMENT PLANT SITE			
21 (a)	Plant Borehole 1	-26.11833	26.16778
21 (a)	Plant Borehole 2	-26.11769	26.16722
21 (a)	Plant Borehole 3	-26.11892	26.18448
21 (a/h)	Townlands Dam Processing and Cooling	-26.12845	26.18405
21 (g)	Coal Stockpiles	-26.13337	26.13337
21 (g)	Gypsum Stockpiles	-26.13475	26.18203
21 (g)	Additive Stockpiles	-26.13365	26.18692
21 (g)	Limestone Stockpiles	-26.13055	26.18700
21 (g)	PCD 1	-26.13466	26.17969
21 (g)	PCD 2	-26.13431	26.18723
21 (g)	B Works Ablution	-26.14116	26.18669
21 (g)	Palletiser Ablution	-26.13551	26.17889
21 (g)	Packing Plant Ablution	-26.13338	26.18177
21 (g)	Electrical Workshop Ablution	-26.13385	26.18258
21 (g)	Limestone Tip Ablution	-26.13099	26.18615
21 (g)	Main Road Reception Ablution	-26.14224	26.17887
21 (g)	Swart Dam Ablution	-26.13541	26.18600

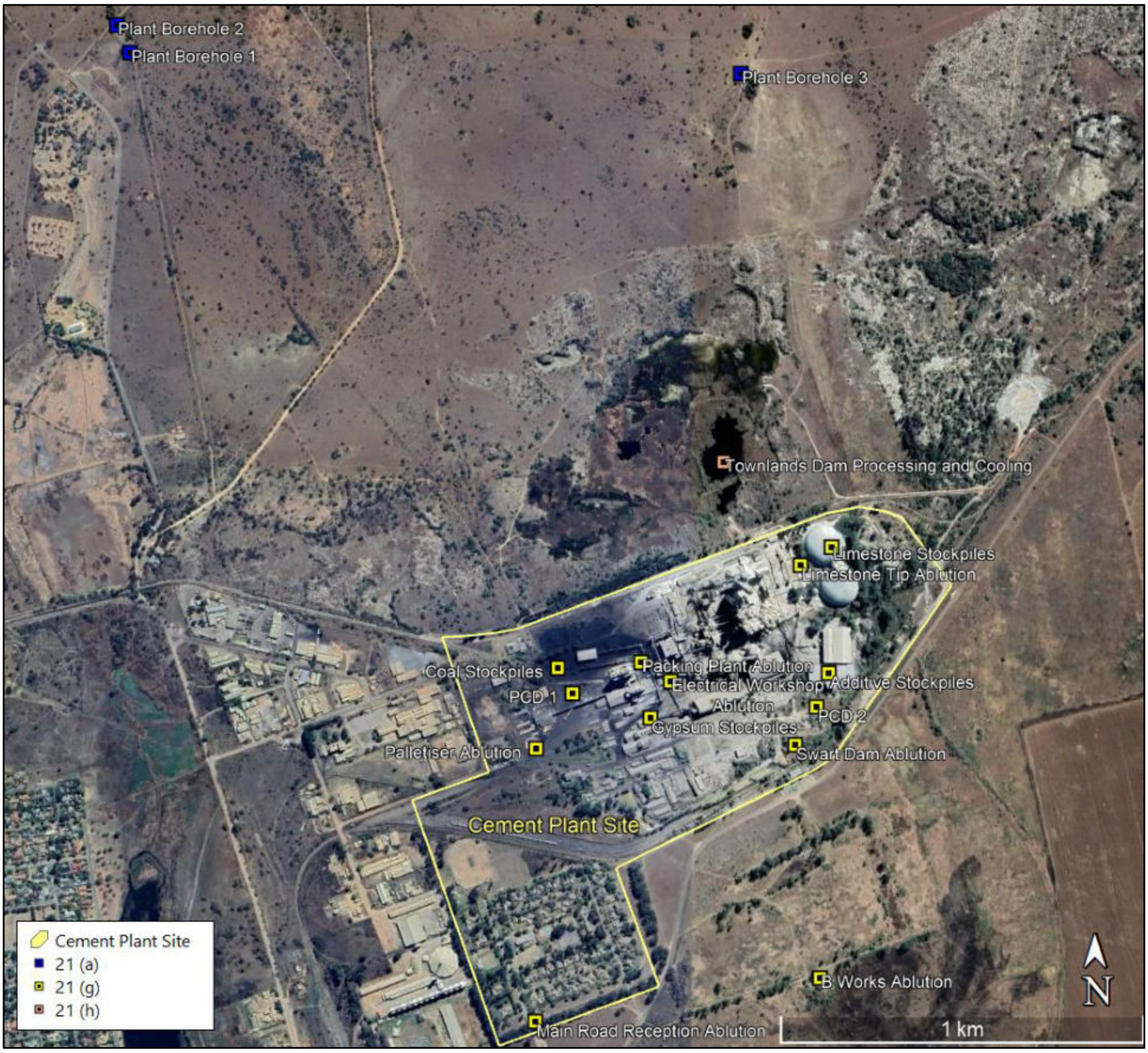


Figure 2: Site Plan showing Water Use Applications

5 BOREHOLE YIELD ASSESSMENT

5.1 Test Methodology

The water use application boreholes were designated LBH1, LBH2 and LBH3 as per previous records. A summary of the field observed borehole information is presented in Table 2.

Table 2: Summary Application Borehole Information

Borehole ID	Latitude	Longitude	Borehole Depth (m)	Static Water Level (mbgl)	Equipment	Average Abstraction Rate (l/s)
LBH1	-26.118356	26.167734	27	15.94	PD Pump	0
LBH2	-26.117704	26.167383	27	16.27	PD Pump	5.88
LBH3	-26.118903	26.184492	27	19.59	PD Pump	0

The observed operations were that LBH2 was the main supply borehole for the plant, while LBH1 served as a backup supply, and LBH3 was used for community stock watering.

The yield testing of the boreholes was carried out by Ganu Group and supervised by JG Afrika (Pty) Ltd over the period 19 to 28 August 2022. The yield testing was carried out in accordance with the guidelines of the South African National Standard SANS10299-4:2003 – Part 4: Test Pumping of Water Boreholes, and the recommended guidelines for test pumping of fractured rock aquifers.

The yield testing methodology typically comprises a stepped phase followed by a constant discharge pumping phase. Due to potential supply interruptions at the Cement Plant, the general methodology had to be adapted around the operations of the site. This included the operating of adjacent boreholes during the testing process.

Testing was carried out using the existing PD pumps in the boreholes and changing the pump drive to achieve the variable rates required for the testing schedule. The capacity of the existing pumps was therefore a limitation in the testing methodology. For LBH3, the previous test results were reviewed and used to plan the schedule. It was evident that with the limited drawdown and pump capacity, step testing would not be meaningful and the constant discharge test was actioned. Constant discharge testing was scheduled for 24 hours in each borehole. Recovery was carried out for a period equivalent to pumping or at least 95% of the original static water level as per the guidelines.

5.2 Borehole LBH1

Yield testing was carried out in LBH1, with LBH2 operating continuously at 5.8 l/s for the duration of the test. The analysis is based on the inferred scenario of combined pumping of LBH1 and LBH2 and is considered conservative. The yield testing comprised a stepped discharge and recovery phase, followed by a constant discharge and recovery phase. Step test data was used to determine the 24 hour constant discharge phase rate. Step testing was carried out as follows:

Step	Duration (minutes)	Abstraction rate (l/s)	Max drawdown at end of step (m)
1	60	2.10	1.25
2	60	4.02	3.84
3	60	7.00	6.06
4	-	-	-

Recovery to 100% of the pre-test static level occurred within 40 minutes of the termination of step testing indicating no dewatering taking place. The step test data indicated a possible boundary effect on step 2, however, steps 1 and 3 did not show evidence of boundaries. It was inferred that the critical depth was therefore below the pump depth. A critical drawdown of 6.06 m was used. Constant discharge testing was then carried out at a rate of 3.04 l/s for a period of 24 hours. The test resulted in a maximum drawdown of 1.55 m or 26 % of the drawdown to the critical depth after 24 hours of pumping. The water level recovered to 100 % of the pre-test static after 20 minutes of the CD test being terminated, indicating no dewatering taking place. The yield test data and analysis is presented in Annexure B.

From the semi-log plot, the gradient doubled after 720 minutes of pumping indicating a no flow boundary. This may be attributed to the operations of LBH2. From the log-log plot, bilinear flow was achieved early in the test and the derivative indicated a possible double porosity aquifer. A transmissivity of 50 m^2/d was determined from the recovery plot. It is likely that the main fracture is deeper than the available drawdown of 6.06 m. A conservative minimum critical drawdown of 6.06 m (22.0 mbgl) was used. A summary of sustainable yield analysis using the various methods of the FC program are as follows:

LBH1						
Method	**Sustainable yield (l/s)**	**Std. Dev**	**Early T (m^2/d)**	**Late T (m^2/d)**	**S**	**AD used**
Basic FC	2.06	0.52	202	120.2	2.20E-03	6.0
Advanced FC			202	120.2	1.00E-03	6.0
FC inflection point	1.90	0.49				6.0
Cooper-Jacob	3.31	2.15		104.5	1.63E-01	6.0
FC Non-Linear	1.03	0.91	20.0		1.00E-03	6.0
Barker	5.45	3.61	K_f = 12	S_s =	1.60E-04	6.0
Average Q_sust (l/s)	**2.08**	**0.94**	b = 11.07	Fractal dimension n =	2.29	

Recommended abstraction rate (L/s)	**2.50**	for 24 hours per day
Hours per day of pumping	12	3.54 L/s for 12 hours per day
Daily volume on recommended cycle	152.76	m3/d
Persons Served (Basic Human Needs)	6111	

The maximum daily volume that can be abstracted from the borehole at 2.5 l/s for 24 hours of pumping is 216 m^3/d. The recommended daily volume on an 12 hour duty at 3.54 l/s is 153 m^3/d.

5.3 Borehole LBH2

Yield testing was carried out in LBH2, with LBH1 operating continuously for the duration of the test. The abstraction rate at LBH1 could not be determined as the flow meter was not accessible. The analysis is based on the inferred scenario of combined pumping of LBH1 and LBH2 and is considered conservative. The yield testing comprised a stepped discharge and recovery phase, followed by a constant discharge and recovery phase. Step test data was used to determine the 24 hour constant discharge phase rate. Step testing was carried out as follows:

Step	Duration (minutes)	Abstraction rate (l/s)	Max drawdown at end of step (m)
1	60	4.02	0.11
2	60	10.03	0.16
3	60	20.04	0.25
4	-	26.01 (max)	3.64

Recovery to 100% of the pre-test static level occurred within 2 minutes of the termination of step testing indicating no dewatering taking place. From the step test data, a boundary effect was evident during step 4. It was inferred that the critical depth was however below the pump depth. A critical drawdown of 7.73 m was therefore used. Constant discharge testing was then carried out at a rate of 20.2 l/s for a period of 24 hours. The test resulted in a maximum drawdown of 1.84 m or 24 % of the drawdown to the critical depth after 24 hours of pumping. The water level recovered to 100 % of the pre-test static after 2 minutes of the CD test being terminated, indicating no dewatering taking place. The yield test data and analysis is presented in Annexure B.

From the semi-log plot, a no flow boundary was evident after 150 minutes, indicating a possible shallow fracture or, as a result of the operations of LBH1. The log-log plot showed similar evidence of boundary effects at 150 minutes, but from this point, bilinear flow was achieved, and the derivative indicated a possible double porosity aquifer. A transmissivity of 160 m^2/d was determined from the recovery plot. It is likely that the main fracture is deeper than the available drawdown of 7.73 m. A conservative minimum critical drawdown of 7.73 m (24.0 mbgl) was used. A summary of sustainable yield analysis using the various methods of the FC program are as follows:

LBH2								
Method	Sustainable yield (l/s)	Std. Dev	Early T (m^2/d)		Late T (m^2/d)		S	AD used
Basic FC	14.32	3.98	645		585.0		2.20E-03	7.7
Advanced FC			645		585.0		1.00E-03	7.7
FC inflection point	13.01	3.75						7.7
Cooper-Jacob	25.64	16.59			630.1		9.75E-03	7.7
FC Non-Linear	23.23	20.49	1000.0				1.00E-01	7.7
Barker	29.54	17.02	K_f =	321		S_s =	2.00E-03	7.7
Average Q_sust (l/s)	21.06	5.96	b =	2.05	Fractal dimension n =		2.02	

Recommended abstraction rate (L/s)	21.10	for 24 hours per day
Hours per day of pumping 12	29.85 L/s for 12	hours per day
Daily volume on recommended cycle	1289.33	m3/d
Persons Served (Basic Human Needs)	51573	

The maximum daily volume that can be abstracted from the borehole at 21.1 l/s for 24 hours of pumping is 1823 m^3/d. The recommended daily volume on an 12 hour duty at 29.8 l/s is 1289 m^3/d.

5.4 Borehole LBH3

No step testing was carried out in LBH3 since the borehole response was evident from previous testing. The test commenced directly with the constant discharge phase. It was inferred that the critical depth was below the pump intake and a critical drawdown of 4.4 m was therefore used. Constant discharge testing was carried out at a rate of 20.0 l/s for a period of 24 hours. The test resulted in a maximum drawdown of 2.58 m or 59 % of the drawdown to the critical depth after 24 hours of pumping. The water level recovered to 100 % of the pre-test static after10 minutes of the CD test being terminated, indicating no dewatering taking place. The yield test data and analysis is presented in Annexure B.

From the semi-log plot, radial flow was evident after 20 minutes of pumping. No no-flow boundaries were evident from the semi-log or log-log plots. The derivative and second derivative indicated a possible double porosity aquifer and radial flow for most of the test. A transmissivity of 316 m^2/d was determined from the recovery plot. It is likely that the main fracture is deeper than the available drawdown of 4.41 m. A conservative minimum critical drawdown of 4.41 m (24.0 mbgl) was used. A summary of sustainable yield analysis using the various methods of the FC program are as follows:

LBH3								
Method	Sustainable yield (l/s)	Std. Dev	Early T (m^2/d)		Late T (m^2/d)		S	AD used
Basic FC	17.90	5.98	5270		1054.1		2.20E-03	4.4
Advanced FC			5270		1054.1		1.00E-03	4.4
FC inflection point	18.24	1.14						4.4
Cooper-Jacob	17.09	11.06			9936.0		1.36E-79	4.4
FC Non-Linear								4.4
Barker	21.33	8.48	K_f =	251		S_s =	2.00E-07	4.4
Average Q_sust (l/s)	17.74	0.59	b =	0.22	Fractal dimension n =		2.37	

Recommended abstraction rate (L/s)	17.10	for 24 hours per day
Hours per day of pumping 12	24.19 L/s for 12	hours per day
Daily volume on recommended cycle	1044.90	m3/d
Persons Served (Basic Human Needs)	41796	

The maximum daily volume that can be abstracted from the borehole at 17.1 l/s for 24 hours of pumping is 1478 m^3/d. The recommended daily volume on a 12 hour duty at 24.19 l/s is 1045 m^3/d.

5.5 Water Quality

Groundwater samples were collected from the boreholes for chemical analysis by JG Afrika (Pty) Ltd during the site assessment. The borehole samples were collected on 27 August 2022 and submitted to Talbot Laboratory for analysis of selected determinants of the Domestic Consumption SANS241 (2015) raw water suite. The results of analysis are summarized in Table 3, and the laboratory certificate of analysis is presented in Annexure C. The results of analysis were compared to screening guidelines to assess the potability and suitability for use. The SANS241 (2015) Drinking Water Standards were used for comparative purposes. The screening guideline values are included in the summary of results table. The results of analysis indicate that total coliforms exceeded the operational screening limits in LBH3, and heterotrophic plate counts exceeded the operational screening limits in LBH1 and LBH3. These results may be indicative of sample holding times and/or the increased activity in the boreholes associated with the yield testing. Shock treatment with a once off chlorine dose is recommended and future monitoring according to the groundwater monitoring plan will determine if these counts are persistent.

Table 3: Summary Results of Water Quality Analysis by Talbot Laboratory

Sample Position		LBH1	LBH2	LBH3	SANS 241 : 2015 Drinking Water		
Sample Date		28-Aug-22	28-Aug-22	28-Aug-22			
Sampled by		MN	MN	MN			
Sample Method		submersible	submersible	submersible	Upper Limits		
Laboratory Certificate Number		023361/22	023362/22	023363/22			
Laboratory Sample Reference					Acute health	Aesthetic	Operational
Determinand	Unit	LICH 0111	LICH 0112	LICH 0113	Chronic health		
Micro biological determinands							
E. coli or faecal coliforms	Count per 100 mL	<1	<1	<1	Not detected		
Total coliforms	Count per 100 mL	<1	<1	613			≤ 10
Heterotrophic plate count	Count per mL	>1000	109	>1000			1 000
Physical and aesthetic determinands							
Colour	mg/L Pt-Co	<10	<10	<10		15	
Conductivity at 25 °C	mS/m	69.8	65.2	72.4		170	
Total dissolved solids	mg/L	360	390	468		1200	
Turbidity	NTU	0.45	0.11	0.8		5	1
pH at 25 C	pH units	7.3	7.1	7.1			5 to 9.7
Chemical determinands — macro-determinands							
Nitrate as N	mg/L	4.14	4.1	4.62	11		
Nitrite as N	mg/L	<0.05	<0.05	<0.05	0.9		
Combined nitrate-nitrite	-	0.43	0.43	0.48	1		
Sulphate as SO_4^{2-}	mg/L	33.6	33.6	36.9	500	250	
Fluoride as F^-	mg/L	0.12	0.12	0.12	1.5		
Ammonia as N	mg/L	<1.5	<1.5	<1.5		1.5	
Chloride as Cl^-	mg/L	7.75	7.91	8.28		300	
Sodium as Na	mg/L	5.1	4.9	5.2		200	
Zinc as Zn	mg/L	0.0053	0.0023	0.0134		5	
Chemical determinands — micro-determinands							
Aluminium as Al	µg/L	<1	2.4	18.9	300		
Antimony as Sb	µg/L	<1	<1	<1	20		
Arsenic as As	µg/L	<1	<1	<1	10		
Barium as Ba	µg/L	7.4	7.3	11.1	700		
Boron as B	µg/L	24	33	31	2400		
Cadmium as Cd	µg/L	<1	<1	<1	3		
Total chromium as Cr	µg/L	9.7	15.6	13.8	50		
Copper as Cu	µg/L	3.6	2.4	<1	2000		
Cyanide (recoverable) as CN^-	µg/L	<20	<20	<20	200		
Iron as Fe	µg/L	<1	<1	11.6	2000	300	
Lead as Pb	µg/L	<1	<1	<1	10		
Manganese as Mn	µg/L	<1	<1	2.9	400	100	
Mercury as Hg	µg/L	<10	<10	<10	6		
Nickel as Ni	µg/L	<1	<1	1	70		
Selenium as Se	µg/L	<1	<1	<1	40		
Uranium as U	µg/L	<1	<1	<1	30		
Chemical determinands —							
Total organic carbon as C	mg/L	3	4.8	0.82	10		
Phenols	µg/L	2	<2	7		10	

5.6 Borehole Management Plan

Based on analysis of the yield test data and water quality, a summary of the borehole management plan is presented in Table 4.

Table 4: Borehole Management Plan

Borehole ID	LBH1	LBH2	LBH3
Water Quality	SANS241 operational limits have been exceeded	All within SANS241 limits	SANS241 operational limits have been exceeded
Compounds of Concern	Heterotrophic plate count	none	Total coliforms Heterotrophic plate count
Risk	operational	none	operational
Treatment / Action	Once of shock treatment, biannual monitoring	Biannual monitoring	Once of shock treatment, biannual monitoring
Sustainable Yield (l/s)	2.5	21.1	17.1
Recommended Duty	12	12	12
Abstraction Rate for Duty Period (8 hrs)	3.54	29.85	24.19
Volume on Specified Duty (m^3/d)	152.76	1289.33	1044.90
Critical Drawdown (mbgl)	22	24	24
Anticipated Maximum Head (m)	46	47	43
Recommended Pump Installation Depth (mbgl)	22	24	24

The water use application abstraction rates should be selected on the sustainable yield values on a 24 hour duty to accommodate the maximum sustainable yield of the borehole. This equates to approximately 78840, 665395 and 539105 m^3/a for LBH1, LBH2 and LBH3 respectively. The cumulative annual volume is 1283340 m^3/a.

6 HYDROCENSUS

6.1 Introduction

A hydrocensus was required to determine existing groundwater use in the project area and to establish possible impacts on existing resources from the Cement Plant site activities. The hydrocensus further served to collect current water levels from known resources for the development of the groundwater model.

6.2 National Groundwater Archive (NGA)

The National Groundwater Archive (NGA) of the Department of Water and Sanitation was interrogated to establish the existence of any groundwater resources and groundwater use in proximity to the site. The NGA reported 108 (No.) resources within 5 km of the site. The NGA database of resource information is presented in Annexure D. The locations of resources as presented in the DWS database are shown in Figure 3. A summary of the information presented in the NGA for the listed resources is presented Table 5.

Table 5: Summary NGA Resource Information

Field Description	No of Resources.	Field Description	No of Resources.
Purpose		Status	
Production	9	Unknown	18
Exploration	1	Not Selected	78
Exploration / Production	0	Inaccessible	-
Not Specified	78	Abandoned	4
Equipment		Destroyed	4
Positive Displacement Pump	2	Monitoring	4
Submersible	1	Standby	2
Not Specified	105	Obstructed	-
Yield			
0	58		
>0	26		
Not Specified	21		
Statistical Information (Only Specified Boreholes)	**Minimum**	**Maximum**	**Average**
Water Level	0.3	55	12.97
Yield	0.01	12	1.38
Depth	8	222	47.07
Strike Depth	30.48	57.91	43.49

Key	IDENTIFIER	Key	IDENTIFIER
1	1137	55	2626AA00277
2	20-00076	56	2626AA00278
3	20-00077	57	2626AA00279
4	20-00078	58	2626AA00280
5	20-00079	59	2626AA00281
6	20-00080	60	2626AA00282
7	20-00081	61	2626AA00283
8	20-00082	62	2626AA00284
9	20-00083	63	2626AA00285
10	20-00091	64	2626AA00286
11	20-00093	65	2626AA00287
12	20-00098	66	2626AA00288
13	20-00106	67	2626AA00328
14	20-00107	68	2626AA00329
15	20-00108	69	2626AA00335
16	2624DC00042	70	2626AA00336
17	2626AA00008	71	2626AA00354
18	2626AA00009	72	2626AA00355
19	2626AA00011	73	2626AA00356
20	2626AA00016	74	2626AA00405
21	2626AA00017	75	2626AA00406
22	2626AA00018	76	2626AA00407
23	2626AA00019	77	2626AA00408
24	2626AA00214	78	2626AA00435
25	2626AA00217	79	2626AA00436
26	2626AA00218	80	2626AA00437
27	2626AA00219	81	2626AA00438
28	2626AA00223	82	2626AA00439
29	2626AA00229	83	2626AA00440
30	2626AA00230	84	2626AA00441
31	2626AA00233	85	2626AA00442
32	2626AA00234	86	2626AA00443
33	2626AA00235	87	2626AA00444
34	2626AA00236	88	2626AA00445
35	2626AA00238	89	2626AA00446
36	2626AA00239	90	2626AA00447
37	2626AA00259	91	2626AA00448
38	2626AA00260	92	2626AA00449
39	2626AA00261	93	2626AA00450
40	2626AA00262	94	2626AA00451
41	2626AA00263	95	2626AA00452
42	2626AA00264	96	2626AA00453
43	2626AA00265	97	2626AA00454
44	2626AA00266	98	2626AA00455
45	2626AA00267	99	2626AA00456
46	2626AA00268	100	2626AA00457
47	2626AA00269	101	2626AA00458
48	2626AA00270	102	2626AA00459
49	2626AA00271	103	2626AA00464
50	2626AA00272	104	2626AA00472
51	2626AA00273	105	2626AA00473
52	2626AA00274	106	2626AD00015
53	2626AA00275	107	31385
54	2626AA00276	108	35030

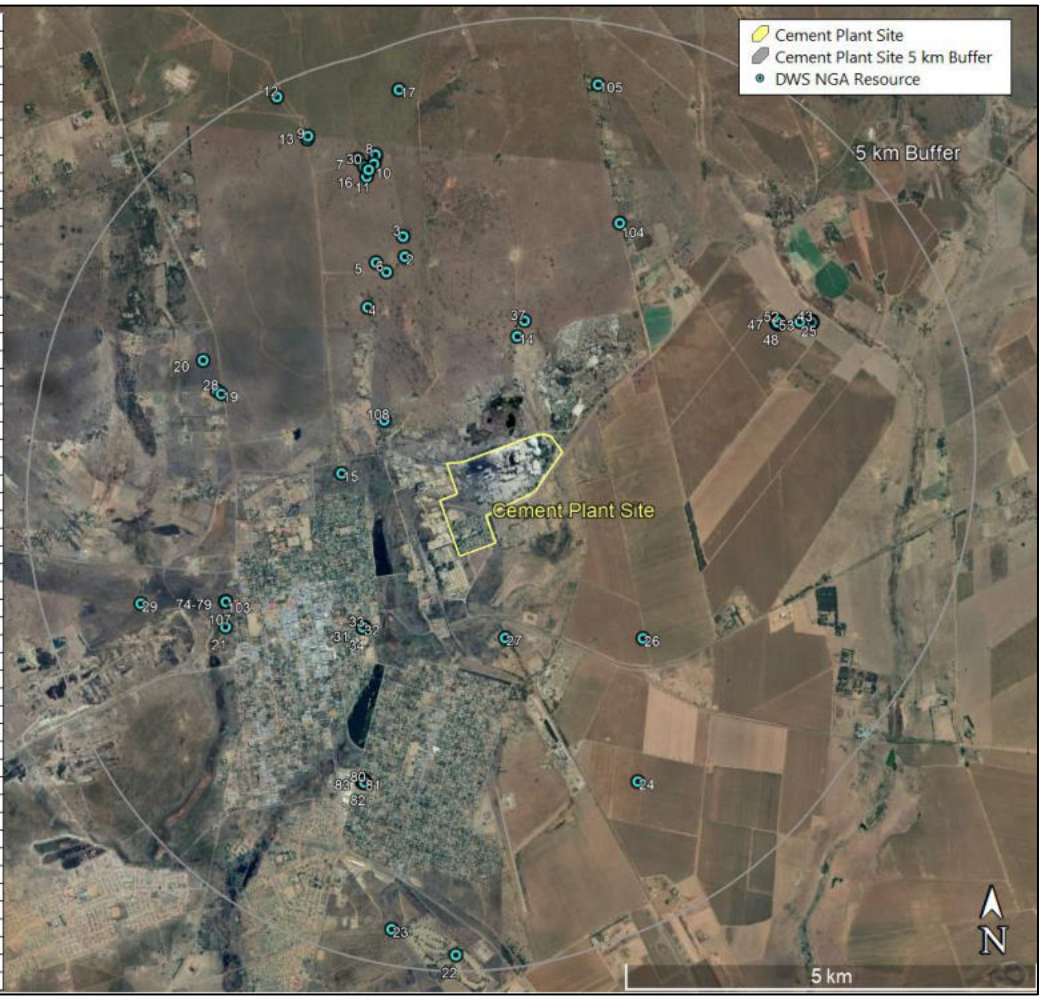


Figure 3: Locations of Resources as Presented in the NGA

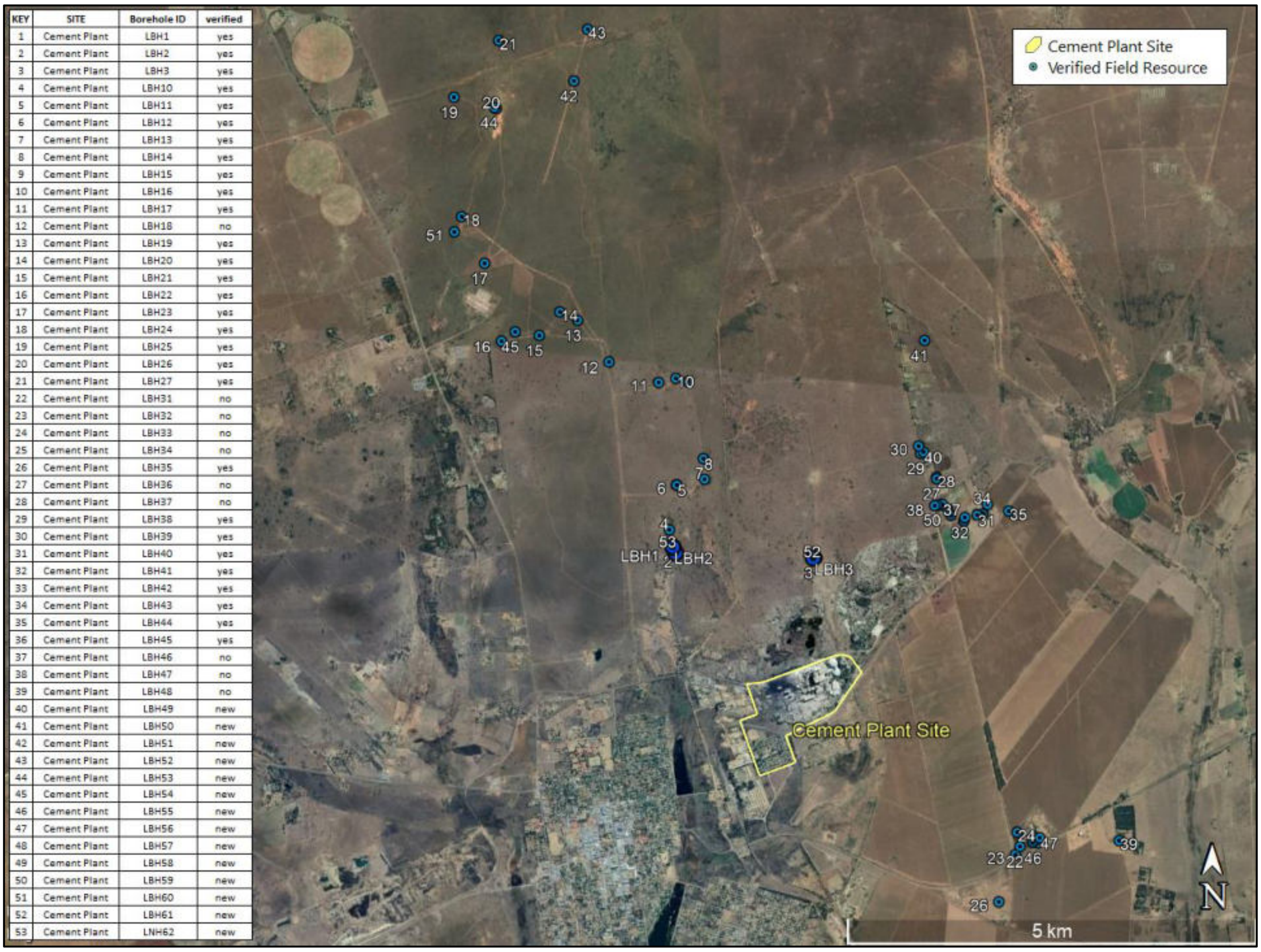
6.3 Field Verification

A field verification hydrocensus survey was carried out using the hydrocensus information collected during previous studies[1]. The survey was augmented with additional resources and current field information. A total of 53 (No.) resources were identified during the previous and current survey. A summary of the resource information is presented in Table 6 and the approximate distribution of the boreholes is presented in Figure 4. The hydrocensus resource photos are presented in Annexure D. A total of 39 (No.) water supply boreholes, and 14 (No.) unused boreholes were identified..

[1] Report reference GW-16-09-CV414B of Tucana Solutions, titled "Lafarge Lichtenburg Cement Plant and Tswana Quarry – Geohydrological Report", version 1.4, dated February 2017

Table 6: Summary Hydrocensus Borehole Information

KEY	SITE	Borehole ID	verified	Latitude	Longitude	Elevation (mamsl)	Water level (mbgl) July 22	Water level (mbgl) Feb 17	Borehole depth (m)	Pump depth (m)	Pump rate (l/s)	Pumping duration (hr/d)	Pump type	Water use	Owner	Telephone number
1	Cement Plant	LBH1	yes	-26.11836	26.16773	1489	15.94	16	27	24	5.56	Level probes	Mono	Domestic/Industrial	Lafarge	018-6333000
2	Cement Plant	LBH2	yes	-26.11770	26.16738	1480	16.27	17	27	24	5.88	Level probes	Mono	Domestic/Industrial	Lafarge	018-6333000
3	Cement Plant	LBH3	yes	-26.11890	26.18449	1496	19.59	18.7	27	24	11.11	1hr on/3 hr rest	Mono	Domestic/Stock Watering	Lafarge	018-6333000
4	Cement Plant	LBH10	yes	-26.11587	26.16692	1499	-		60	50	~2.78	24	Sub	Municipal Supply	Ditsobotla LM	636915075
5	Cement Plant	LBH11	yes	-26.11095	26.16778	1501	19.74	19	60	50	~11.11	24	Mono	Municipal Supply	Ditsobotla LM	636915075
6	Cement Plant	LBH12	yes	-26.11095	26.16780	1499	11.12		80	60	~19.44	24	Sub	Municipal Supply	Ditsobotla LM	636915075
7	Cement Plant	LBH13	yes	-26.11033	26.17118	1498	-	28.5	60	50	~16.67	24	Sub	Municipal Supply	Ditsobotla LM	636915075
8	Cement Plant	LBH14	yes	-26.10807	26.17103	1502	-		60				Mono	Municipal Supply	Ditsobotla LM	636915075
9	Cement Plant	LBH15	yes	-26.09964	26.16916	1500	25.89		40				None	Municipal Supply	Ditsobotla LM	636915075
10	Cement Plant	LBH16	yes	-26.09930	26.16767	1496	-	30.4	60	Dry			None	Municipal Supply	Ditsobotla LM	636915075
11	Cement Plant	LBH17	yes	-26.09975	26.16559	1497	-		60		~2.78	24	Mono	Municipal Supply	Ditsobotla LM	636915075
12	Cement Plant	LBH18	no	-26.09751	26.15954	1502			60	50	~16.67	24	Sub	Municipal Supply	Ditsobotla LM	636915075
13	Cement Plant	LBH19	yes	-26.09297	26.15573	1507	-	31.7	60	Dry			None	Municipal Supply	Ditsobotla LM	636915075
14	Cement Plant	LBH20	yes	-26.09205	26.15356	1505	-		60	50	~6.94	24	Sub	Municipal Supply	Ditsobotla LM	636915075
15	Cement Plant	LBH21	yes	-26.09463	26.15106	1501	32.73	30.4	60				None	Municipal Supply	Ditsobotla LM	636915075
16	Cement Plant	LBH22	yes	-26.09526	26.14647	1497	34.97		80	60	~16.67	24	Sub	Municipal Supply	Ditsobotla LM	636915075
17	Cement Plant	LBH23	yes	-26.08675	26.14440	1506	36.52		60	36	~13.89	24	Sub	Municipal Supply	Ditsobotla LM	636915075
18	Cement Plant	LBH24	yes	-26.08166	26.14160	1503	-		60		dry		Sub	Municipal Supply	Ditsobotla LM	636915075
19	Cement Plant	LBH25	yes	-26.06860	26.14066	1504	35.71		60		~15.28	24	Sub	Municipal Supply	Ditsobotla LM	636915075
20	Cement Plant	LBH26	yes	-26.06984	26.14580	1496	29.09		60		~15.28	24	Sub	Municipal Supply	Ditsobotla LM	636915075
21	Cement Plant	LBH27	yes	-26.06239	26.14608	1511	35.3	34.5	Problem with equi		unknown			Municipal Supply	Ditsobotla LM	636915075
22	Cement Plant	LBH31	no	-26.15049	26.20969	1510							Sub	Domestic	Danie Zimmerman	
23	Cement Plant	LBH32	no	-26.15138	26.20915	1492					low		Wind	Not used	Danie Zimmerman	
24	Cement Plant	LBH33	no	-26.14891	26.20935	1492					blocked		None	Not used	Danie Zimmerman	
25	Cement Plant	LBH34	no	-26.15004	26.21124	1475					>5		Sub	Domestic	Danie Zimmerman	
26	Cement Plant	LBH35	yes	-26.15656	26.20713	1484	20.3	15			6.94		Sub	Domestic	Horatio Mathewson	842838537
27	Cement Plant	LBH36	no	-26.11023	26.19943	1499		38.6	60				None	Not used	Neels v Staden	825624785
28	Cement Plant	LBH37	no	-26.11006	26.19942	1499			85				Sub	Domestic	Neels v Staden	825624785
29	Cement Plant	LBH38	yes	-26.10747	26.19746	1506	-				low		Sub	Domestic	Antoinette Ras	814731227
30	Cement Plant	LBH39	yes	-26.10666	26.19721	1509	30.23			Dry	dry		None	Not used	Antoinette Ras	814731227
31	Cement Plant	LBH40	yes	-26.11418	26.20436	1510	21.26		32	Dry	dry		None	Not used	Johann Pistor	793281243
32	Cement Plant	LBH41	yes	-26.11447	26.20286	1501	23.11				~4.17	5	Sub	Domestic/irrigation	Johann Pistor	793281243
33	Cement Plant	LBH42	yes	-26.11405	26.20508	1501	26.73				3.61		Sub	Domestic	De beer	824007570
34	Cement Plant	LBH43	yes	-26.11303	26.20561	1503	27		36	Dry	dry		Sub	Not used	Vosser	
35	Cement Plant	LBH44	yes	-26.11375	26.20820	1503	-			Dry	dry		None	Not used	Vosser	
36	Cement Plant	LBH45	yes	-26.11489	26.20273	1502	29.05	34.5	40				None	Not used	Tony	827005154
37	Cement Plant	LBH46	no	-26.11302	26.20011	1503							Wind	Not used	Tony	827005154
38	Cement Plant	LBH47	no	-26.11318	26.19918	1500		39.2					Sub	Not used	Tony	827005154
39	Cement Plant	LBH48	no	-26.14984	26.22179	1481							Sub	Stock Watering	Hendy Manhe	763099212
40	Cement Plant	LBH49	new	-26.10731	26.19781	1507	-			Dry				Stock Watering	Antoinette Ras	814731227
41	Cement Plant	LBH50	new	-26.09511	26.19791	1509	24.47				low		Sub	Stock Watering	Johann Pistor	793281243
42	Cement Plant	LBH51	new	-26.06680	26.15523	1511	34.1						sub	Municipal Supply	Ditsobotla LM	636915075
43	Cement Plant	LBH52	new	-26.06116	26.15689	1511	24.76						Sub	Municipal Supply	Ditsobotla LM	636915075
44	Cement Plant	LBH53	new	-26.06971	26.14555	1513	-			Dry			None	Municipal Supply	Ditsobotla LM	636915075
45	Cement Plant	LBH54	new	-26.09423	26.14813	1505	33.21				low		None	Municipal Supply	Ditsobotla LM	636915075
46	Cement Plant	LBH55	new	-26.15011	26.21189	1486	24.19		80				Sub	Domestic	Mr Watson	837851073
47	Cement Plant	LBH56	new	-26.14952	26.21210	1486	60.61		120				Sub	Domestic	Mr Watson	837851073
48	Cement Plant	LBH57	new	-26.11425	26.20118	1503	36.21						Sub	Irrigation	Tony	827005154
49	Cement Plant	LBH58	new	-26.11352	26.20076	1500	-						Sub	Stock Watering	Tony	827005154
50	Cement Plant	LBH59	new	-26.11310	26.19948	1501	28.71				low		None	not used	Tony	827005154
51	Cement Plant	LBH60	new	-26.08332	26.14073	1505	35.08				not operating		Sub	Municipal Supply	Ditsobotla LM	636915075
52	Cement Plant	LBH61	new	-26.11891	26.18490	1492					blocked		none	not used	unknown	
53	Cement Plant	LNH62	new	-26.11784	26.16731	1489					blocked		none	not used	unknown	



KEY	SITE	Borehole ID	verified
1	Cement Plant	LBH1	yes
2	Cement Plant	LBH2	yes
3	Cement Plant	LBH3	yes
4	Cement Plant	LBH10	yes
5	Cement Plant	LBH11	yes
6	Cement Plant	LBH12	yes
7	Cement Plant	LBH13	yes
8	Cement Plant	LBH14	yes
9	Cement Plant	LBH15	yes
10	Cement Plant	LBH16	yes
11	Cement Plant	LBH17	yes
12	Cement Plant	LBH18	no
13	Cement Plant	LBH19	yes
14	Cement Plant	LBH20	yes
15	Cement Plant	LBH21	yes
16	Cement Plant	LBH22	yes
17	Cement Plant	LBH23	yes
18	Cement Plant	LBH24	yes
19	Cement Plant	LBH25	yes
20	Cement Plant	LBH26	yes
21	Cement Plant	LBH27	yes
22	Cement Plant	LBH31	no
23	Cement Plant	LBH32	no
24	Cement Plant	LBH33	no
25	Cement Plant	LBH34	no
26	Cement Plant	LBH35	yes
27	Cement Plant	LBH36	no
28	Cement Plant	LBH37	no
29	Cement Plant	LBH38	yes
30	Cement Plant	LBH39	yes
31	Cement Plant	LBH40	yes
32	Cement Plant	LBH41	yes
33	Cement Plant	LBH42	yes
34	Cement Plant	LBH43	yes
35	Cement Plant	LBH44	yes
36	Cement Plant	LBH45	yes
37	Cement Plant	LBH46	no
38	Cement Plant	LBH47	no
39	Cement Plant	LBH48	no
40	Cement Plant	LBH49	new
41	Cement Plant	LBH50	new
42	Cement Plant	LBH51	new
43	Cement Plant	LBH52	new
44	Cement Plant	LBH53	new
45	Cement Plant	LBH54	new
46	Cement Plant	LBH55	new
47	Cement Plant	LBH56	new
48	Cement Plant	LBH57	new
49	Cement Plant	LBH58	new
50	Cement Plant	LBH59	new
51	Cement Plant	LBH60	new
52	Cement Plant	LBH61	new
53	Cement Plant	LNH62	new

Figure 4: Field Verified Resources (After Tucana Solutions 2017)

7 NUMERICAL GROUNDWATER MODEL

7.1 Desktop Assessment

7.1.1 Study Area Selection

Since the focus of this study was to model the groundwater impacts of the Lafarge operations on the surrounding environment, it is important to delineate the study area based on physical properties that will be translated into boundary conditions for the groundwater model. When selecting the delineation criteria, the model extent must be large enough to accommodate considered receptors. The geohydrological map indicating the groundwater occurrence and the structural lineaments traversing the area were used as the main delineation criteria. The resulting model boundary is based on the quaternary catchment C31A boundary on the western side, the Harts River on the eastern and southern side, and the chert-rich dolomite in the north, and is presented in Figure 5.

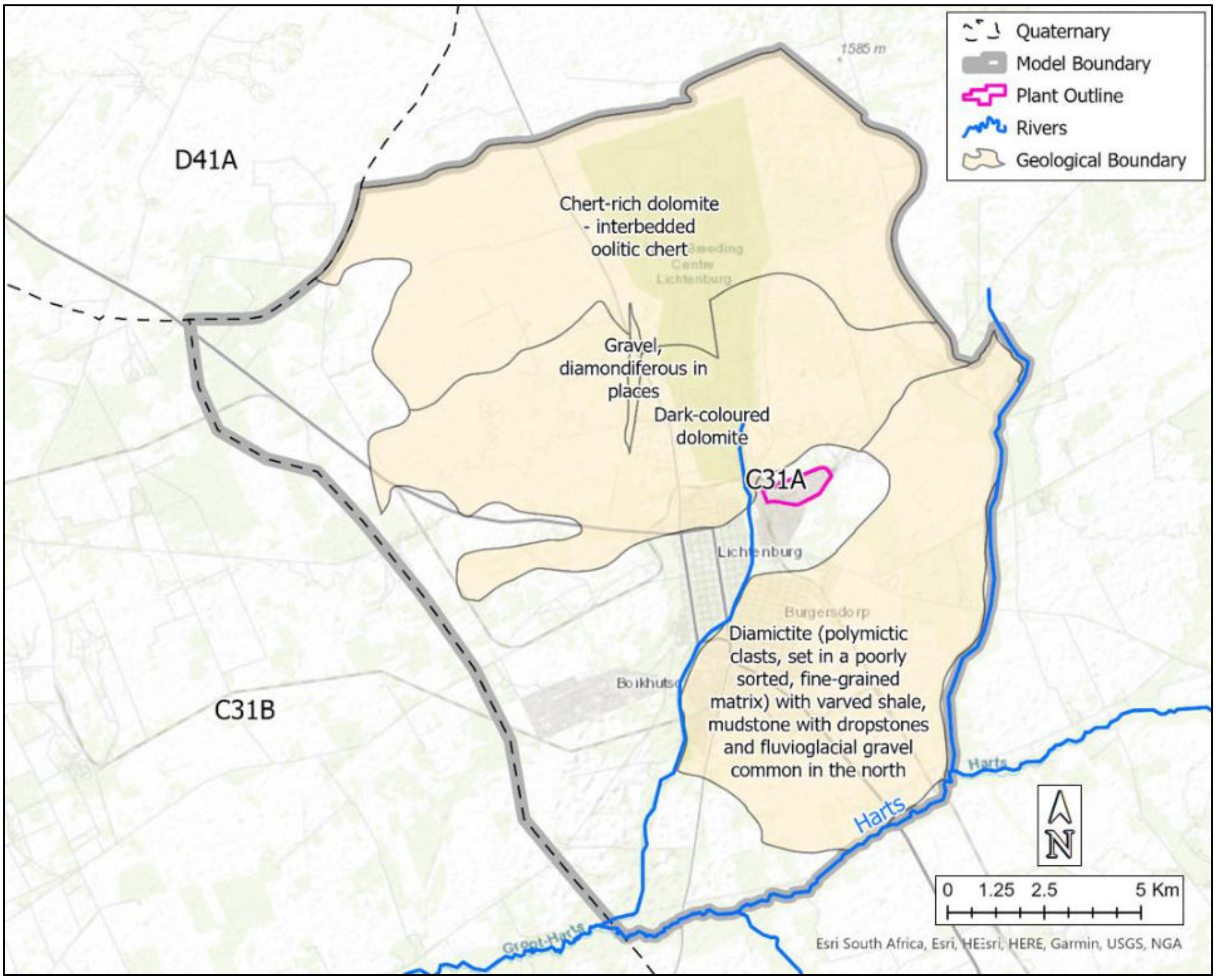


Figure 5: Cement Plant Boundary of the Numerical Model Extent

7.1.2 Topography and Drainage

The study area has a relatively flat topography which ranges from 1428 mamsl to 1520 mamsl over a distance of 23 km. The study area boundary intersects quaternary catchment C31A which also forms the western boundary of the model. A summary of the hydrological parameters for the quaternary catchment are presented in Table 7.

Table 7: Summary of Quaternary Catchment Hydrological Parameters

Quaternary Name	Area (km^2)	MAP (mm/a)	MAE (mm/a)	MAR (mm/a)	Baseflow (mm/a)	No Flow (%)
C31A	1402	577	1860	10.7	0	38

The topography and drainage of the model area is presented in Figure 6.

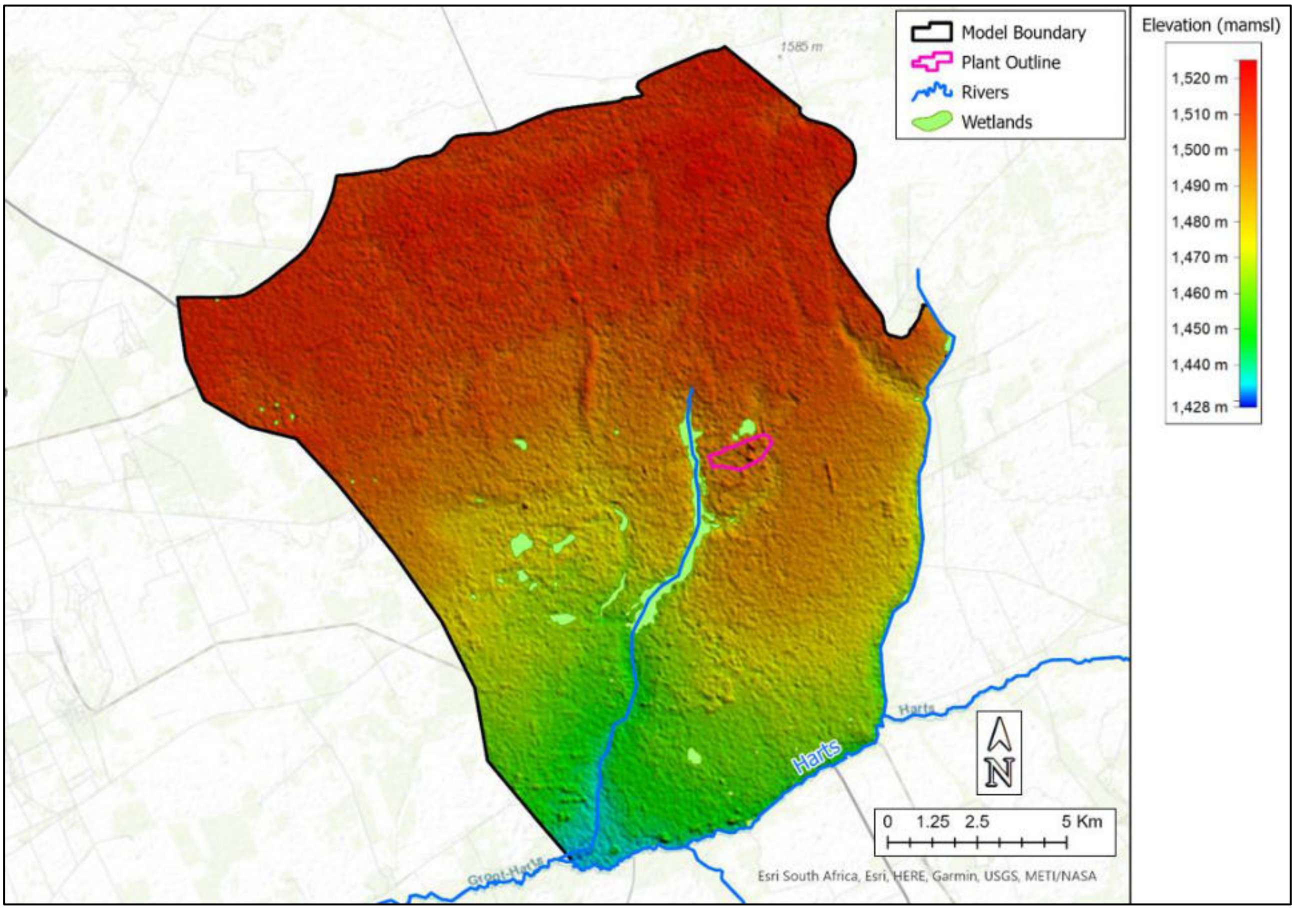


Figure 6: Topography and Drainage of the Model Extent

7.1.3 Regional Geology

The regional geology of the Lichtenburg area comprises quaternary and tertiary aged sands and rock which are underlain by Karoo Sequence Dwyka Formation, which in turn is underlain by Monte Christo, Oaktree and Black Reef Formations of the Transvaal Sequence, and finally by the Ritgat, Klipriviers and Alberton Formations of the Ventersdorp Supergroup. The various rock lithologies of geology in the project area are summarised in Table 8. The regional geology is presented in Figure 7.

Table 8: Geological Lithologies

Age	Supergroup / Sequence	Group / Subgroup	Formation	Lithology	Symbol
Quaternary				soil cover, quaternary sands	Qs
Tertiary				calcrete	T-Qc
Carboniferous	Karoo Sequence		Dwyka	tillite	C-Pd
Vaalian	Transvaal Sequence	Chuniespoort	Monte Christo	chert rich dolomite	Vmm
			Oaktree	dark chert poor dolomite	Vo
			Black Reef	quartzite, conglomerate, shale	Vbr
	Ventersdorp Supergroup	Platberg	Rietgat	breccia, conglomerate; greywacke, shale, limestone, tuff	R-Vk
Randian		Klipriviersberg		basaltic lava, agglomerate	Rk
			Alberton	Feldspar porphyry	Ra

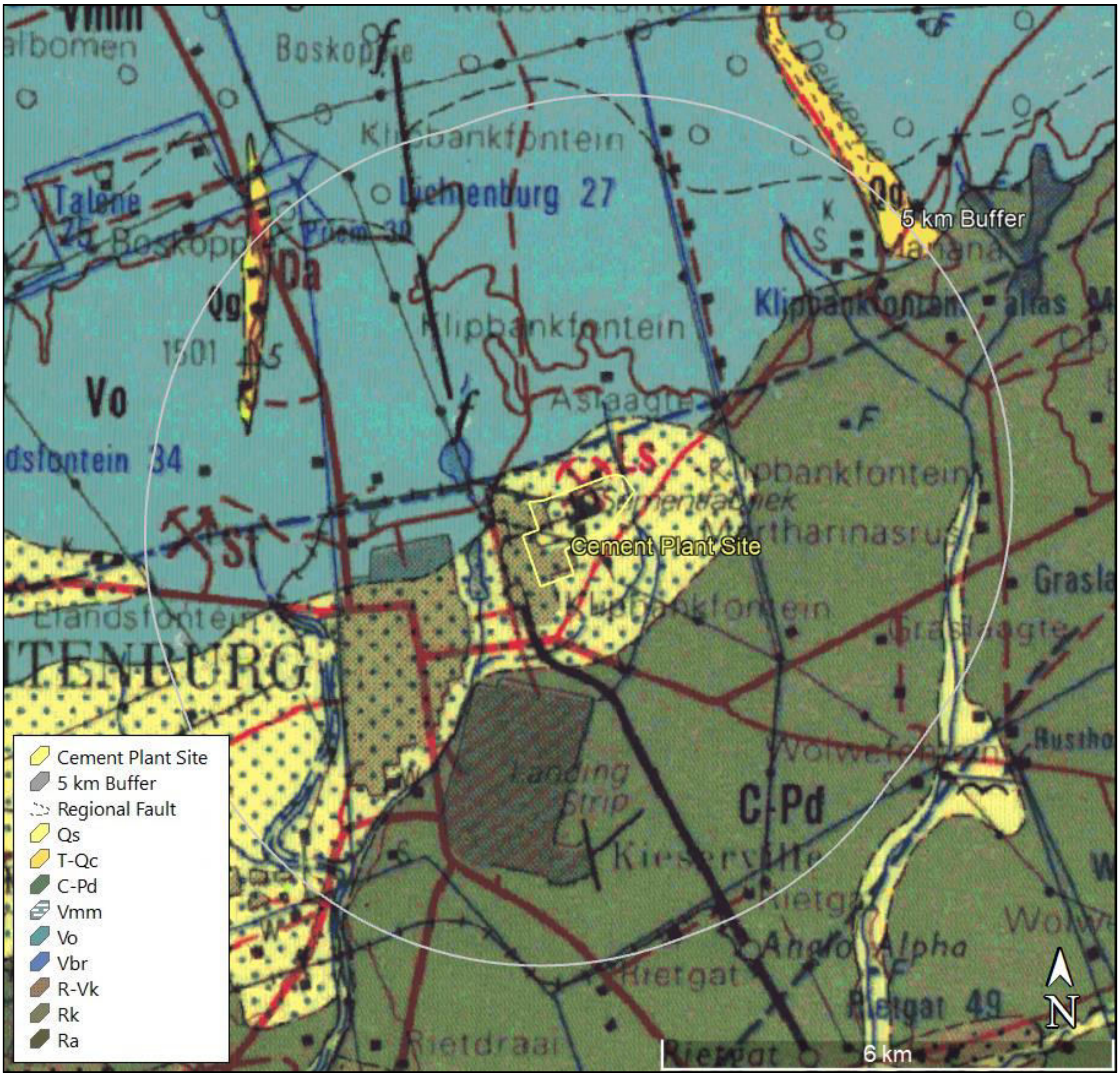


Figure 7: Regional Geology and Structures

7.1.4 Regional Structures

Dykes

The dolomite formations are subdivided by diabase dykes trending WSW to ENE and N to S which result in compartmentalisation in the dolomites.

Quartz Veins

Quartz veins trending NNE to SSW are evident with the disappearance of veins to the south.

Fractures

Major dyke and quartz veining correlates closely with joint directions within the Malmani Subgroup and present regional stress fields within the area. Regional faults are evident trending WSW to ENE. One regional fault is located within 500 m of the northern side of the site.

7.1.5 Site Geology and Structures

The regional geology is of a karst nature and the specific surface deposits and structures traversing the area in a west to east direction are presented in Figure 8. Selected borehole logs indicate the presence of karst or dolomites underlying the area. The borehole logs are presented in Annexure E.

Boreholes presented in the DWS NGA database containing dolomite were used to delineate the top of the dolomite layer. The resulting contour of the top of the dolomites in the project area is presented in Figure 9.

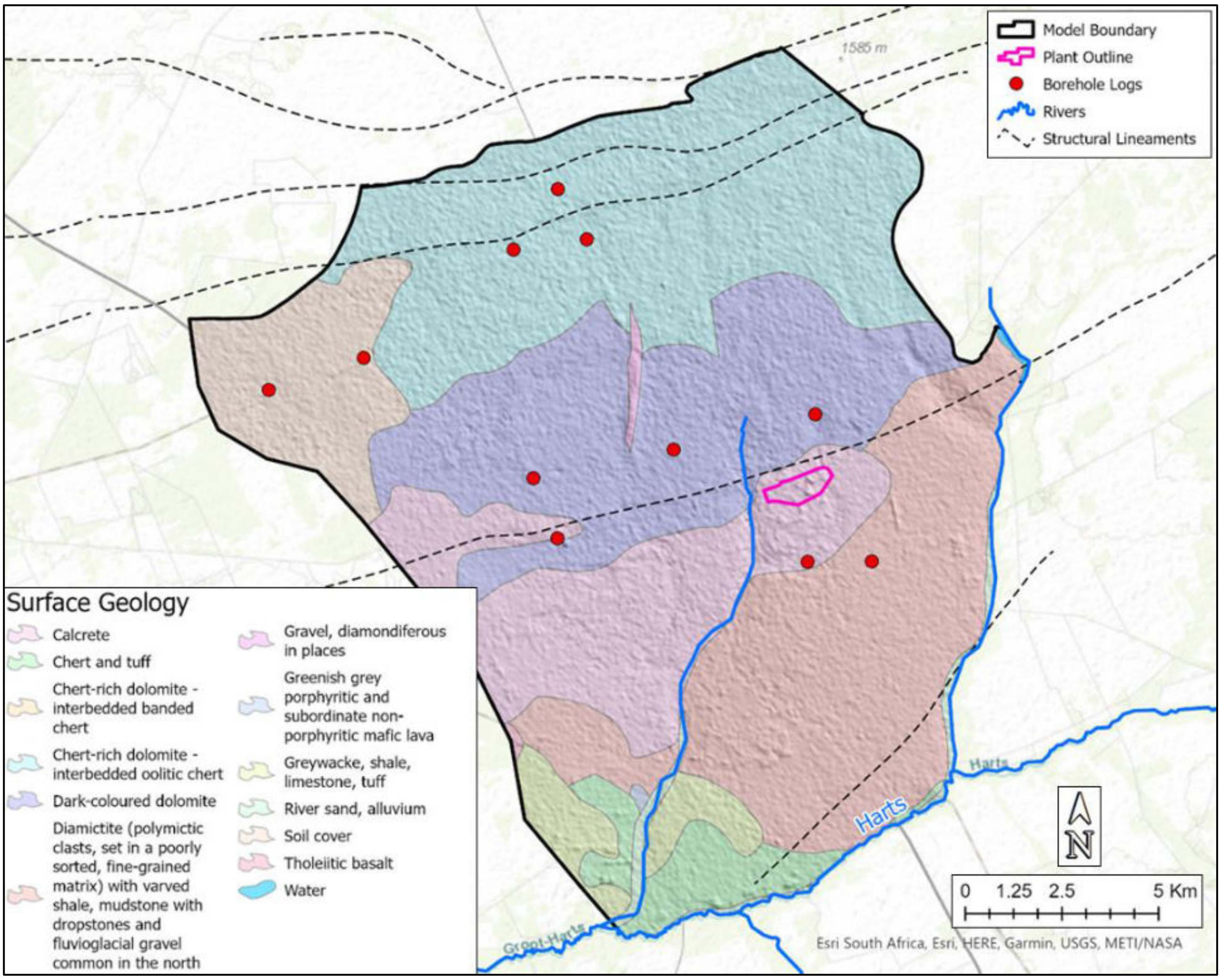


Figure 8: Surface Geology and Structures in the Model Extent

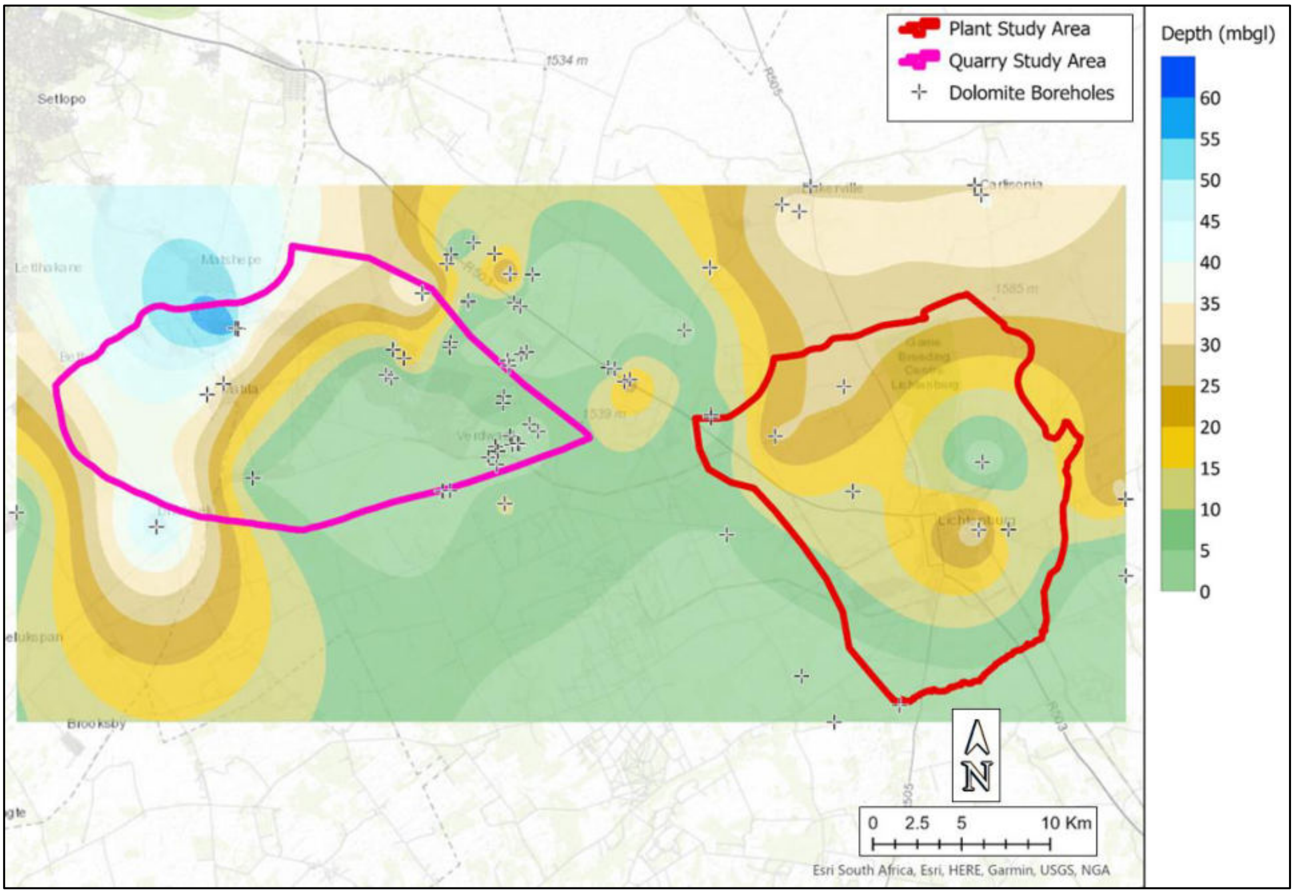


Figure 9: Interpolated Top of Dolomite Layer

7.1.6 Regional Magnetic Mapping

The regional magnetic mapping with a contour interval of 100 nT is presented in Figure 10. The mapping indicates that magnetic flux for the site has a range of 31450 nT to 32400 nT. Notable magnetic anomalies are evident within proximity of the project footprint and confirm the presence of the structural lineaments, in particular the WSW to ENE trending structural feature north of the plant site.

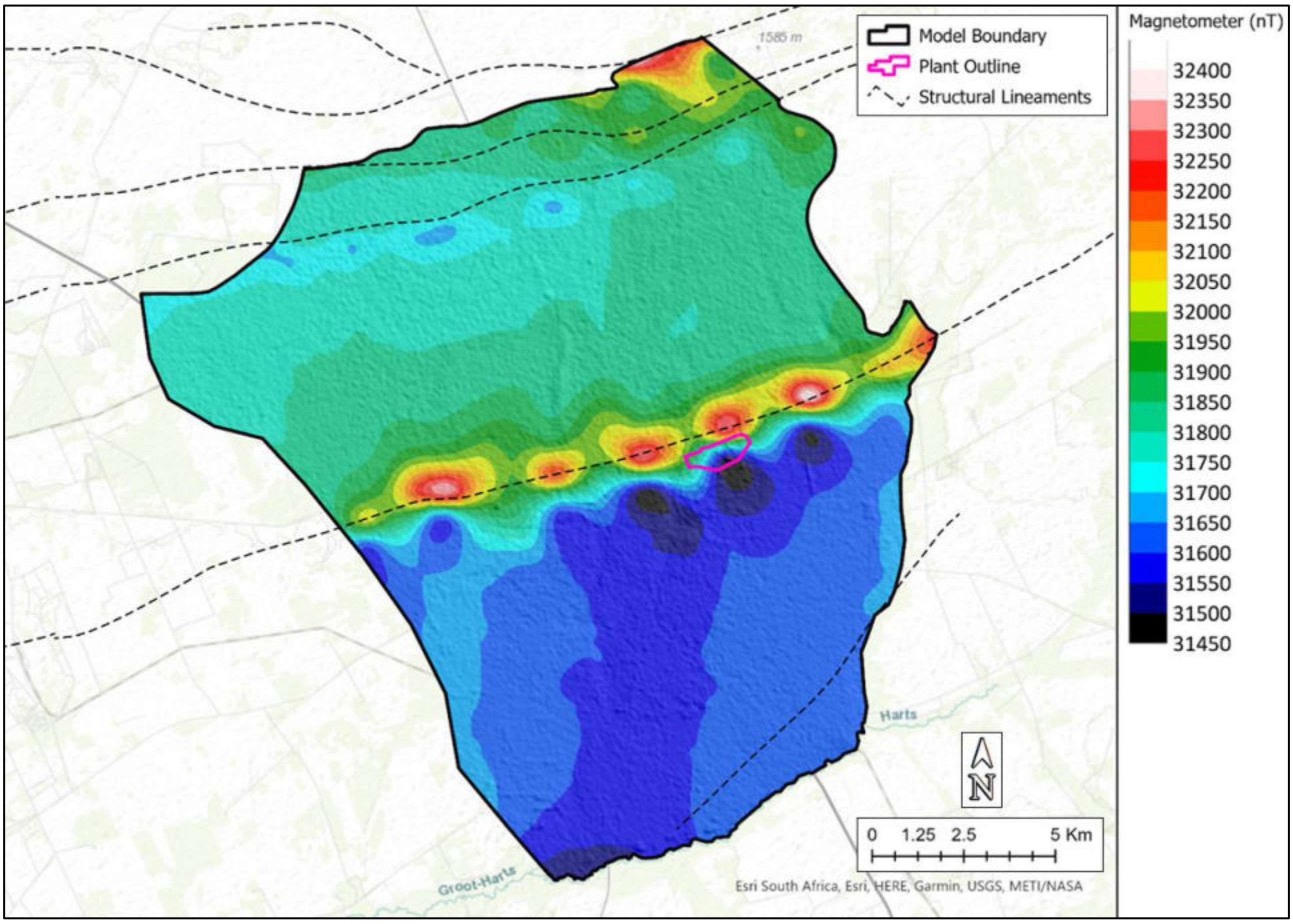


Figure 10: Regional Magnetic Mapping

7.1.7 Regional Geohydrology

The regional geohydrology of the project area can be broadly described as predominantly carbonate rocks comprising dolomite. The principal groundwater occurrence is from a karst aquifer type with median borehole yields in the range 0.5 to 2.0 l/s. Further north, the median yields are > 5.0 l/s

The project area comprises four aquifer class units. The cement plant site and adjacent southern, western and eastern areas are characterised in terms of the South African Aquifer Classification System as *Minor*, while 1 km to the north of the cement plant site, it is characterised as *Major*. The regional geohydrology of the project area is presented in Figure 11.

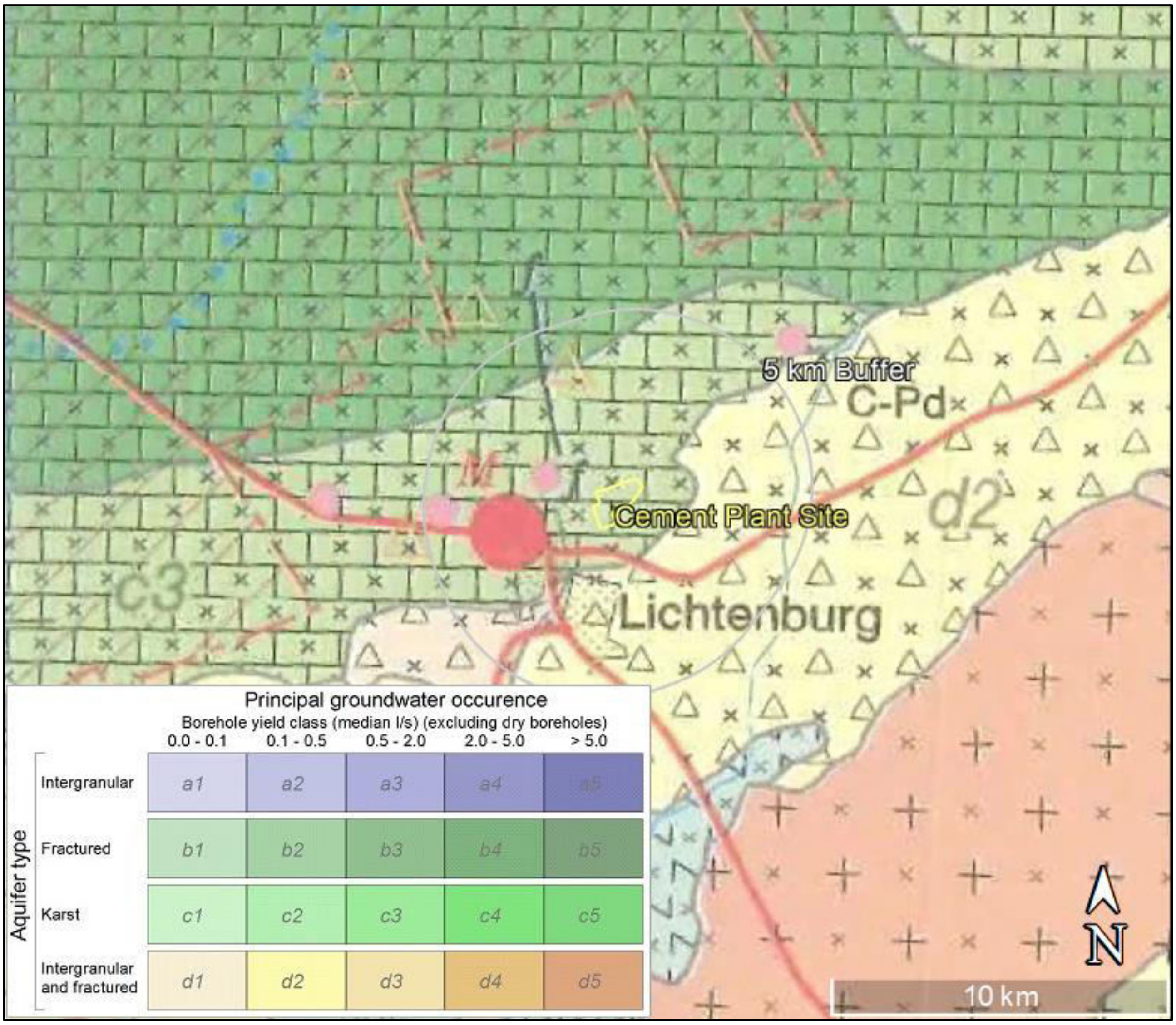


Figure 11: Regional Geohydrology

Groundwater Occurrence

Structurally controlled preferential solution of the dolomitic rock has occurred adjacent to dykes and within some linear depressions, This has developed a highly transmissive formation with strong borehole yields. Yields from dolomitic rock and brecciated chert zones can exceed 70 l/s, with average yields being approximately 20 l/s. Most boreholes penetrating the dolomite are generally shallow (less than 50 m) and the major water strikes are at depths of between 20 – 35 m. Boreholes drilled into the lower part of the dolomite formation at lower elevations generally have poor yields, irrespective of depths drilled. Yields of 1.0 l/s are then considered to be good. Boreholes within the lavas are generally low yielding, and dykes can also provide reasonable groundwater targets.

Aquifer Classification

It is inferred that one underlying aquifer is present beneath the site, but shallow or perched aquifers may also exist in the study area within the tertiary or recent deposits. The Parsons aquifer classification scheme allows the grouping of aquifer areas into types according to their associated supply potential, water quality and local importance as a resource. The revised South African aquifer classification system is presented in Table 9.

Table 9: Aquifer Classification Scheme

Aquifer System	Defined by Parsons (1995)	Defined by DWAF Min Requirements (1998)
Sole Source Aquifer	An aquifer which is used to supply 50 % or more of domestic water for a given area, and for which there are no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.	An aquifer, which is used to supply 50% or more of urban domestic water for a given area for which there are no reasonably available alternative sources should this aquifer be impacted upon or depleted.
Major Aquifer	High permeable formations usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (<150 mS/m).	High yielding aquifer (5-20 L/s) of acceptable water quality.
Minor Aquifer	These can be fractured or potentially fractured rocks, which do not have a high primary permeability or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying baseflow for rivers.	Moderately yielding aquifer (1-5 L/s) of acceptable quality or high yielding aquifer (5-20 L/s) of poor quality water.
Non-Aquifer	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and need to be considered when assessing the risk associated with persistent pollutants.	Insignificantly yielding aquifer (< 1 L/s) of good quality water or moderately yielding aquifer (1-5 L/s) of poor quality or aquifer which will never be utilised for water supply and which will not contaminate other aquifers.
Special Aquifer	An aquifer designated as such by the Minister of Water Affairs, after due process.	An aquifer designated as such by the Minister of Water Affairs, after due process.

Aquifer Vulnerability

Aquifer vulnerability can be classified according to the DRASTIC method. The DRASTIC aquifer vulnerability method makes use of seven (7) factors to calculate the vulnerability index value (Aller et al. 1987):

- Depth to groundwater (D) – determines the maximum distance contaminants travel before reaching the aquifer
- Net recharge (R) – the amount of water that is able to travel from ground surface to the water table
- Aquifer (A) – the composition of the aquifer material
- Soil media (S) – the uppermost portion of the unsaturated zone
- Topography (T) – the slope of the ground surface
- Impact of vadose zone (I) – the type of material present between the bottom of the soil zone and water table
- Hydraulic conductivity of the aquifer (C) – indicates the aquifer's ability to allow for the flow of water to occur.

This vulnerability index is used to determine the aquifer's vulnerability to pollution and the index ranges from 1 to 200, where 200 represents the theoretical maximum aquifer vulnerability. The DRASTIC index ranges between 65 and 160 over the study area, and is between 110 and 140 in the immediate vicinity of the plant site as shown in Figure 12.

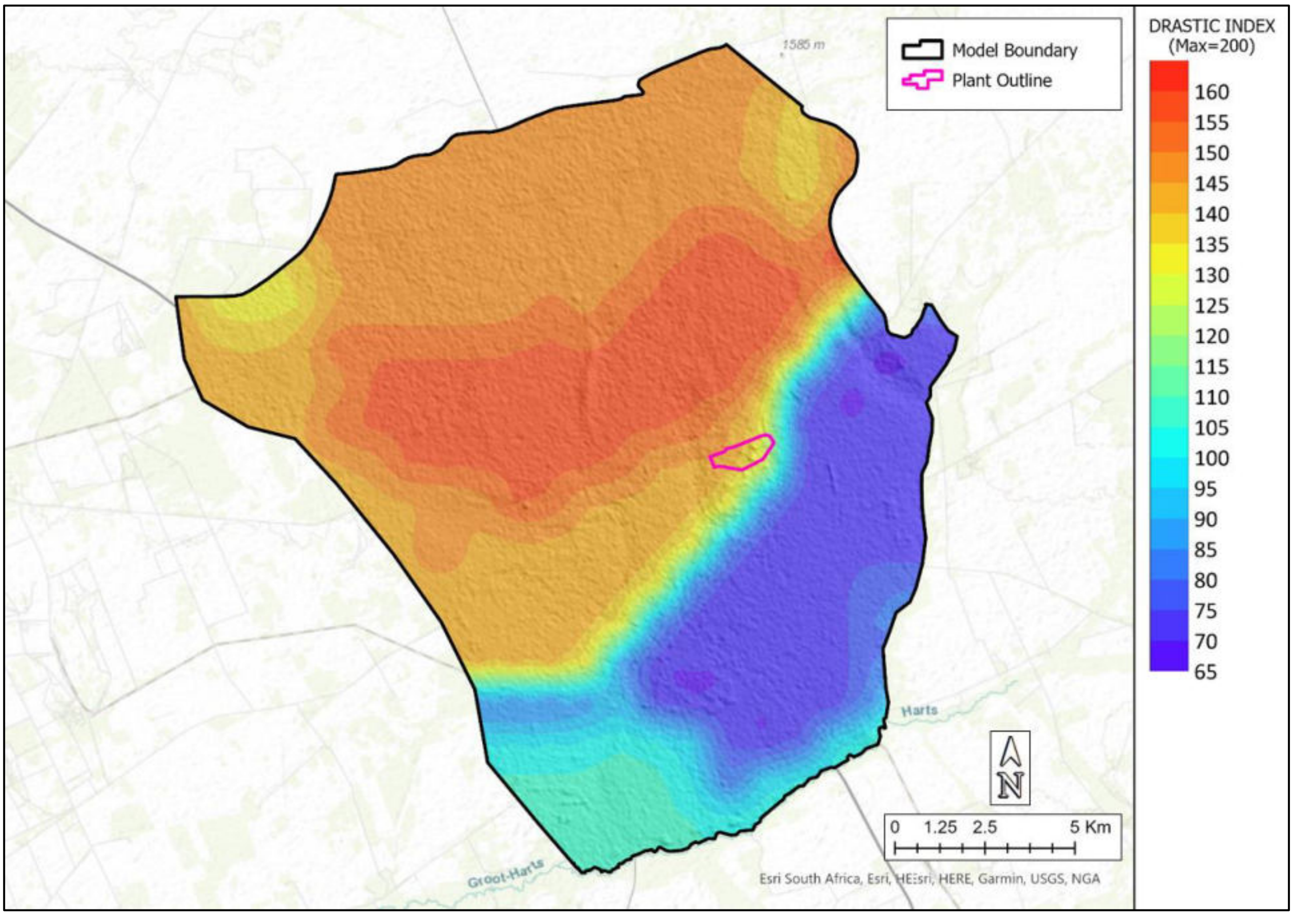


Figure 12: Aquifer Vulnerability Map of the Study Area

When considering the first variable (aquifer system) as a *Minor* aquifer and the second variable (vulnerability) as *Medium to High*, the underlying aquifer requires a medium level of protection. For *Major* aquifer areas located north of the plant site, the underlying aquifer requires a high level of protection.

TABLE A and B: Ratings for the Groundwater Quality Management classification system.			
AQUIFER SYSTEM MANAGEMENT CLASSIFICATION		SECOND VARIABLE CLASSIFICATION AQUIFER VULNERABILITY CLASSIFICATION	
Class	Points	Class	Points
Sole Source Aquifer System	6	High	3
Major Aquifer System	4	Medium	2
Minor Aquifer System	2	Low	1
Non-aquifer System	0		
Special Aquifer System	0 -6		

TABLE C: Appropriate level of groundwater protection required, based on the Groundwater Quality Management classification	
GQM INDEX	LEVEL OF PROTECTION
< 1	Limited protection
01-03	Low level protection
03-06	Medium level protection
06-10	High level protection
> 10	Strictly non-degradation

Variable 1	Variable 2
Aquifer System	Second Variable Description
Minor Aquifer System	Vulnerability Medium High
2	2.5
GQM Index	Level of Protection
5.0	Medium level protection

7.1.8 Rainfall and Recharge

A summary of the quaternary rainfall and recharge figures are presented in Table 10 and Figure 13. The GRAII data set results in an average recharge of 4% of MAP and the Vegter estimate translate to a recharge of 8.5% of MAP.

Table 10: Summary of Quaternary Rainfall and Recharge

Quaternary Name	MAP (mm/a)	Recharge (GRAII) (mm/a)	Recharge (Vegter) (mm/a)
C31A	577	24.91	45

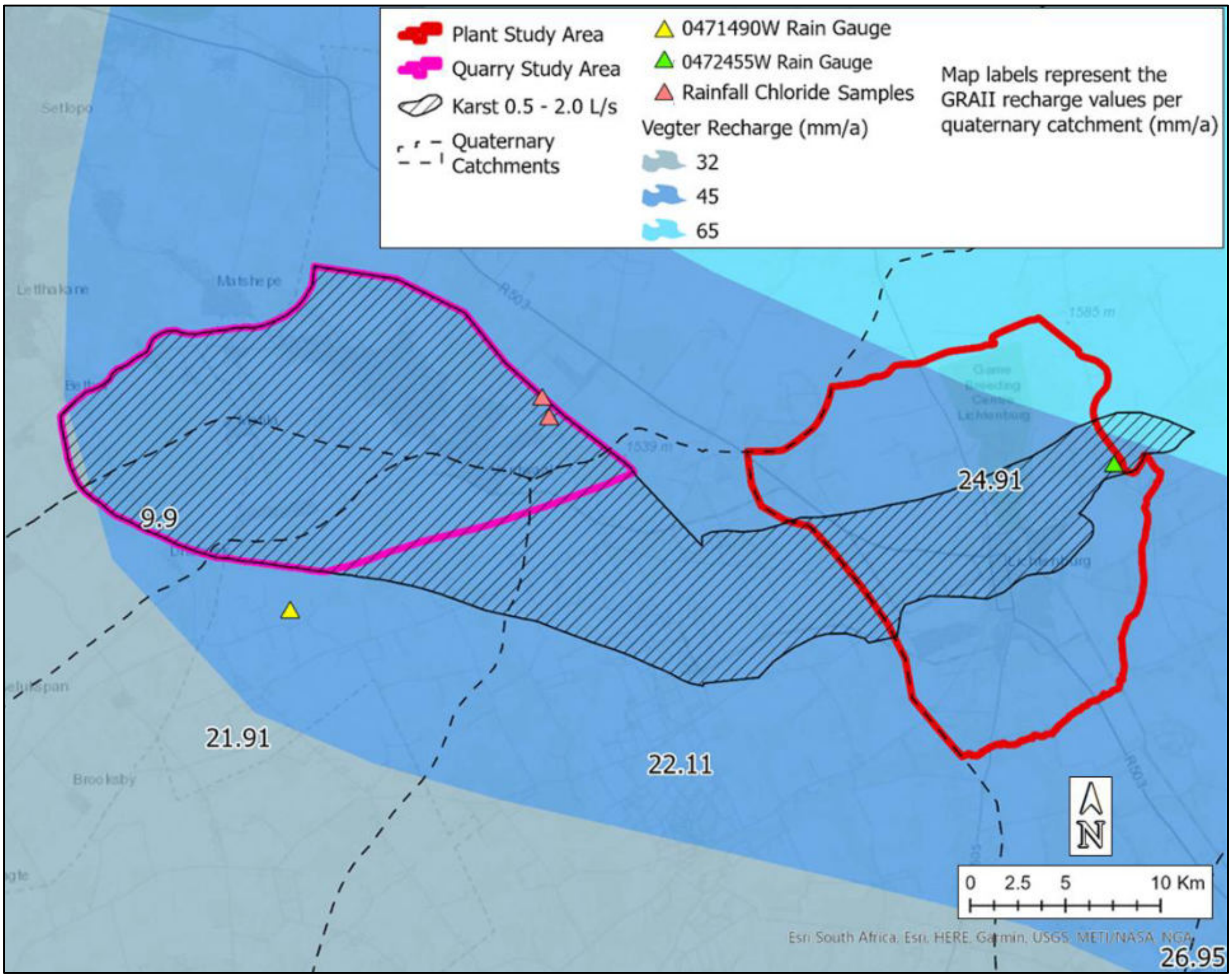


Figure 13: Study Area Recharge Values

Rainfall data for the project area was obtained from the SAWS rainfall station 0472455 W which is located approximately 3.2 km northeast of the site. The station was selected based on its record period and the reliability of historical rainfall data. The details of this rainfall station are presented in Table 11.

Table 11: Rainfall Station Details

Station Number	Station Name	MAP (mm)	Years Assessed	Reliability (%)	Longitude	Latitude
0472455W	Manana	614	1950 - 1999	91	26.10051°	26.21943°

Most of the rainfall falls over the summer period (October to March), with a total rainfall depth over these six months equating to 547 mm. It is also noted that low rainfall values are recorded over the winter months (May to September), with a total rainfall depth equating to 51 mm.

7.2 Model Assumptions and Limitations

The following needs to be described in a groundwater model:

- Geological and hydrogeological features
- Boundary conditions of the study area (based on the geology and hydrogeology)
- Initial water levels of the study area
- The processes governing groundwater flow
- Assumptions for the selection of the most appropriate numerical code.

Field data is essential in solving the conditions listed above and developing the numerical model into a site-specific groundwater model. Specific assumptions related to the available field data include:

- The top of the aquifer is represented by the generated groundwater heads
- The available geological/hydrogeological information was used to describe the different aquifers
- The available information on the geology and field tests are considered as correct
- All data provided by the client is correct and have been correctly analysed
- Many aquifer parameters have not been determined in the field and therefore must be estimated.

To develop a numerical model of an aquifer system, specific assumptions must be made and include:

- The system is initially in equilibrium and therefore in steady state[2], even though natural conditions have been disturbed
- No abstraction boreholes were included in the initial model; however, they are included for the scenarios
- The boundary conditions assigned to the model are considered correct
- The impacts of other activities (e.g., agriculture) have not been considered.

A numerical groundwater model is a representation of the real system. It is therefore at most an approximation, and the level of accuracy depends on the quality of the data that is available. This implies that there are always errors associated with groundwater models due to uncertainty in the data and the capability of numerical methods to describe natural physical processes.

7.3 Generation of a Finite Difference Network

To investigate the behaviour of aquifer systems in time and space, it is necessary to employ a mathematical model. MODFLOW, a modular three-dimensional finite difference groundwater flow model was the software used during this investigation. It is an internationally accepted modelling package, which calculates the solution of the groundwater flow equation using the finite difference approach.

The simulation model used in this modelling study is based on three-dimensional groundwater flow as described by the following equation:

[2] In steady state systems, inputs and outputs are in equilibrium so that there is no net change in the system with time. In transient simulations, the inputs and outputs are not in equilibrium so there is a net change in the system with time. Steady state models provide average, long-term results. Transient models should be used when the groundwater regime varies over time

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right)\pm W=S\frac{\partial h}{\partial t}$$

where,

h	=	Hydraulic head
Kx, Ky, Kz	=	Hydraulic conductivity in different directions
S	=	Storage coefficient
t	=	Time
W	=	Source (recharge) or sink (pumping) per unit area
x, y, z	=	Coordinate into model

For steady state conditions the groundwater flow equation reduces to the following:

$$\frac{\partial}{\partial x}\left(K_x\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_y\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_z\frac{\partial h}{\partial z}\right)\pm W=0$$

The model network was constructed using a cell size of 50m x 50m over two layers resulting in a total of 237534 active cells.

7.4 Boundary Conditions

A model boundary is the interface between the model area and the surrounding environment. Conditions on the boundaries must be specified. Boundaries occur at the edges of the model area and at locations in the model area where external influences are represented, such as rivers, wells, and leaky impoundments.

Criteria for selecting hydraulic boundary conditions are primarily topography, hydrology and geology. The topography and/or geology may yield boundaries such as impermeable strata or potentiometric surfaces controlled by surface water, or recharge/discharge areas such as inflow boundaries along mountain ranges. The flow system allows the specification of boundaries in situations where natural boundaries are a great distance away.

Boundary conditions are specified for the entire boundary and may vary with time. At a given boundary section, just one type of boundary condition can be assigned. As an example, it is not possible to specify groundwater flux and groundwater head at an identical boundary section. Boundaries in groundwater models can be specified as (but not limited to):

- Dirichlet (also known as fixed head or constant concentration) boundary conditions
- Neuman (or specified flux) boundary conditions
- General Head Boundary (GHB) (also known as a head dependant flux boundary).

The model area delineation is presented in Figure 5 and the boundaries were selected as no-flow boundaries, with the rivers selected as a constant head. The pit areas were modelled with the GHB condition.

7.5 Model Parameters

Every model consists of sources and sinks to add and remove water from the model domain to maintain the overall model water balance. In addition to the sources and sinks, this section describes the purpose and model parameters assigned to each layer of the model.

7.5.1 Layer Parameters

There is a distinct dolomitic unit underlying the surface geology and for this reason a two layer model was constructed. The top of layer 1 is the surface elevation of the model area and the bottom of layer 1 represents the top of the dolomitic unit. Layer 2 represents the dolomitic unit. A section through the model grid that illustrates the dip of the dolomitic unit is presented in Figure 14.

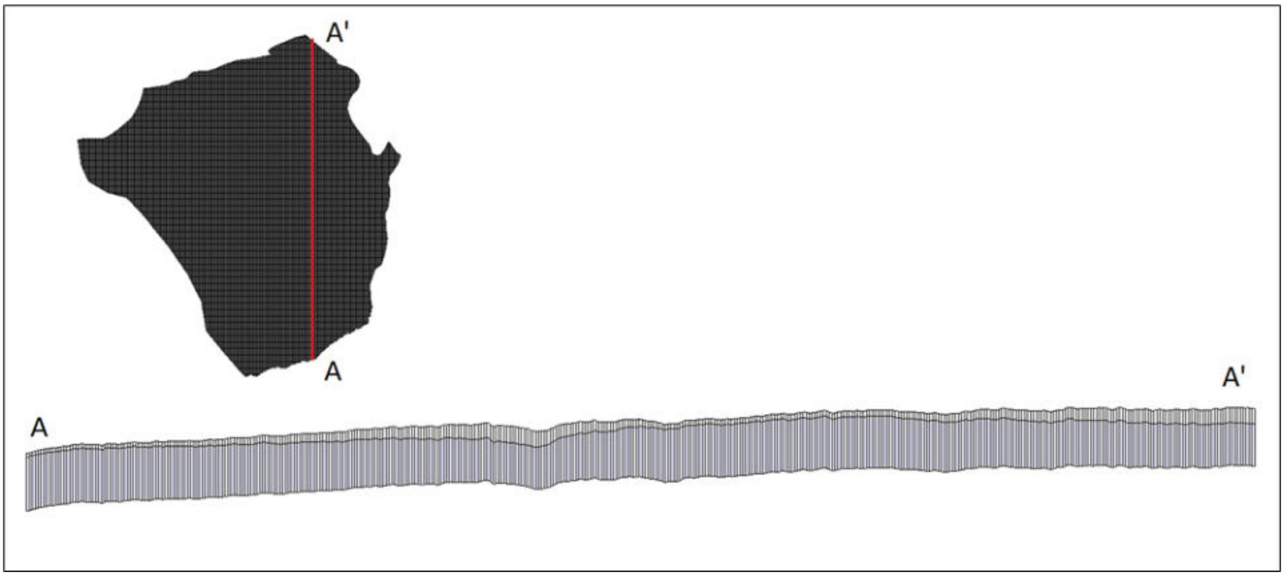


Figure 14: Two Layer Model Cross Section

A summary of the initial layer parameters estimated from available data is presented in Table 12.

Table 12: Summary of Layer Parameters

Layer No	Horizontal K (m/d)	Vertical Anisotropy	Porosity	Longitudinal Dispersivity
1	0.01 - 0.13	10	0.3	50
2	0.22 – 2.49	10	0.1	50

7.5.2 Structural Lineaments

No information was available of the physical properties of the structural lineaments, thus they were modelled as features having a horizontal and vertical hydraulic conductivity. The respective hydraulic conductivities were obtained through the calibration process. The distribution of horizontal hydraulic conductivities present in both layers of the model is presented in Figure 15.

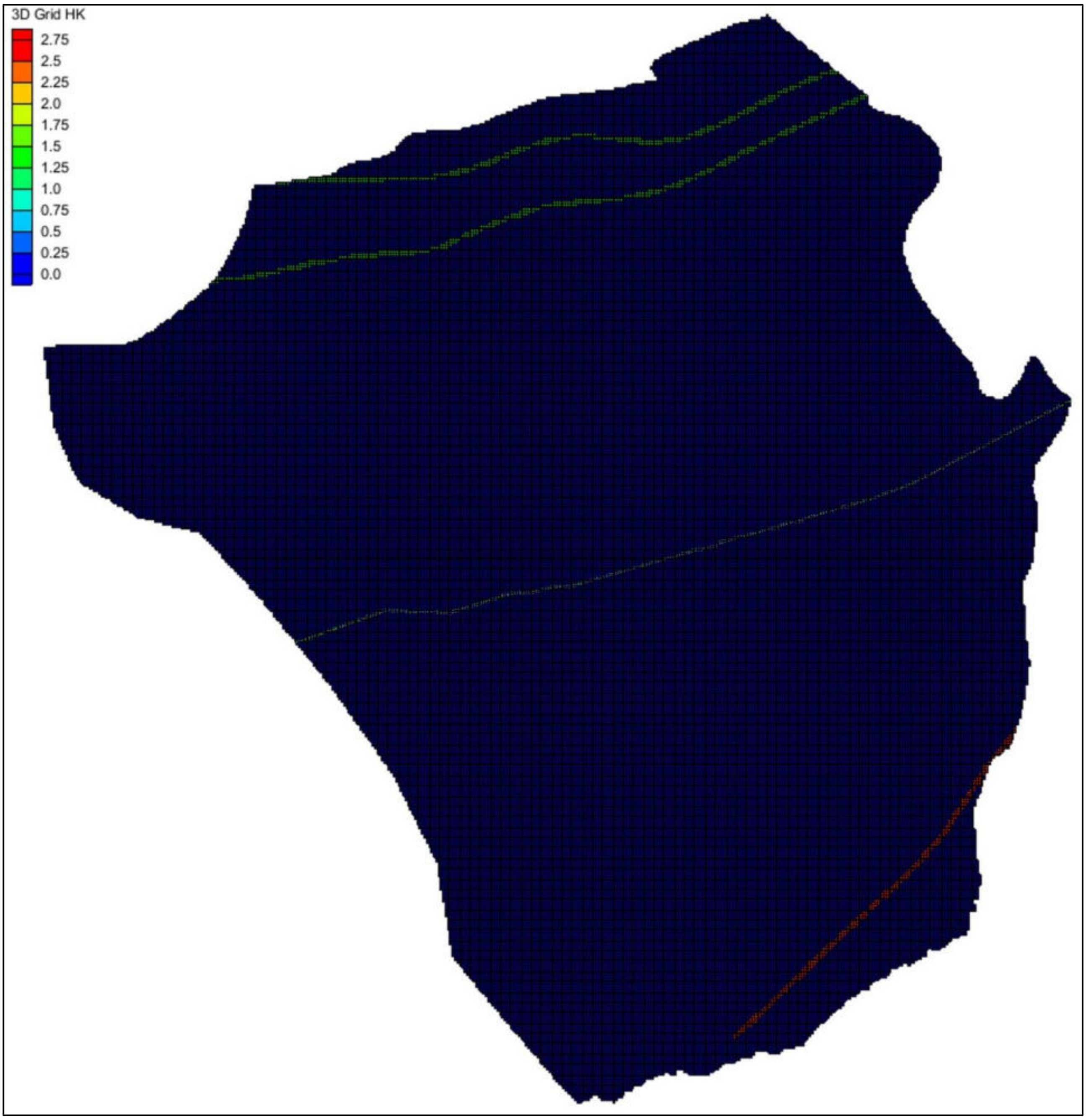


Figure 15: Structures Modelled as Variable Hydraulic Conductive Features

7.5.3 Recharge

Groundwater recharge is generally determined using the water balance method that relates a change in head to a change in volume through the storage coefficient considering rainfall, or through the chloride mass balance method, where the chloride in the groundwater is assumed to be a conservative tracer originating from rainfall. The latter method was used to estimate the initial recharge values since chloride monitoring data was available. The chloride mass balance method is expressed mathematically in the equation below.

$$R(mm/a) = \frac{PCl_p + D}{Cl_{gw}}$$

where,

P = Precipitation
D = Cl dry deposition (mg/m2/a)
Clp = Cl in precipitation
Clgw = Cl in groundwater

The chloride dry deposition is generally not available and common practice is to assume a dry deposition value of zero. The chloride mass balance method is further dependent on the chloride concentration in rainfall. The chemistry of rainfall seldom forms part of a monitoring program and therefore an estimation of the rainfall chloride concentration is required. Rainfall chloride values for different locations are presented in Figure 16. A distinction is made between locations close to the coast and those inland, as coastal areas typically have higher concentrations of chloride than inland areas with an equivalent MAP.

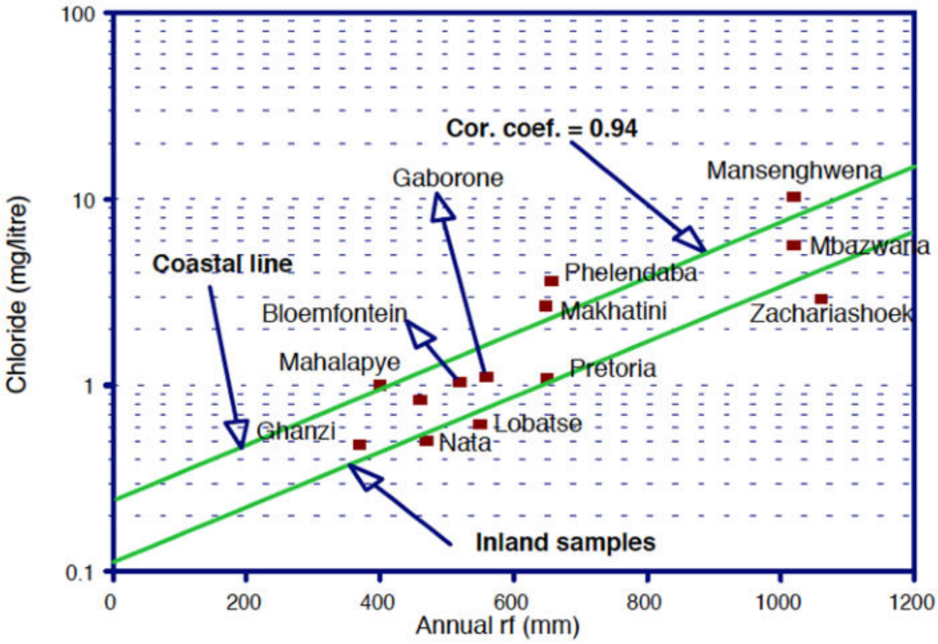


Figure 16:Typical Chloride Values Related to MAP

It is a general practice to calculate the representative groundwater chloride concentration using the harmonic mean as expressed in the equation below.

$$Cl_{gw} = N\left(\sum_{i=1}^{N} \frac{1}{Cl_{igw}}\right)^{-1}$$

The contributions of the borehole chloride concentrations are inversely proportional to the concentration itself in the harmonic mean formulation. This has the advantage that high concentration values, which are generally not related to the rainfall recharge tracer mechanism are suppressed. The calculated harmonic mean for the available borehole chemistry is 24.69 mg/l. From the DWS NGA, two historic rainfall chloride values in the project area were available. The average of the rainfall chloride values was calculated and the calculated recharge is then expressed as:

$$Recharge(mm/a) = \frac{PCl_p + D}{Cl_{gw}} = \frac{614(2.25)}{24.69} = 56\ mm/a$$

The calculated recharge is higher than the Vegter value, but translates to 4% of MAP, which is considered acceptable for the geology under consideration.

7.6 Initial Conditions

The model was initialized with parameter values presented earlier, and with initial water levels, to solve the steady-state equation. Making use of historic borehole water levels that are considered static water levels, there exists a high correlation between surface topography and water levels across the study area. However, some water levels do not follow the water level correlation trend due to current abstraction taking place. The distribution of boreholes, abstractions points, and registered irrigation points on the WARMS database, is presented in Figure 17 and Figure 18. It is clear from this why certain clusters of boreholes do not follow the water level correlation. Since model calibration is done for the steady state, only boreholes not affected by pumping were used in the calibration process. The correlation is presented in Figure 19.

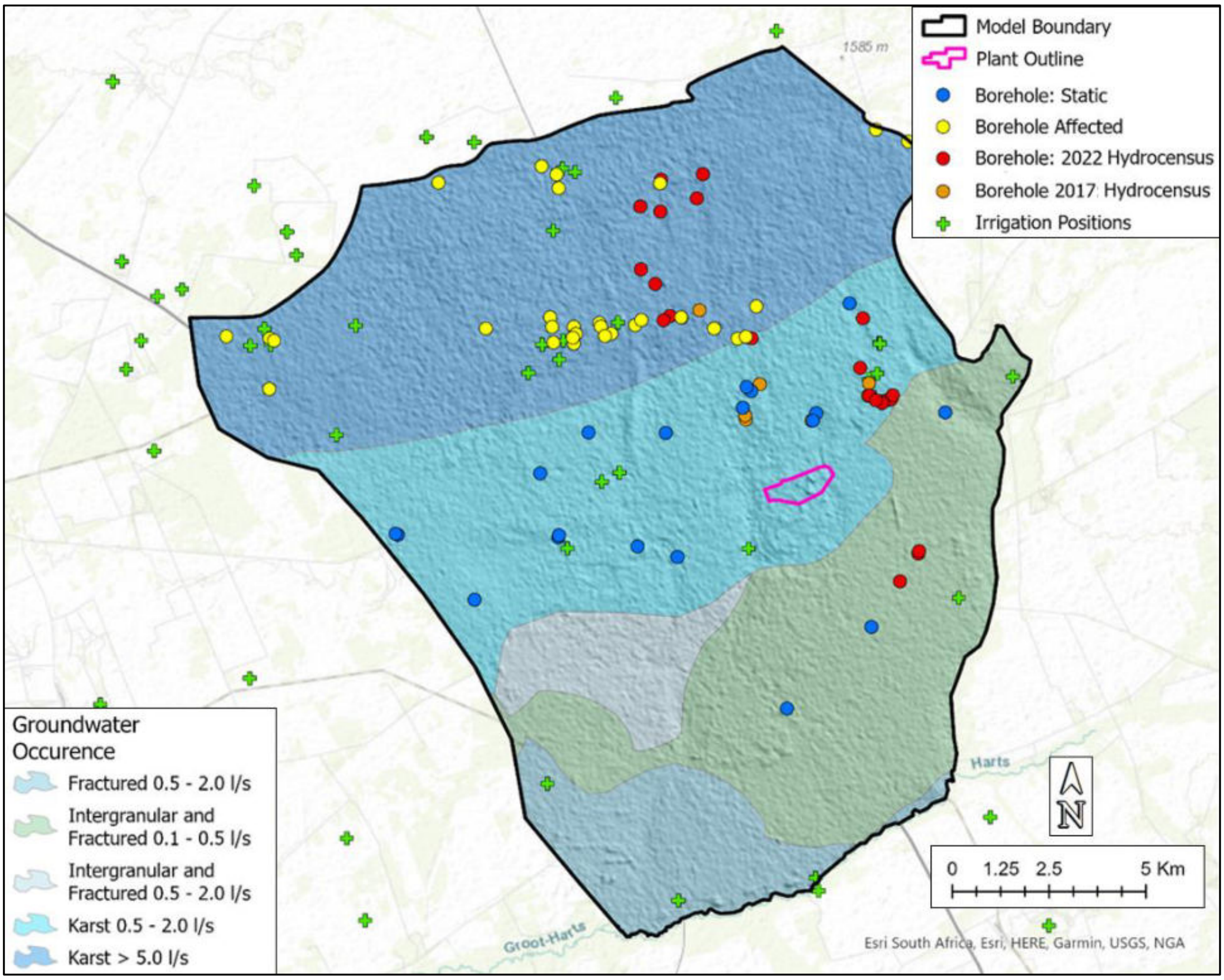


Figure 17: Spatial Distribution of Water Level Boreholes in the Model Domain

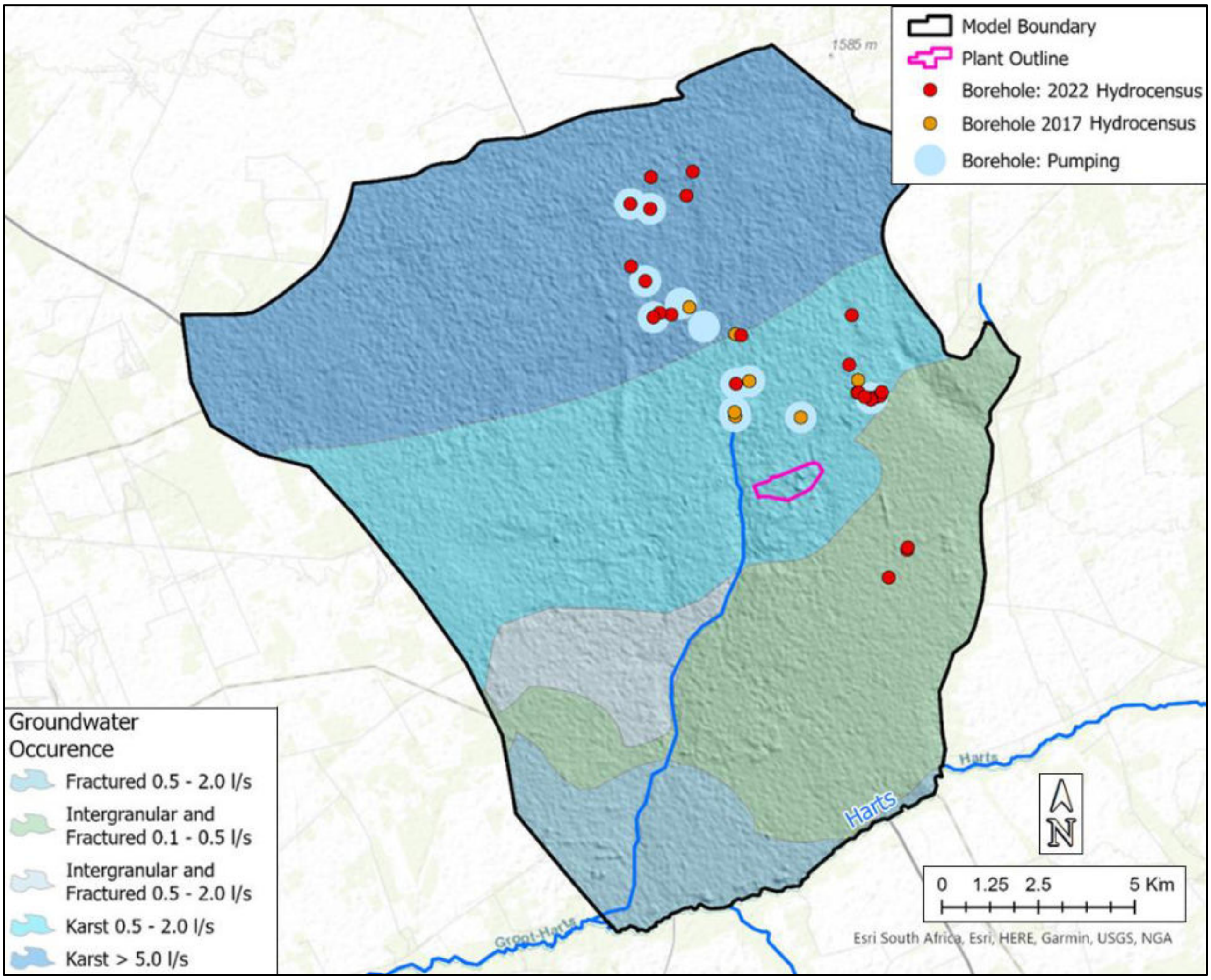


Figure 18: Distribution of Known Abstraction Boreholes

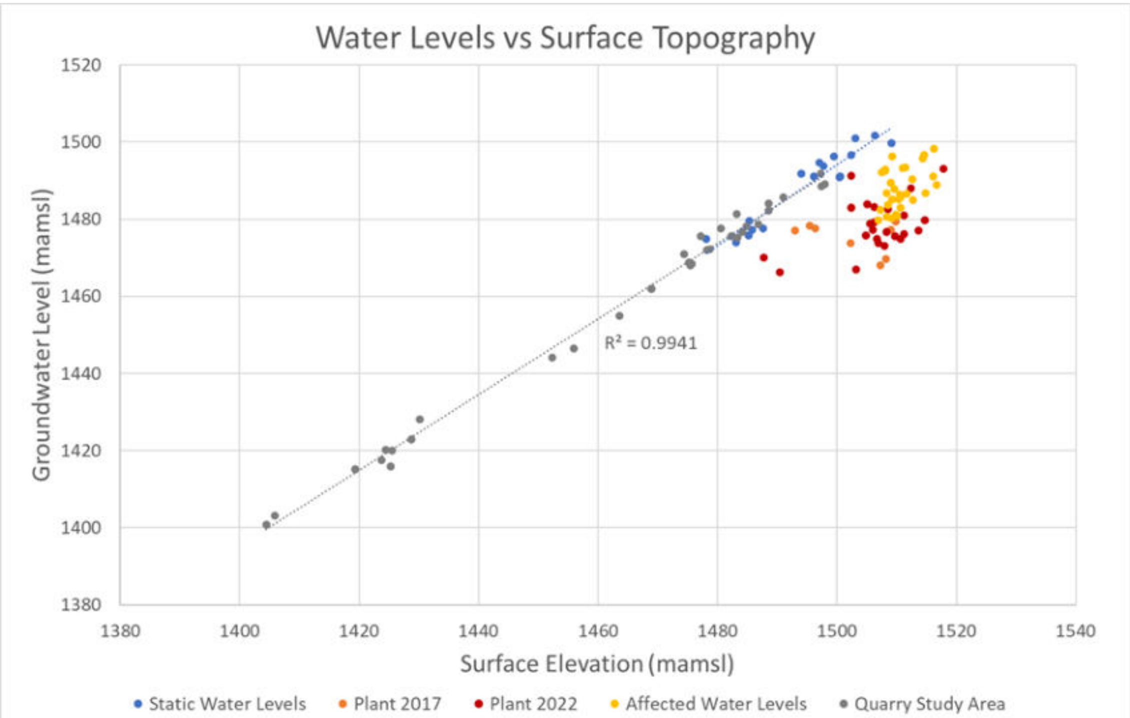


Figure 19: Water Level Correlation with Surface Topography

The Bayesian interpolation method to generate water levels is well suited when there exists a high correlation between surface topography and water level elevation. The Bayesian method employs Bayes' probability theorem that describes the probability of an observation, based on prior knowledge of conditions that might be related to the observation. The main advantage of using the Bayesian interpolation is that water levels can also be extrapolated to areas where no water level information exists, but where elevation data is available that will be used in the probability calculation of the estimated water level. The resultant initial model water levels is presented in Figure 20.

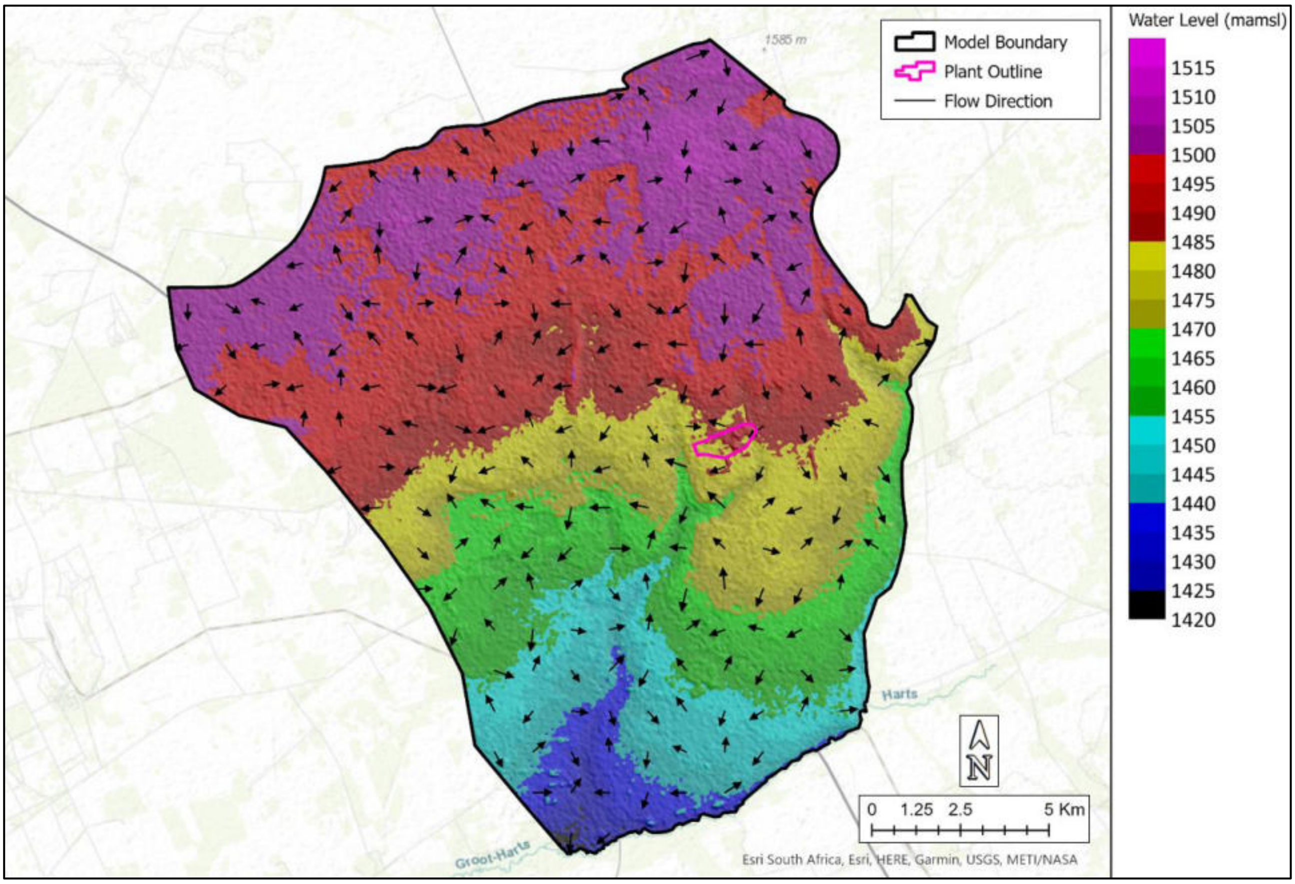


Figure 20: Static Water Level Map for Model Area

7.7 Model Calibration

The steady state head distribution is dependent upon the recharge, hydraulic conductivity, sources, sinks, and boundary conditions specified. For a given recharge component and set of boundary conditions, the head distribution across the aquifer under steady-state conditions can be obtained for a specific hydraulic conductivity value. The simulated head distribution can then be compared to the measured head distribution and the hydraulic conductivity or recharge values can be altered until an acceptable correspondence between measured and simulated heads is obtained. The advantage of a steady state model is that the parameter for specific storage is not required to solve the groundwater flow equation, therefore there are fewer unknown parameters to determine.

The calibration process was done by changing the model parameters for hydraulic conductivity and recharge. Borehole water levels were used to calibrate the steady state groundwater flow model. The calibration objective was reached when an acceptable correlation was obtained between the observed and simulated piezometric heads.

The observed versus simulated water levels for each calibration borehole are presented in Figure 21 and the spatial distribution of the boreholes used is presented in Figure 22. Not all NGA and hydrocensus boreholes were used in the calibration process due to the following:

- Boreholes subject to other abstraction points are not representative of static water levels. Both the NGA and hydrocensus datasets contain these cases (see Figure 18)
- Water levels measured at different periods in time are subject to different rainfall and different site conditions resulting in variable outputs
- Dramatic differences between adjacent boreholes in close proximity, either due to monitoring at different times or intersection of different aquifer systems or geological features. To account for these types of borehole responses, substantial monitoring data is required to understand the behaviour with time, as well as a detailed understanding of the borehole construction.

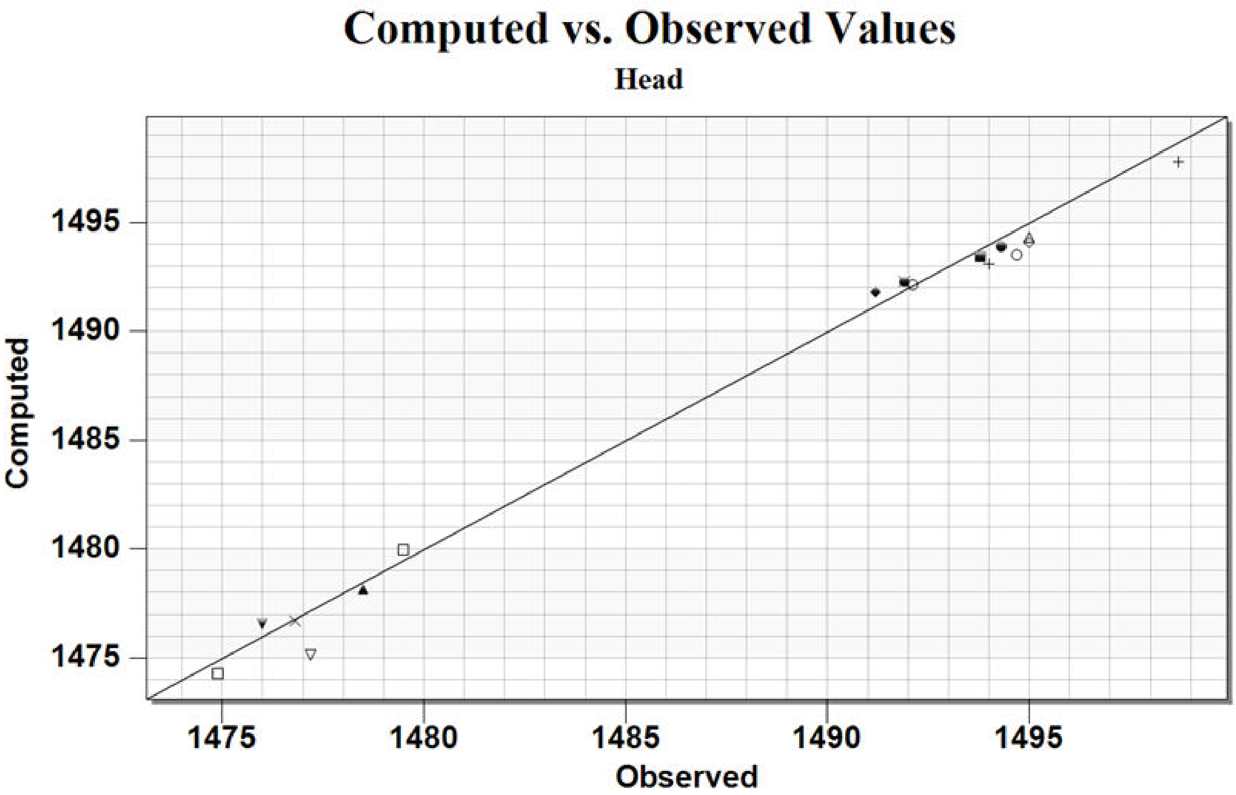


Figure 21: Correlation between Observed and Simulated Water Levels

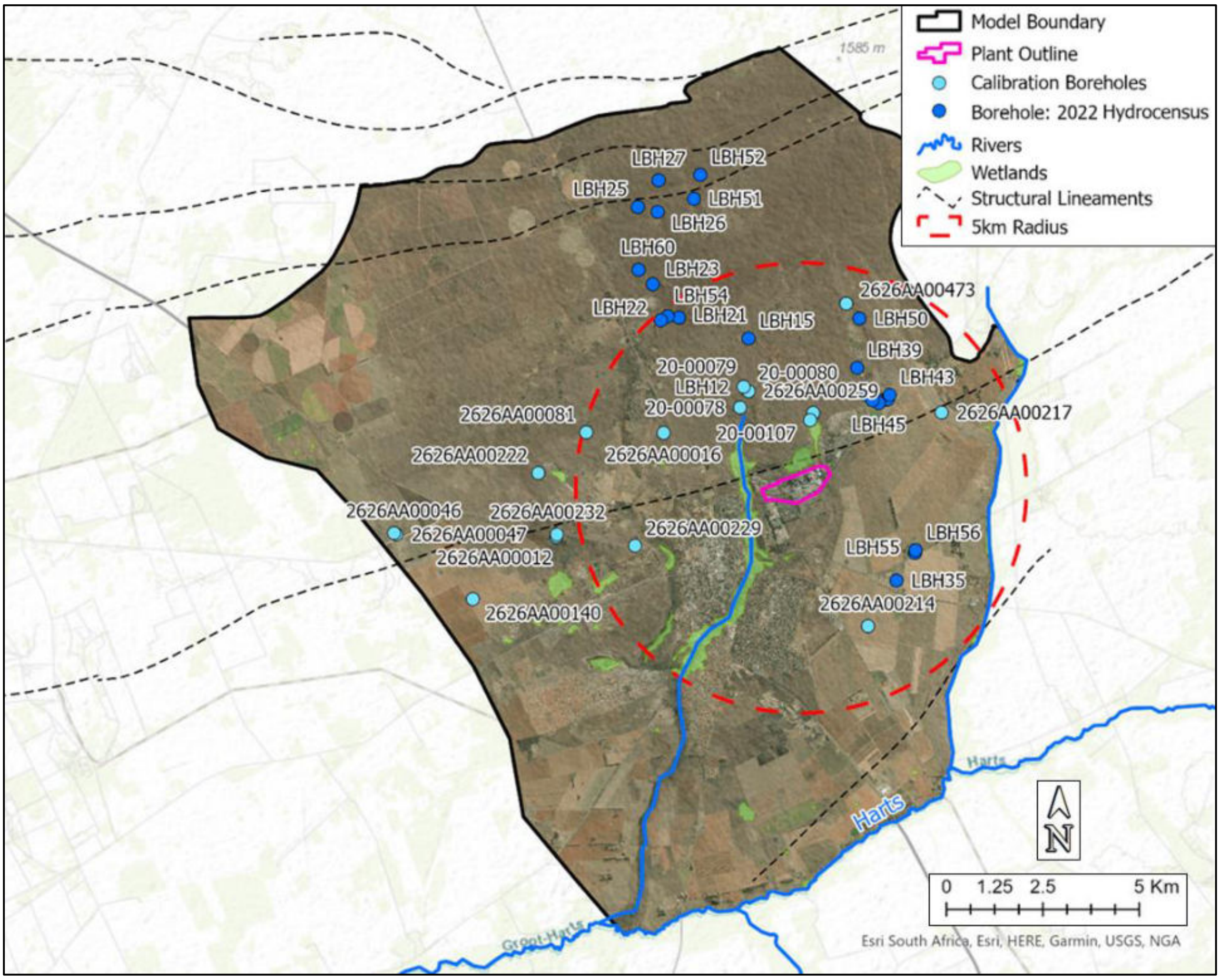


Figure 22: Spatial Distribution of Calibration Boreholes

7.8 Model Scenarios and Outputs

7.8.1 Methodology

To determine the impact on the receiving environment, the groundwater flux into the mine pit was modelled through the numerical groundwater flow model, and the potential sources of pollution were modelled through the use of mass transport.

Since insufficient source concentration data was available to model individual constituents of the source concentrations, it is assumed that a source concentration is 100 % and the pollution plume is expressed in terms of the percentage decay. Conservative mass transport was assumed and it should be highlighted that since a steady state model was used, it must be considered as the worst case scenario, as it can take a long time to reach steady state. Dynamic changes in the geohydrological system are not considered in steady state.

Four time steps at 25, 50, 75 and 100 years for mass transport were considered. The pit area was simulated with and without evaporation to illustrate the concentrating effect of evaporation on the source concentrations over prolonged periods of time. This report presents the simulations with evapotranspiration. Scenarios without evapotranspiration are included in Annexure F for reference.

7.8.2 Modelled Pit Inflows

The water level in the pit was inferred from site observations and from elevations acquired from the SRTM30 Digital Elevation Model. The pit flow is based on the regional model perspective, and has some limitations on accuracy. Survey of the pit is required to get better confidence and accuracy in the flows presented, since the flows diminish as the pit level drops. Further refinement can be obtained through additional monitoring boreholes in the vicinity of the pit. Additional parameters and factors that influence the flow calculation include, recharge, constant heads, and the accurate dimensions of the top to bottom of the model layers.

The model results indicate that the net inflow is dependent on the water level in the pit such that the higher the pit level, the greater the net inflow, and groundwater is in continual balance with the evaporation component resulting in a near zero net flow for a particular pit level. The modelled inflows assume there is only a rainfall and groundwater inflow component, although it is understood that the pit does receive plant operational inputs. The pit inflow reduces as the pit level drops. The variability of the contribution from rainfall and stormwater is offset by continuous evaporation, resulting in a general water balance in the pit, and as a result, the pit level does fluctuate periodically given these inputs. The modelled pit inflows were carried out for selected pit levels at 1 m increments. The total pit inflows are summarised in Table 13. It is also evident that the total inflows are a factor lower than the Tswana pit inflows.

Table 13: Summary Modelled Pit Inflows

Water Level in Pit (mamsl)	Total Pit Inflow (m^3/d)	Total Pit Outflow (m^3/d)	Evapotranspiration Component (m^3/d)	Nett Flow (Balance) (m^3/d)
1490	172.650	172.650	172.650	0.0005
1489	171.949	171.948	171.948	0.0017
1488	171.249	171.247	171.247	0.0019
1487	170.547	170.546	170.546	0.0015
1486	169.899	169.900	169.900	-0.0009
1485	168.526	168.627	168.627	-0.1013

7.8.3 Mass Transport Model Results

The potential pollution sources that were considered are presented in Table 1 and Figure 2, with the known and reported abstraction rates from abstraction boreholes summarised in Table 14.

Table 14: Abstraction Borehole Rates Input in the Model Domain

Abstraction Borehole ID	Q (m^3/d)[3]
LBH1	1200
LBH2	1797
LBH3	2401
LBH10	596
LBH11	2401
LBH12	4199
LBH13	3602
LBH17	596
LBH18	3602

[3] Report reference 5707 of JG Afrika (Pty) Ltd, titled “Lichtenburg Lafarge Cement Plant Water Balance Study”, draft, dated March 2022

LBH20	1503
LBH22	3602
LBH23	2998
LBH25	3300
LBH26	3300
LBH41	898

Boreholes LBH1, LBH2 and LBH3 have abstraction rates that are overstated when comparing these figures to the sustainable yields determined in Section 5 of this report. The potential pollution sources are presented in Figure 23 for reference.

The conservative mass transport model results for the identified sources in steady state for Layer 1 and Layer 2 are presented in Figure 24 though Figure 31. The summary results of the 10 % and 91 % concentration contour travel distances for layer 1, and 10 % and 28% (maximum) for layer 2 at the most significant migration point, are presented in Table 15 to show the model plume migration with time. The travel distances were measured from a common reference point being the edge the selected pollution source.

Table 15: Summary Mass Transport Model Results - Travel Distances

Layer	Period (Years)	91 % Travel Distance (m)	10 % Travel Distance (m)
1	25	215	626
	50	242	997
	75	247	1106
	100	252	1241
Layer	**Period (Years)**	**28 % Travel Distance (m)**	**10 % Travel Distance (m)**
2	25	916	1166
	50	917	1170
	75	955	1495
	100	960	1664

The contained migration is due to the evaporation component. With the evaporation switched on, the pits acts as a "pump" which contains the plume migration. Since the evaporation rate is more than three times that of rainfall, and recharge is about 4% of MAP, and as long as the pits are not shielded from evaporation through backfill, evaporation will create a gradient between the pit level and that of the immediate groundwater level surrounding the excavations. The result of this is that the plume movement around these features stay contained in the absence of immediate abstraction near the pit. It is evident that pumping borehole do have an influence on plume migration. It is also evident that the source concentrations increase over time as the evaporation process does not allow for mass transport out of the system. This leads to a concentration of salts over time. Due to the contrast between the hydraulic conductivities in layer 1 and 2, as well as the induced pumping gradient, the major source concentrations propagate in layer 1.

The scenario results without the effect of evaporation turned off are presented in Annexure F. The source concentration remains constant. The results indicate that there is not a significant difference between the resulting plumes due to the area of evaporation being relatively small and the gradient between the pit area and the abstraction boreholes.

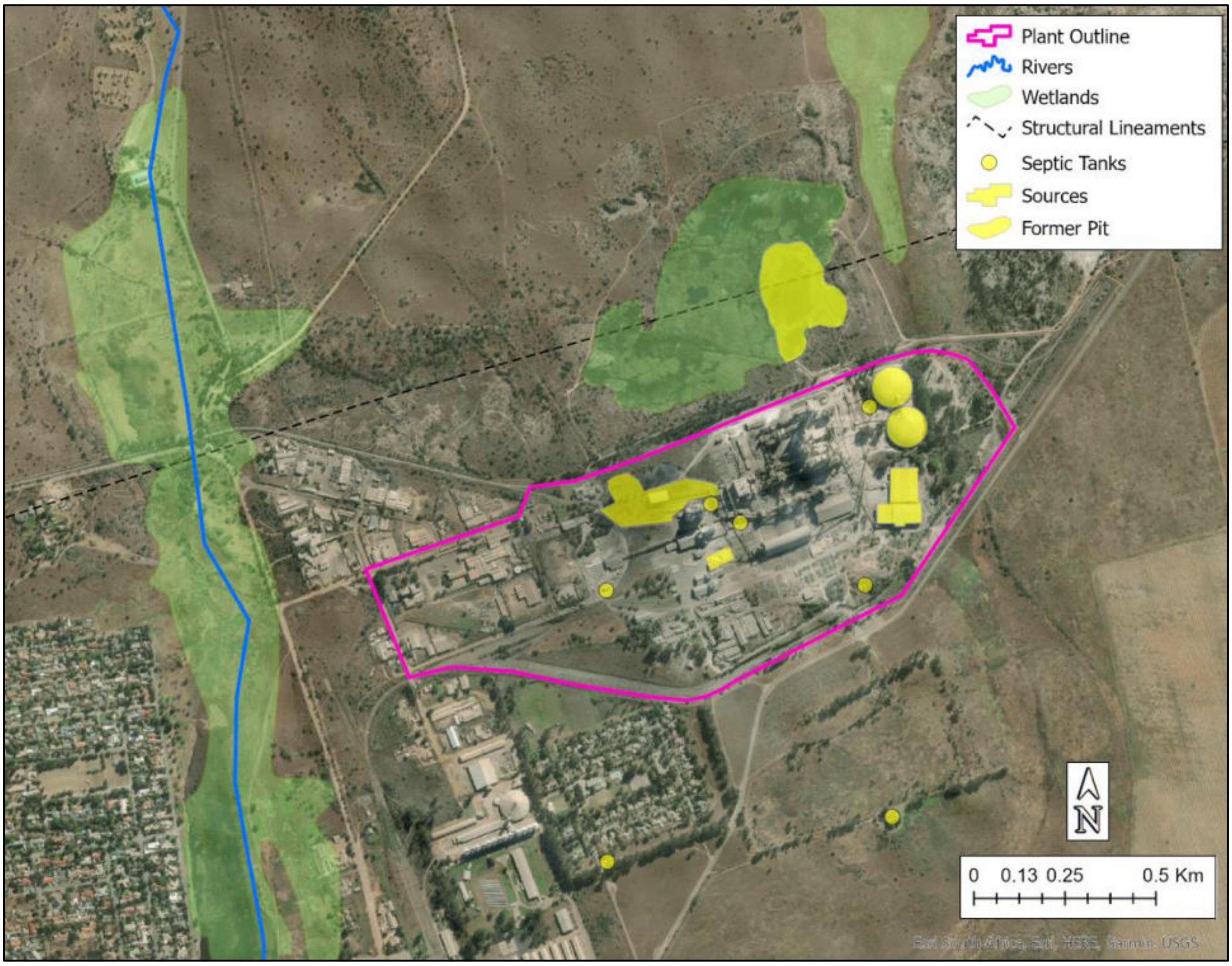


Figure 23: Spatial Distribution of Potential Pollution Sources

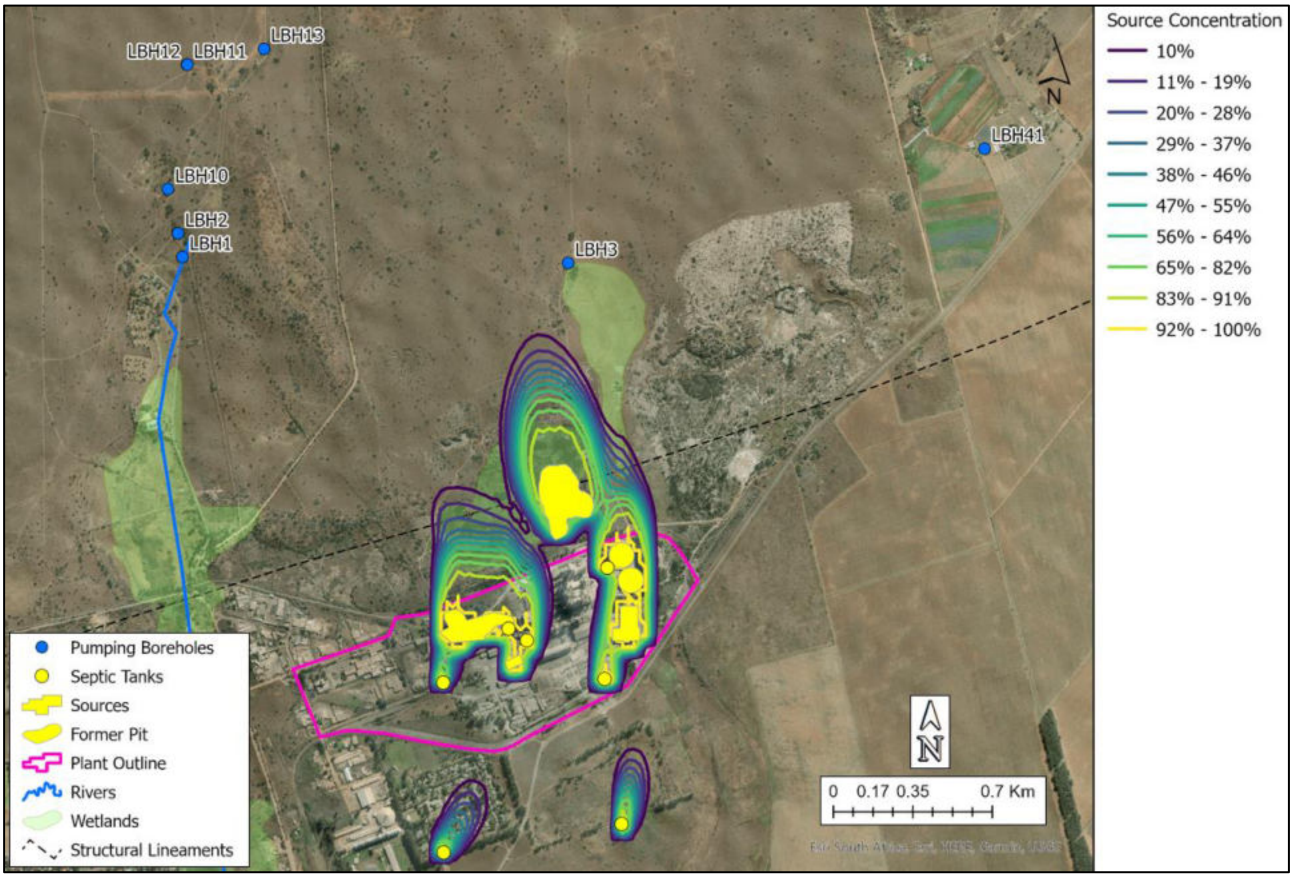


Figure 24: Mass Transport for Layer 1 - 25 Years

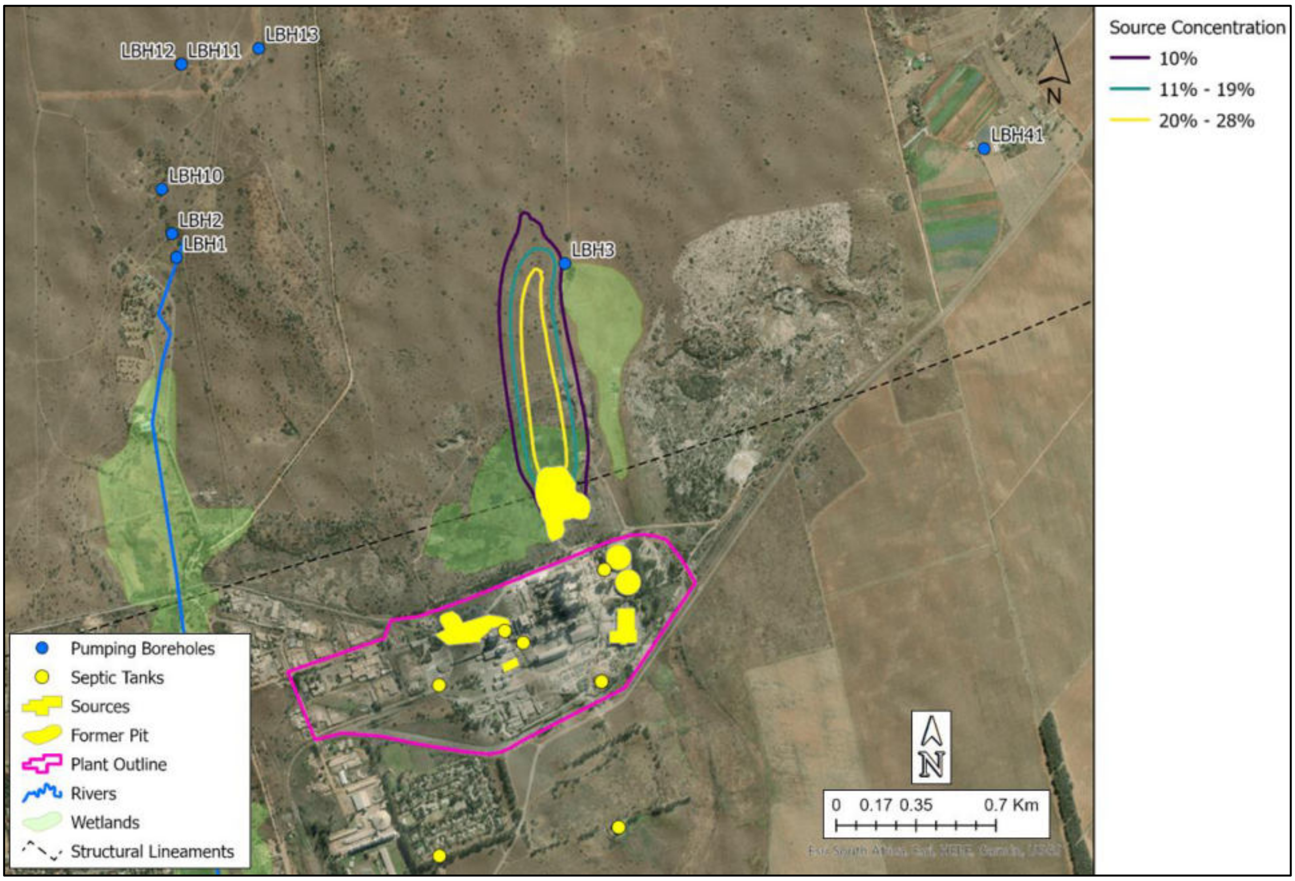


Figure 25: Mass Transport for Layer 2 - 25 years

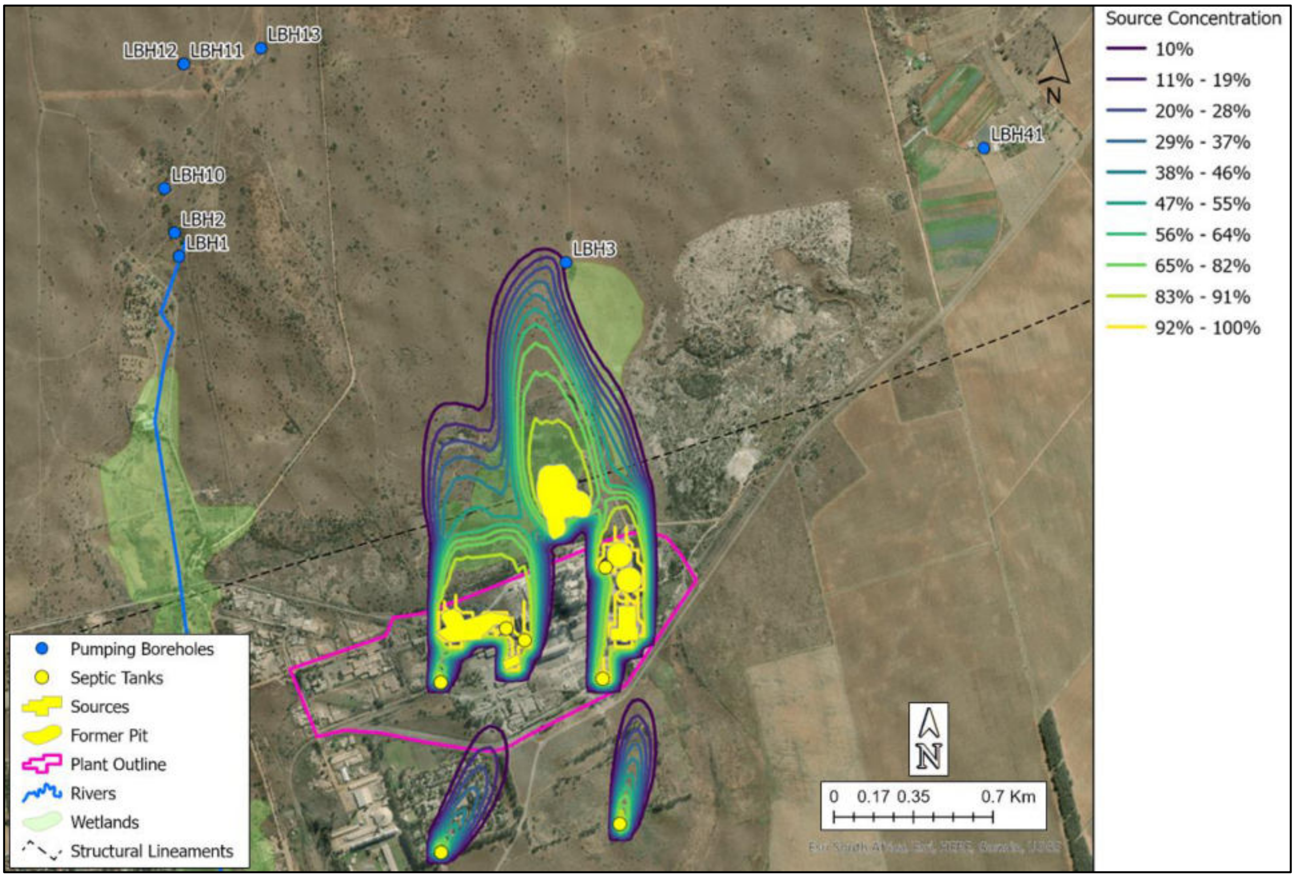


Figure 26: Mass Transport for Layer 1 - 50 Years

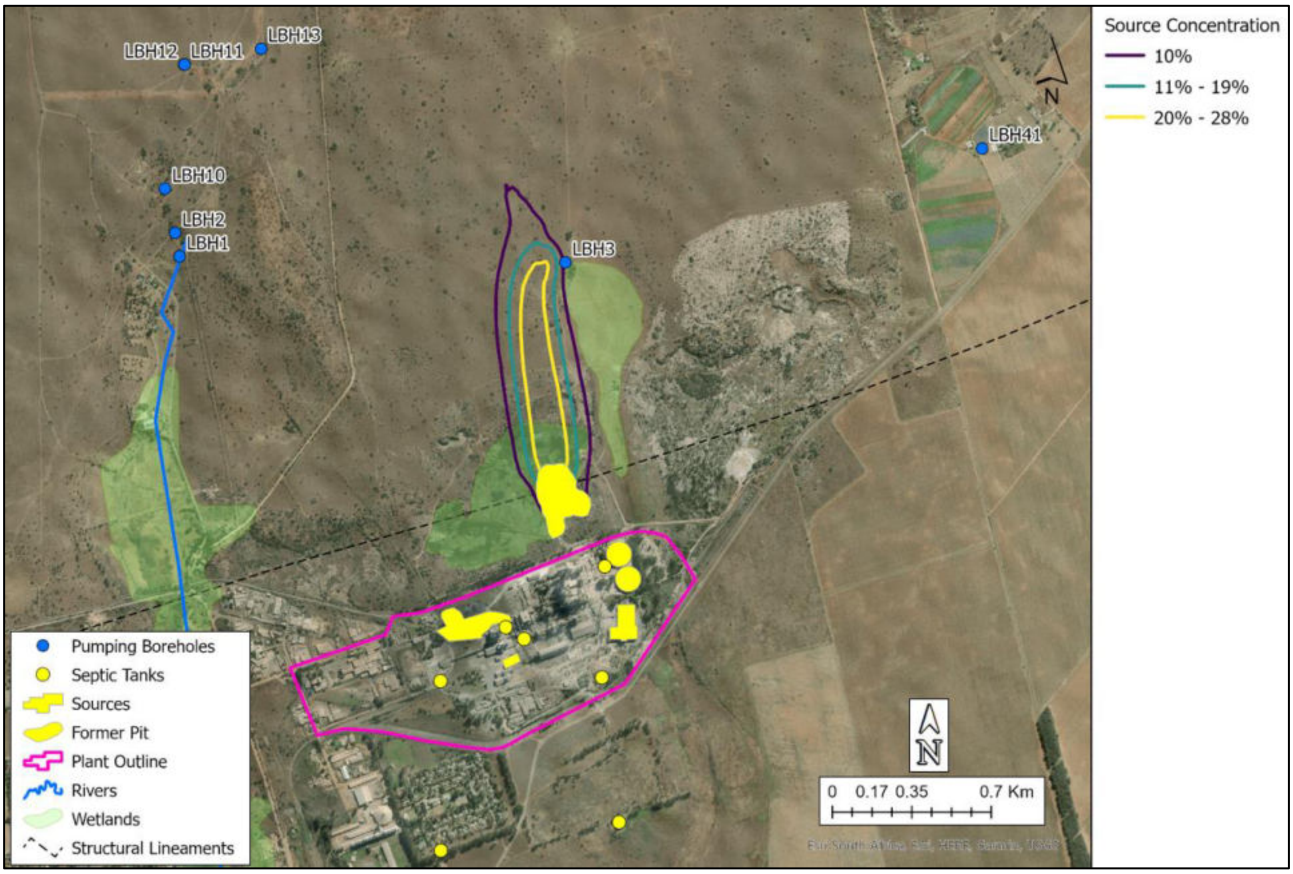


Figure 27: Mass Transport for Layer 2 - 50 Years

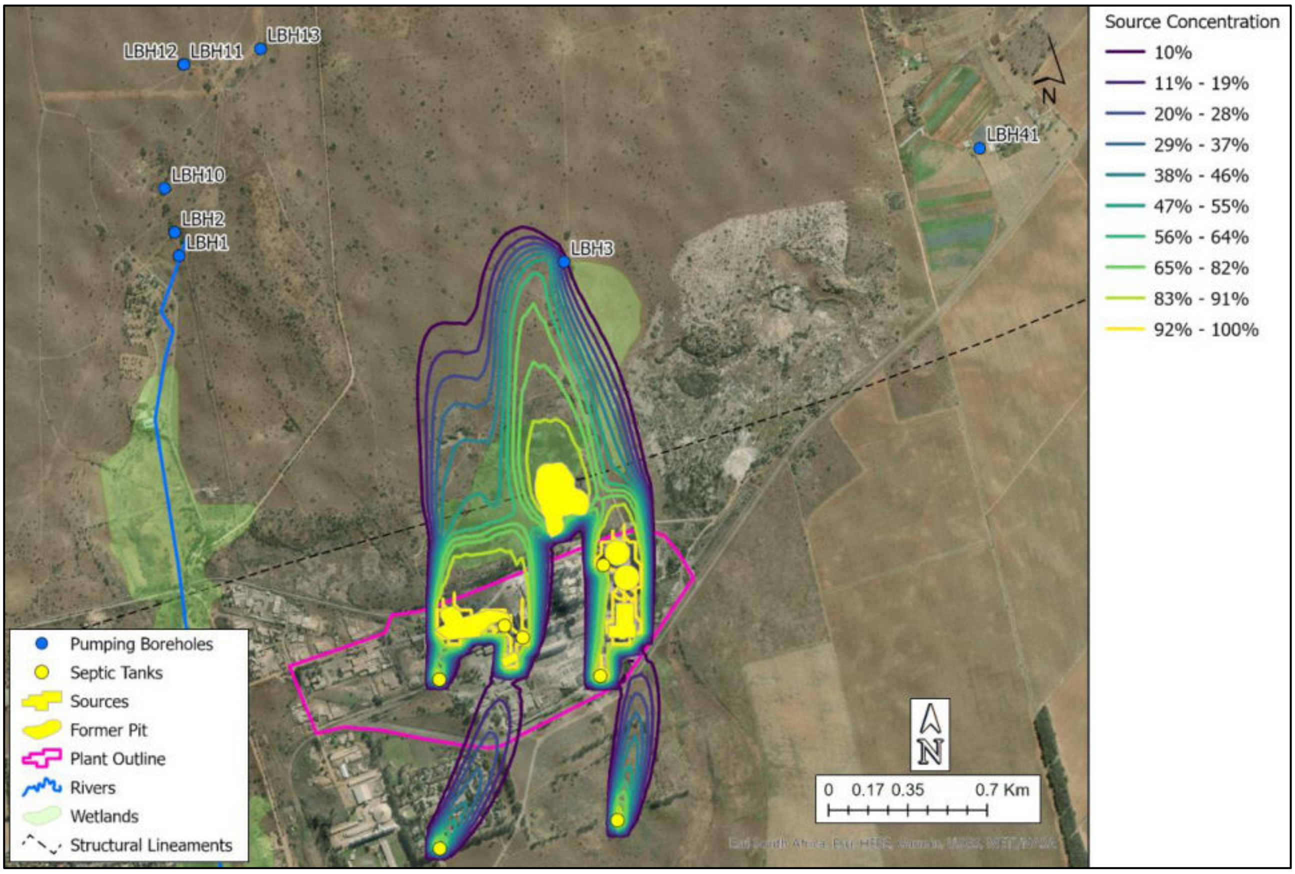


Figure 28: Mass Transport for Layer 1 - 75 Years

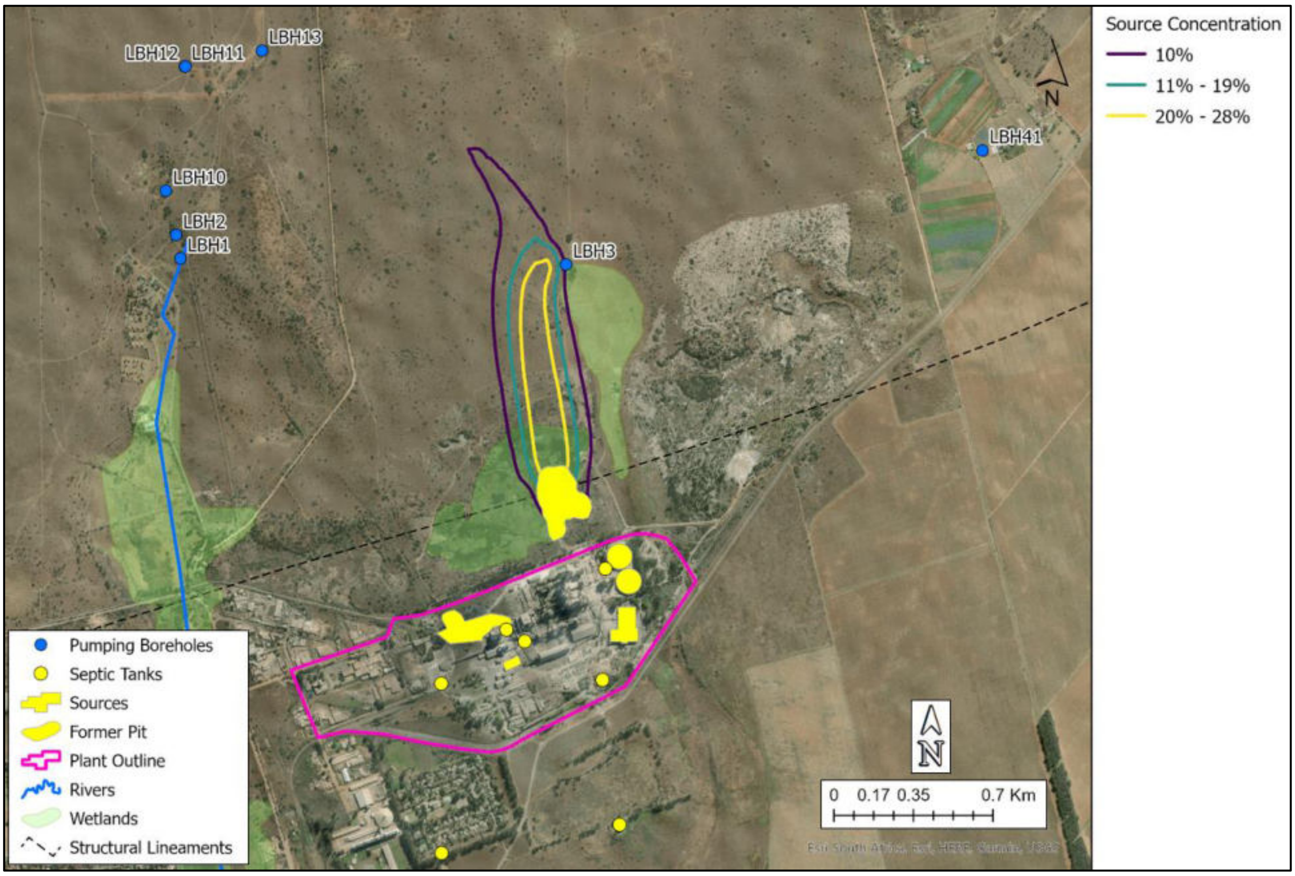


Figure 29: Mass Transport for Layer 2 - 75 Years

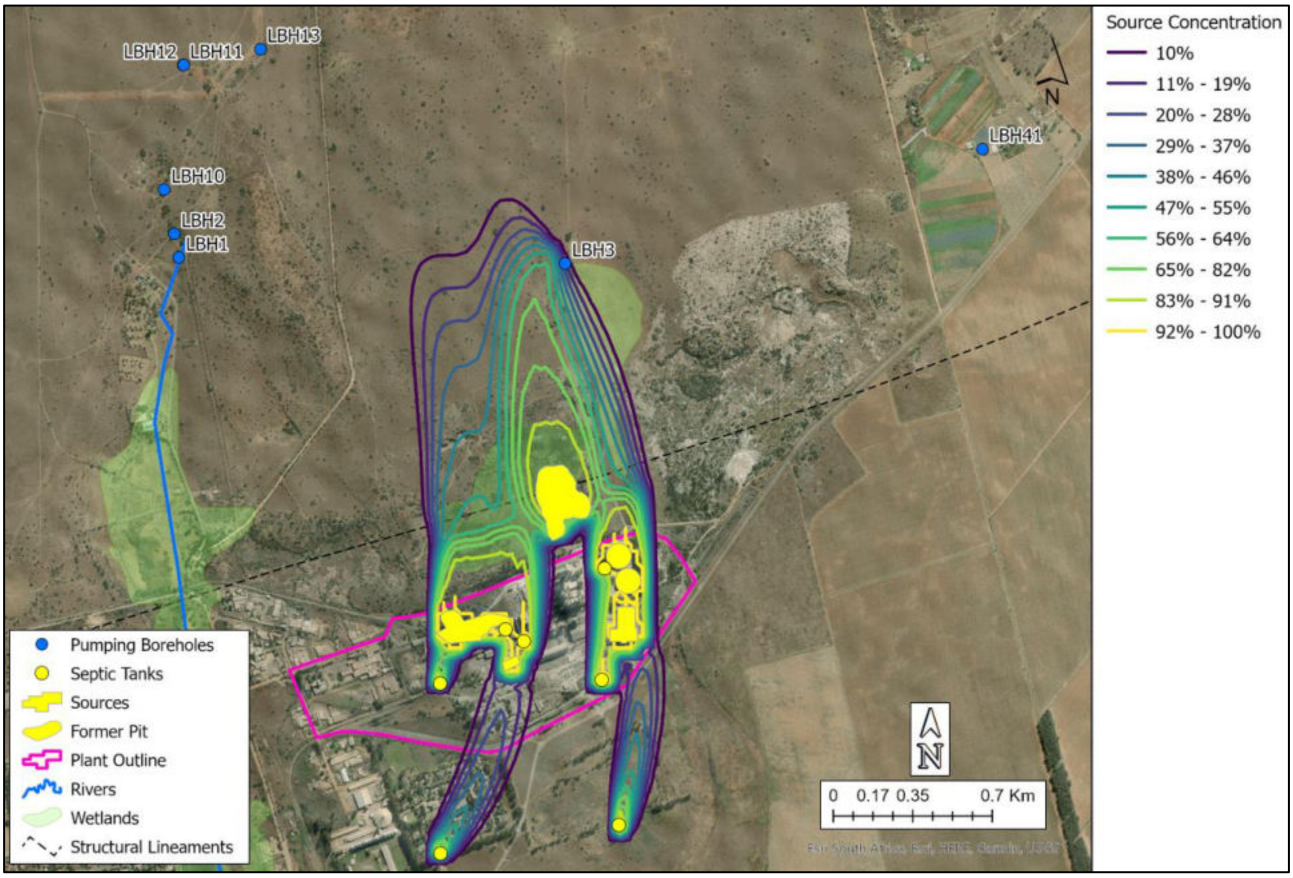


Figure 30: Mass Transport for Layer 1 - 100 Years

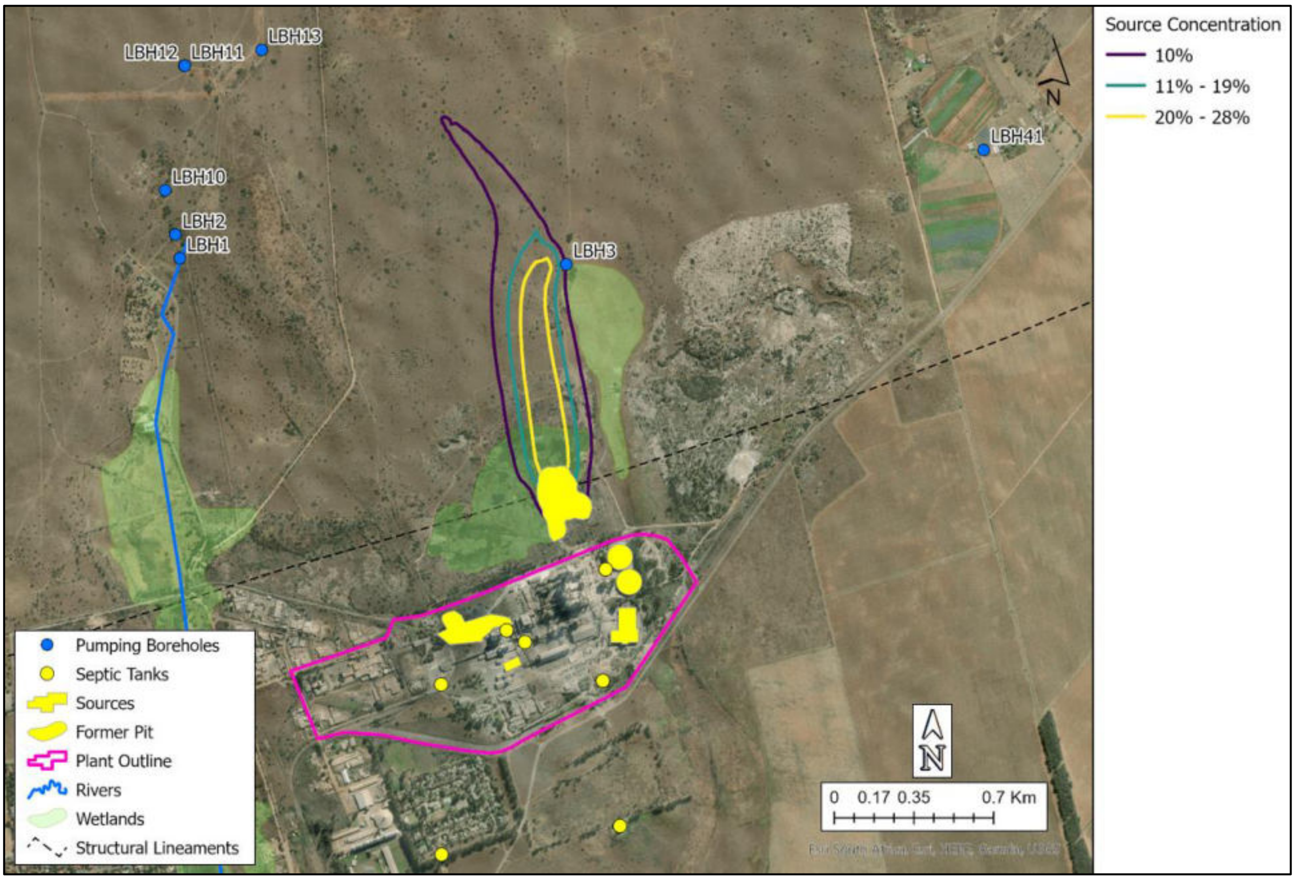


Figure 31: Mass Transport for Layer 2 - 100 Years

7.9 Quantitative Environmental Risk Assessment and Mitigation

The quantitative environmental risk assessment (ERA) identifies operational phase activities that may impact on the groundwater receiving environments. The Significance Points (SP) score is calculated from the following equation using ranking scales:

$$SP = \text{probability} \times (\text{duration} + \text{scale} + \text{magnitude})$$

The ERA methodology is presented in Annexure G. The ERA for the operational phase for the groundwater receiving environment is summarised in Table 16. Most activities identified scored LOW or MODERATE for the pre mitigation ratings. PCDs and stockpiles scored HIGH. Most scores can be reduced with the introduction of mitigation measures include in Table 16.

Table 16: Summary Risk Assessment Scoring

Significance / Consequence	Activity	Probability	Duration	Scale	Magnitude	Significance	PRE MITIGATION SP SCORE and RATING	>60 indicates high environmental significance <30 indicates low environmental significance	Mitigation	POST MITIGATION SP SCORE and RATING	>60 indicates high environmental significance <30 indicates low environmental significance	Variation
Section 21 (a) - taking water from a water resource												
Quantity	Aquifer dewatering	medium to high	permanent	site to local	moderate	medium negative	3.5(5+1.5+6) = 44	MODERATE	operate borehole within the design yield monitoring	2(5+1+4) = 20	LOW	24
Quality	Deterioration of groundwater quality through abstraction	improbable to low	permanent	site	minor to low	low negative	1.5(5+1+3) = 14	LOW	none	1.5(5+1+3) = 14	LOW	0
Section 21 (b) - storing water												
Quantity	recharge of the groundwater system	high	permanent	site	minor	positive	4(5+1+2) = 32	MODERATE	none	4(5+1+2) = 32	MODERATE	0
Quality	Deterioration of groundwater quality through recharge	high	long	site to local	moderate	medium negative	4(4+1.5+6) = 46	MODERATE	monitor and manage control inflow water quality	2.5(4+1.5+5) = 26	LOW	20
	Use of dam water for dust suppression and impacts on groundwater quality in surrounding areas	high	long	site to local	low to moderate	medium negative	4(4+1.5+5) = 42	MODERATE	Improved water quality / treatment Controlled use	3(4+1.5+4) = 29	LOW	14
Section 21 (g) - disposing of waste in a manner which may detrimentally impact on a water resource												
Quantity	recharge of the groundwater system (see 21 (b))	high	permanent	site	minor	positive	4(5+1+2) = 32	MODERATE	none	4(5+1+2) = 32	MODERATE	0
Quality	Deterioration of groundwater quality through recharge (see 21 (b))	high	long	site to local	moderate	medium negative	4(4+1.5+6) = 46	MODERATE	monitor and manage control inflow water quality	2.5(4+1.5+5) = 26	LOW	20
	Impacts on downstream groundwater users	high	long	site to local	moderate	medium negative	4(4+1.5+6) = 46	MODERATE	monitor and manage groundwater model for mass transport - 50 years model refinement with additional monitoring points	2.5(4+1.5+5) = 26	LOW	20
	Future pit decant	improbable	permanent	site	minor	low negative	1(5+1+2) = 8	LOW	none	1(5+1+2) = 8	LOW	0
	Salt loading through evaporation process	high	long	site to local	moderate to high	medium high negative	4(4+1.5+7) = 50	MODERATE	monitor and manage control inflow water quality	3.5(4+1+7) = 42	MODERATE	8
	Major loss of containment, dam overflows and impacts on groundwater quality	low	short to medium	local	high	high negative	2(2.5+2+8) = 25	LOW	Management of facilities Improved water quality through reuse / treatment Rapid clean up response	2(2+2+6) = 20	LOW	5
	Prolonged leaks / leachate from PCD facilities and stockpile and impacts on groundwater quality	high	permanent	local	high	high negative	4(5+2+8) = 60	HIGH	lining of PCD and water reuse / treatment Minimise stockpiles with water collection systems	3(5+1.5+6) = 38	MODERATE	23
	Sludge removal and impacts on groundwater quality	high	short	site to local	moderate	high negative	4(2+1.5+6) = 38	MODERATE	Operational procedures Appropriate disposal	2.5(2+1.5+6) = 24	LOW	14

8 MONITORING PLAN

8.1 Introduction

This section serves to provide the Client with a methodology to conduct groundwater monitoring to ensure reproducible and reliable results through consistent and appropriate sampling techniques. Monitoring information needs to be gathered in a confident manner to interpret groundwater chemistry over time, and to determine impacts associated with site infrastructure, such that meaningful management measures can be implemented for the site.

Two aspects in the monitoring plan need to be considered. These include;

- Groundwater levels
- Groundwater quality.

The procedures form the essence of the sampling plan. A borehole monitoring plan has already been established for the Cement Plant site.

Groundwater chemistry should be monitored bi-annually and should be based on the investigation and detection monitoring developed by the Department of Water and Sanitation, and the General Limits of the of the General Authorisations[4].

8.2 Methodology

It is recommended that groundwater sampling be carried out in accordance with the Water Research Commission's Comprehensive Guide for Groundwater Sampling, as presented by Weaver and Cavé of Groundwater Sciences, CSIR (WRC Report No TT 303/07), and JG Afrika's standard operating procedures for environmental monitoring and field work.

For boreholes that are already in operation, samples can be collected from the existing borehole pump outlets (preferably at a reservoir or tap outlet at the wellhead). No purging will be required due to ongoing operation of the boreholes, however, sample taps need to be sanitized and flushed prior to sample collection.

Un equipped boreholes will be purged using a submersible pump where appropriate. Purging of at least three well volumes is required. Groundwater samples will be collected from the discharge of the portable submersible pump and placed directly in sample bottles supplied by the laboratory. At the time of sampling, field measurements of pH, EC and temperature should be recorded on the sampling log. Sample bottles will be labelled and cooled in an insulated cool box on site. All samples will be dispatched to the laboratory within the laboratory's required sample holding times for the designated analysis. All sampling and monitoring equipment will be rinsed and decontaminated between each sampling point.

Water samples will be analysed by an SANAS accredited laboratory. The results of water level monitoring, purging details, and sampling and analysis are to be presented in a factual report. The results of analysis are to be compared to appropriate screening guideline values to give a comparative indication of chemistry trends and possible contamination. Any negative findings will be highlighted and recommendations made for future sampling and possible remedial measures.

[4] The Department of Water and Environmental Affairs, 6 September 2013. Government Notice No. 665. Revision of the General Authorisations in Terms of Section 39 of the National Water Act, 1998 (Act No. 36 of 1998)

8.3 Analysis Suite

The current groundwater analysis suite being applied at the Cement Plant Site is summarised in Table 17, with the inclusion of additional recommended analysis.

Table 17: Analysis Suites

Frequency	Analytical List	Objective
Bi-annually	pH, EC, Ca, Mg, Na, K, Total Alkalinity, F, Cl, NH4(N), NO3(N), PO4, SO4, Al, Fe, Mn	Water quality and impacts
	SANS214:2015 – Raw Water	Domestic consumption
Annually	Ba, As, Co, Cr, Ni, Pb, Se, Sr, V, Zn, Mn, Cu, Ga, Ge, Rb, Y, Zr, Sn, W, Bi, Th, U, Hg	Water quality and impacts

8.4 Sample Locations

The existing and proposed groundwater monitoring locations are presented in Figure 32. It is noted that existing monitoring boreholes P1 or P3 and P2 need to be reinstated as they are flagged as demolished or dry. Additional monitoring boreholes may include NBH1 and NBH2 to augment the data set. These borehole target the stockpile and PCD area and the regional structure north of the site.

Figure 32: Cement Plant Groundwater Monitoring Network

8.5 Revised Sampling Plan

The revised sampling plan is summarised in Table 18.

Table 18: Revised Sampling Plan

Frequency	Sample Locations	Analytical List	Comments
Bi-annually	P1 or P3	pH, EC, Ca, Mg, Na, K, Total Alkalinity, F, Cl, NH4(N), NO3(N), PO4, SO4, Al, Fe, Mn SANS241 Raw Water	Reinstate borehole
	P2		Reinstate borehole
	LBH1		Ongoing, include monthly water levels and meter readings
	LBH2		
	LBH3		
	NBH1		Proposed
	NBH2		Proposed
Annually	P1 or P3	Ba, As, Co, Cr, Ni, Pb, Se, Sr, V, Zn, Mn, Cu, Ga, Ge, Rb, Y, Zr, Sn, W, Bi, Th, U, Hg	Reinstate borehole
	P2		Reinstate borehole
	LBH1		Ongoing
	LBH2		Ongoing
	LBH3		Ongoing
	NBH1		Proposed
	NBH2		Proposed

9 CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of a detailed geohydrological assessment carried out for Cement Plant site located in Lichtenburg in the North West Province. The geohydrological report has been prepared as a specialist study in support of the water use authorisation for the following water uses as per Section 21 of the National Water Act (Act No. 36 of 1998).

Section 21 (a) - taking water from a water resource
Section 21 (g) - disposing of waste in a manner which may detrimentally impact on a water resource
Section 21 (h) - disposing in any manner of water which contains waste from, or which has been heated in, any industrial or power generation process removing.

The aim of the assessment was to determine the sustainable yield of the current supply boreholes designated LBH1, LBH2 and LBH3, conduct a hydrocensus to establish potential receptors, and to develop a numerical groundwater flow and mass transport model, to determine risk and impact.

The project area is underlain by a karst aquifer type and the aquifer class unit in terms of the South African Aquifer Classification System is characterised as *Minor* beneath the plant site, and *Major* 1 km to the north of the plant. A groundwater model was developed for the study area and calibrated making use of data obtained from the NGA as well as from local hydrocensus information. The model was calibrated making use of water levels considered to be representative of static water levels, which represents the natural steady state of the system.

Potential pollution sources identified according to sections 21 (a), (g) and (h) of the National Water Act (Act No. 36 of 1998) were introduced into the model for the purpose of mass transport modelling over time steps of 25, 50, 75 and 100 years. The model outputs were to simulate groundwater influx associated with the quarry pit, and determine mass transport travel distances for the individual model layers over the model time steps in 25 year increments.

The sustainable yield of the supply boreholes were determined as 78840, 665395 and 539105 m^3/a for LBH1, LBH2 and LBH3 respectively through yield testing of the boreholes. The model results indicate the groundwater flux in the pit to be in a state of equilibrium with inflows being offset by evaporation. The resulting simulations indicate the evaporation component acts as a “pump” from the pits, thus reducing the zone of impact for mass transport.

The risk and impact of the water uses was reviewed by means of a quantitative environmental risk assessment (ERA) as developed for by the Operational Guideline: Integrated Water and Waste Management Plan. The aquifer vulnerability is considered medium to high, and the Parsons Groundwater Quality Management System gives the site a Medium Level of Protection index for the second variable vulnerability. The quantitative environmental risk assessment identified most listed activities to score LOW to MODERATE with the PCD and stockpile scoring HIGH. All activity scores can be significantly reduced with the application of appropriate mitigation measures, by focusing on the probability and Magnitude factor.

The mass transport results show a northerly plume migration as a result of the abstraction taking place north of the plant. Model calibration is non-unique due to the many degrees of freedom that exist in the unknown parameters and/or uncertainty in measured results. To improve the model confidence, more data would be required to refine the current model. In particular, monitoring points around the pit would enhance the model output for determining groundwater flux in this area. Additional monitoring boreholes were proposed adjacent to and downslope of the stockpile and PCD, around the pit and along the structural feature.

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Annexure A: Declaration of Specialist

DECLARATION OF THE SPECIALIST

I ROBERT SCHAPERS, as the appointed Specialist hereby declare/affirm the correctness of the information provided or to be provided as part of the application, and that:

- In terms of the general requirement to be independent:
  - other than fair remuneration for work performed in terms of this application, have no business, financial, personal or other interest in the development proposal or application and that there are no circumstances that may compromise my objectivity; or
  - ~~am not independent, but another specialist (the "Review Specialist") that meets the general requirements set out in Regulation 13 of the NEMA EIA Regulations has been appointed to review my work (Note: a declaration by the review specialist must be submitted);~~
- I have disclosed to ~~the applicant~~, the EAP, ~~the Review EAP (if applicable), the Department and I&APs~~ all material information that has or may have the potential to influence the decision of the Department or the objectivity of any Report, plan or document prepared or to be prepared as part of the application; and
- I am aware that a false declaration is an offence in terms of Regulation 48 of the EIA Regulations.

12 Sep 2022

Signature of the Specialist: Date:

JG AFRIKA (PTY) LTD

Name of company (if applicable):

Annexure B: Yield Test Results and Analysis

LBH1

Pumping Test Data

Project Name	Lafarge Lichtenburg Geohydrological Assessment			JG AFRIKA / LAFARGE	
BOREHOLE NUMBER	LBH1			Project Reference	5803
				Contractor	Ganu
Co-Ordinates South	-26.118356°	Final Depth	27	Operator	Admire
Co-Ordinates East	26.167734°	Borehole Diameter	120	Supervision	MN
Start Date	26-Aug-22	Static Water Level	15.94	Test Pump Type	Existing BP90
End Date	27-Aug-22	Available DD	6.06	Test Pump Depth	22

Step Testing						Constant Discharge Testing								
Date	26-Aug		Start Time	12:30		Date	26-Aug	Start Time	17:00	Water Level at Start		15.94	Observation Borehole	
Steps			Step Recovery			Contstant Discharge				Constant Recovery			ID	
Step Number	Minutes	Draw down (S)	hh:mm:ss	Minutes	Draw down (S')	hh:mm:ss	Minutes	Draw down (S)	Rate	hh:mm:ss	Minutes	Draw down (S')	Draw down (S)	Draw down (S')
Step 1	1	0.43	0:01:00	1	5.64	0:01:00	1	0.66		0:01:00	1	1.11		
	2	0.61	0:02:00	2	5.21	0:02:00	2	0.75		0:02:00	2	0.75		
	3	0.70	0:03:00	3	4.01	0:03:00	3	0.89		0:03:00	3	0.53		
	5	0.93	0:05:00	5	2.15	0:05:00	5	0.95	3.040	0:05:00	5	0.40		
	7	1.05	0:07:00	7	1.54	0:07:00	7	1.00		0:07:00	7	0.29		
Average	10	1.08	0:10:00	10	1.00	0:10:00	10	1.04		0:10:00	10	0.10		
Rate	15	1.10	0:15:00	15	0.68	0:15:00	15	1.06		0:15:00	15	0.04		
2.100	20	1.15	0:20:00	20	0.30	0:20:00	20	1.09		0:20:00	20	0.00		
	30	1.17	0:30:00	30	0.12	0:30:00	30	1.12		0:30:00	30			
	40	1.19	0:40:00	40	0.00	0:40:00	40	1.13		0:40:00	40			
	50	1.21	0:00:00			1:00:00	60	1.15	3.040	1:00:00	60			
	60	1.25	0:00:00			1:30:00	90	1.21		1:30:00	90			
Step 2	1	1.96	0:00:00			2:00:00	120	1.23		2:00:00	120			
	2	2.03	0:00:00			2:30:00	150	1.25		2:30:00	150			
	3	2.10	0:00:00			3:00:00	180	1.28		3:00:00	180			
	5	2.15	0:00:00			3:30:00	210	1.29		3:30:00	210			
	7	2.20	0:00:00			4:00:00	240	1.31		4:00:00	240			
Average	10	2.39	0:00:00			5:00:00	300	1.32		5:00:00	300			
Rate	15	2.51	0:00:00			6:00:00	360	1.34		6:00:00	360			
4.020	20	2.72	0:00:00			7:00:00	420	1.34		7:00:00	420			
	30	2.94	0:00:00			8:00:00	480	1.35		8:00:00	480			
	40	3.20	0:00:00			9:00:00	540	1.36	3.040	9:00:00	540			
	50	3.51	0:00:00			10:00:00	600	1.37		10:00:00	600			
	60	3.84	0:00:00			12:00:00	720	1.40		12:00:00	720			
Step 3	1	4.06	0:00:00			14:00:00	840	1.44		14:00:00	840			
	2	4.49				16:00:00	960	1.46		16:00:00	960			
	3	4.65				18:00:00	1080	1.48		18:00:00	1080			
	5	4.85				20:00:00	1200	1.51		20:00:00	1200			
	7	4.97	95% recovery level		0.30	22:00:00	1320	1.53		22:00:00	1320			
Average	10	5.10				24:00:00	1440	1.55	3.040	24:00:00	1440			
Rate	15	5.24												
7.000	20	5.49												
	30	5.71												
	40	5.95												
	50	6.05												
	60													
Step 4	1													
	2													
	3													
	5													
	7													
Average	10													
Rate	15													
11.000	20		Main Strike (mbgl)		-									
	30		Critical Depth (mbgl)		-									
	40		FC CD Rate	Graph CD Rate	Specified CD Rate									
	50						Average Rate		3.040	95% recovery level		0.08		0.00
	60		4.94	3.2	3									

YIELD ANALYSIS

FC-METHOD : Estimation of the sustainable yield of a borehole

LBH1 — Main | Deriv | Inflection point method

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes
Effective borehole radius (r_e) = (enter)	0.80	9.03	Est. r_e / From r(e) sheet
Q (l/s) from pumping test =	3.04	5.43E-03	S-late / Change r_e
s_a (available draw dow n), sigma_s = (enter)	6.0		Sigma_s from risk / Down
Annual effective recharge (mm) =		6.00	s_available w orking draw dow n(m)
t(end) and s(end) of pumping test =	1440	1.55	End time and draw dow n of test
Average maximum derivative = (enter)	0.4	0.5	Estimate of average of max deriv
Average second derivative = (enter)	1.0	0.0	Estimate of average second deriv
Derivative at radial flow period = (enter)	0.24	0.24	Read from derivative graph
	T-early[m^2/d] =	202.35	Aqui. thick (m) 20
T and S estimates from derivatives	T-late [m^2/d] =	120.17	Est. S-late = 1.10E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	2.20E-03	S-estimate could be w rong

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)

(No values of T and S are necessary)

Maximum influence of boundaries at long time

	No boundaries	1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =	6.79	7.94	9.09	12.52
Q_sust (l/s) =	2.68	2.30	2.01	1.46
	Best case	→	→	**Worst case**

Average Q_sust (l/s) = 2.06

w ith standard deviation= 0.52

(If no information exists about boundaries skip advanced solution and go to final recommendation)

Cooper-Jacob method

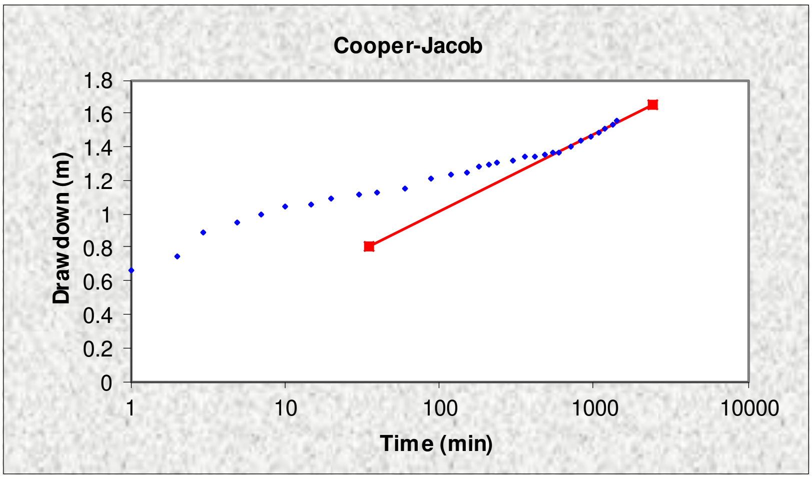
Main | Theis | Cooper-Jacob 2

LBH1

T(m^2/d) =	104.5	r_e (m)=	0.80
S =	1.63E-01	Q (l/s) =	3.04

	No boundaries	1 no-flow	2 no-flow	Closed
Q_sust	6.37	3.19	2.10	1.59
Avg. Q_sust =	3.31	std. dev =	2.15	

including influence of bh's



FC Inflection Point method for sustainable yield estimation

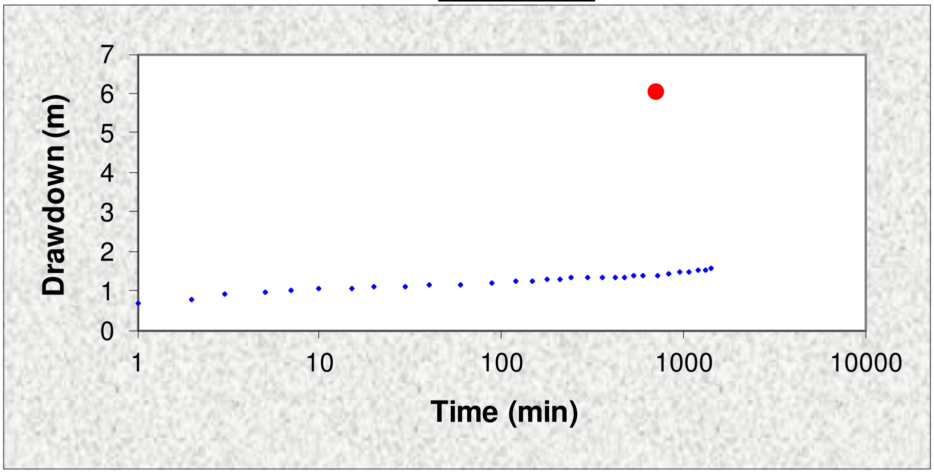
back to Sust_Q sheet | LBH1 | Main

extrapolaltion time in years =	2	1051200
t(min) and s(m) at inflection point =	721.0	6
enter derivative value at inflection point time =	←	0.41

	No boundaries	1 no-flow	2 no-flow	Closed	
sWell(Extrapol.time)	7.29	8.58	9.88	13.75	(including influence of bh's from sust_Q sheet)
Q_sust	2.50	2.12	1.85	1.33	
	Best case			Worst case	

Average Q-sust (l/s)= 1.90 std. dev = 0.49

721.00



Barker- Method

Main | LBH1

r =	0.80	Extpol. t (y)	2	avail. draw	6.00

Manual Fit — NO

K_f [m/d]	S_f [1/m]	b	n
100	1.60E-04	0.2	2

Automatic Fit with SOLVER — YES

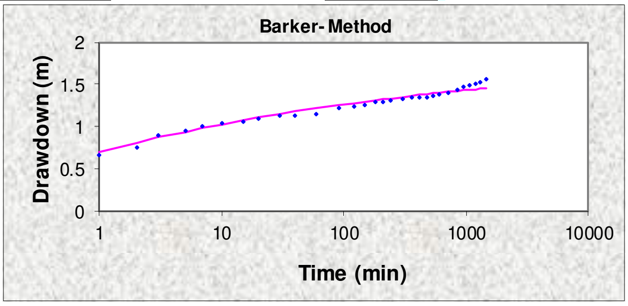
	Min	Value	Max		
K_f [m/d] =	1	11.894908	100000		
S_f [1/m] =	1.00E-07	1.33E-03	0.005	Min, Max time to fit (min)	
b =	0.1	11.072933	100	min	max
n =	1	2.2946853	3	0	10000

	K_f [m/d]	S_f [1/m]	b	n	N
Fit Parameters	11.89	1.33E-03	11.07	2.29	-0.1473

RMSE = 0.051577

	No boundaries	1 no-flow	2 no-flow	Closed	
sWell(Extrapol.time)	1.70	3.99	5.13	6.28	(including influence of bh's from sust_Q sheet)
Q_sust	10.76	4.58	3.55	2.91	

Fractal n = 2.29 **Average Q-sust (l/s)=** 5.45 std. dev = 3.61



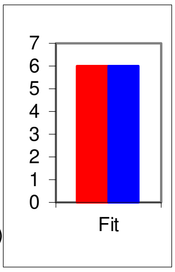
FC - Non Linear Method to estimate Q_Sust

Fit stepdraw down data first: Manual - use buttons OR : Auto - solver

Top	$s(t)=AQ+BQ^{e}(\log(t))^{G}+CQ^{p}\log(t)$				
skin effect	Non-Darcian loss		Darcian loss		
A	C	p	B	n	e
5.88E-03	1.20E-06	2	7.00E-04	1	1.03
4.10E-03	2.78E-06	2.00	1.43E-03	0.00	1.00

Extrapolation	
Ext_pol time (min)	
1051200	
Q (L/s)	Drawdown (m)
2.52	5.94

Fit graph → comment

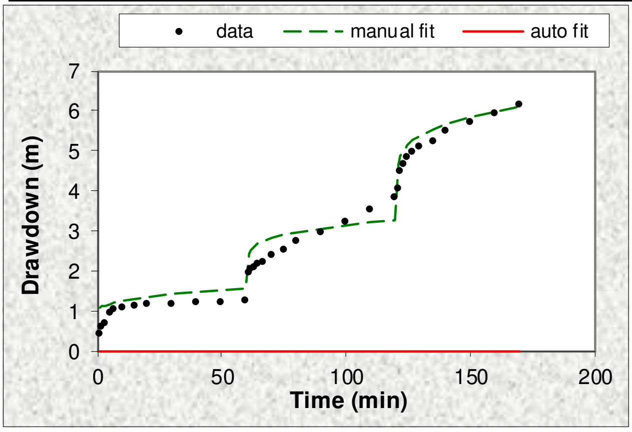


☑ Manual param ☐ Auto fit param

(Choose w hich parameter set to use for Q_sust)

Available drawdown (m) =	6		
No boundaries	1 no-flow	2 no-flow	Closed
2.5	1.3	0.8	0.4

Q_Sust (L/s)= **1.03** std.dev = 0.91



LBH1						
Method	**Sustainable yield (l/s)**	**Std. Dev**	**Early T (m^2/d)**	**Late T (m^2/d)**	**S**	**AD used**
Basic FC	2.06	0.52	202	120.2	2.20E-03	6.0
Advanced FC			202	120.2	1.00E-03	6.0
FC inflection point	1.90	0.49				6.0
Cooper-Jacob	3.31	2.15		104.5	1.63E-01	6.0
FC Non-Linear	1.03	0.91	20.0		1.00E-03	6.0
Barker	5.45	3.61	K_f = 12	S_s =	1.60E-04	6.0
Average Q_sust (l/s)	**2.08**	**0.94**	b = 11.07	Fractal dimension n =	2.29	

Recommended abstraction rate (L/s)	**2.50**	for 24 hours per day
Hours per day of pumping	12	3.54 L/s for 12 hours per day
Daily volume on recommended cycle	152.76	m3/d
Persons Served (Basic Human Needs)	6111	

LBH2

Pumping Test Data

Project Name		**Lafarge Lichtenburg Geohydrological Assessment**		JG AFRIKA EXPERIENCE QUALITY INTEGRITY / LAFARGE	
BOREHOLE NUMBER		**LBH2**		**Project Reference**	5803
				Contractor	Ganu
Co-Ordinates	**South**	-26.117704°	**Final Depth** 27	**Operator**	Admire
	East	26.167383°	**Borehole Diameter** 120	**Supervision**	MN
Start Date		22-Aug-22	**Static Water Level** 16.27	**Test Pump Type**	BP90
End Date		23-Aug-22	**Available DD** 7.73	**Test Pump Depth**	24

Step Testing						**Constant Discharge Testing**								
Date	**22-Aug**		**Start Time**	**12:00**		**Date**	**22-Aug**	**Start Time**	**19:00**	**Water Level at Start**		**-**	**Observation Borehole**	
Steps			**Step Recovery**			**Contstant Discharge**				**Constant Recovery**			**ID**	
Step Number	Minutes	Draw dow n (S)	hh:mm:ss	Minutes	Draw dow n (S')	hh:mm:ss	Minutes	Draw dow n (S)	Rate	hh:mm:ss	Minutes	Draw dow n (S')	Draw dow n (S)	Draw dow n (S')
Step 1	1	0.09	0:01:00	1	1.03	0:01:00	1	0.22		0:01:00	1	0.64		
	2	0.10	0:02:00	2	0.00	0:02:00	2	0.23		0:02:00	2	0.00		
	3	0.11	0:03:00	3		0:03:00	3	0.26		0:03:00	3			
	5	0.11	0:04:00	4		0:05:00	5	0.30		0:05:00	5			
	7	0.10	0:05:00	5		0:07:00	7	0.41		0:07:00	7			
Average	10	0.10	0:07:00	7		0:10:00	10	0.45		0:10:00	10			
Rate	15	0.10	0:10:00	10		0:15:00	15	0.72		0:15:00	15			
4.020	20	0.10	0:15:00	15		0:20:00	20	0.86		0:20:00	20			
	30	0.11	0:40:00	40		0:30:00	30	0.94		0:30:00	30			
	40	0.11	0:50:00	50		0:40:00	40	1.09		0:40:00	40			
	50	0.11	1:00:00	60		1:00:00	60	1.13	22.200	1:00:00	60			
	60	0.11	1:10:00	70		1:30:00	90	1.16		1:30:00	90			
Step 2	1	0.12	1:20:00	80		2:00:00	120	1.19		2:00:00	120			
	2	0.12	1:30:00	90		2:30:00	150	1.24		2:30:00	150			
	3	0.12	1:40:00	100		3:00:00	180	1.30		3:00:00	180			
	5	0.12	1:50:00	110		3:30:00	210	1.39		3:30:00	210			
	7	0.13	2:00:00	120		4:00:00	240	1.44		4:00:00	240			
Average	10	0.15	2:30:00	150		5:00:00	300	1.48		5:00:00	300			
Rate	15	0.15	3:00:00	180		6:00:00	360	1.52		6:00:00	360			
10.030	20	0.15	3:30:00	210		7:00:00	420	1.61		7:00:00	420			
	30	0.15	4:00:00	240		8:00:00	480	1.63		8:00:00	480			
	40	0.16	4:30:00	270		9:00:00	540	1.67		9:00:00	540			
	50	0.16	5:00:00	300		10:00:00	600	1.70	22.200	10:00:00	600			
	60	0.16	5:30:00	330		12:00:00	720	1.73		12:00:00	720			
Step 3	1	0.20	6:00:00	360		14:00:00	840	1.76		14:00:00	840			
	2	0.21				16:00:00	960	1.78		16:00:00	960			
	3	0.22				18:00:00	1080	1.80		18:00:00	1080			
	5	0.22				20:00:00	1200	1.80		20:00:00	1200			
	7	0.22	**95% recovery level**		**0.18**	22:00:00	1320	1.82		22:00:00	1320			
Average	10	0.23				24:00:00	1440	1.84	22.200	24:00:00	1440			
Rate	15	0.23				0:00:00								
20.040	20	0.23				0:00:00								
	30	0.24				0:00:00								
	40	0.25												
	50	0.25												
	60	0.25												
Step 4	1	1.01												
	2	1.15												
	3	1.25												
	5	1.46												
	7	1.74												
Average	10	2.01												
Rate	15	2.35												
26.010	20	2.56	**Main Strike (mbgl)**		**-**									
	30	3.01	**Critical Depth (mbgl)**		**-**									
	40	3.21	FC CD Rate	Graph CD Rate	Specified CD Rate									
	50	3.42					**Average Rate**		**22.200**	**95% recovery level**		**0.09**		**0.00**
	60	3.64	35	23	22.2									

YIELD ANALYSIS

FC-METHOD : Estimation of the sustainable yield of a borehole

LBH2 — Main | Deriv | Inflection point method

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes
Effective borehole radius (r_e) = (enter)	8.00	52.82	Est. r_e / From r(e) sheet
Q (l/s) from pumping test =	22.2	1.02E-02	S-late / Change r_e
s_a (available draw dow n), sigma_s = (enter)	7.7		Sigma_s from risk / Down
Annual effective recharge (mm) =		7.70	s_available w orking draw dow n(m)
t(end) and s(end) of pumping test =	1440	1.84	End time and draw dow n of test
Average maximum derivative = (enter)	0.6	0.8	Estimate of average of max deriv
Average second derivative = (enter)	1.3	0.0	Estimate of average second deriv
Derivative at radial flow period = (enter)	0.54	0.54	Read from derivative graph
	T-early[m^2/d] =	644.79	Aqui. thick (m) 20
T and S estimates from derivatives	T-late [m^2/d] =	585.01	Est. S-late = 1.10E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	2.20E-03	S-estimate could be w rong

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)

(No values of T and S are necessary)

	No boundaries	1 no-flow	2 no-flow	Closed no-flow
		Maximum influence of boundaries at long time		
sWell (Extrapol.time) =	8.89	10.61	12.32	17.48
Q_sust (l/s) =	19.23	16.12	13.87	9.78
	Best case	→		Worst case

Average Q_sust (l/s) = 14.32

w ith standard deviation= 3.98

(If no information exists about boundaries skip advanced solution and go to final recommendation)

Cooper-Jacob method

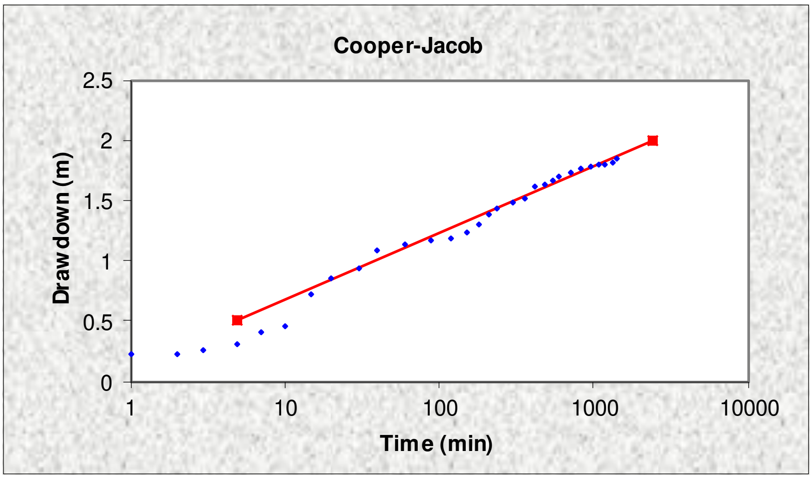
Main | Theis | Cooper-Jacob 2

LBH2

T(m^2/d) =	630.1	r_e (m)=	8.00
S =	9.75E-03	Q (l/s) =	22.2

	No boundaries	1 no-flow	2 no-flow	Closed
Q_sust	49.31	24.65	16.27	12.33
Avg. Q_sust =	25.64	std. dev =	16.59	

including influence of bh's



FC Inflection Point method for sustainable yield estimation

back to Sust_Q sheet | LBH2 | Main

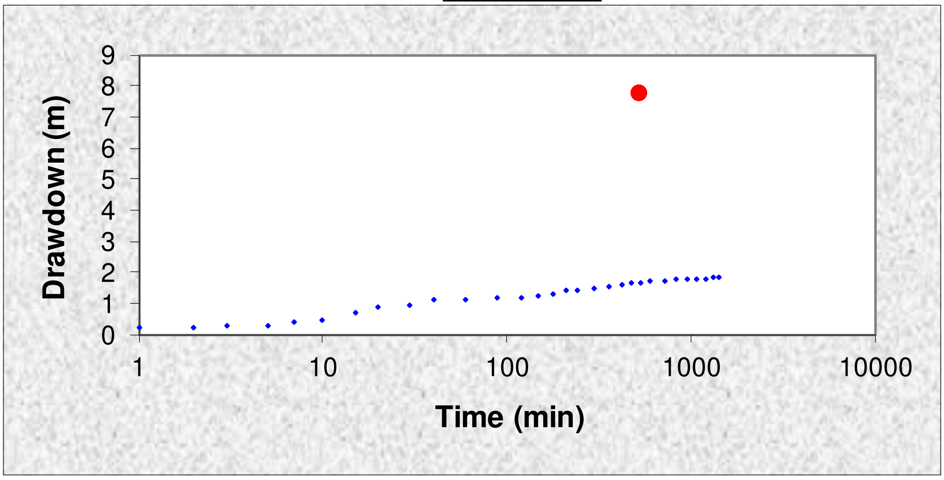
extrapolaltion time in years =	2	1051200
t(min) and s(m) at inflection point =	541.0	7.73
enter derivative value at inflection point time =		0.60

	No boundaries	1 no-flow	2 no-flow	Closed
sWell(Extrapol.time)	9.70	11.68	13.65	19.57
Q_sust	17.69	14.70	12.57	8.77
	Best case			Worst case

(including influence of bh's from sust_Q sheet)

Average Q-sust (l/s)= 13.01 std. dev = 3.75

541.00



Barker- Method | Main | LBH2

r =	8.00	Extpol. t (y)	2	avail. draw	7.70

Manual Fit — YES

K_f [m/d]	S_f [1/m]	b	n
321	2.00E-03	2.05	2.02

Automatic Fit with SOLVER — NO

	Min	Value	Max
K_f [m/d] =	1	19.978234	100000
S_f [1/m] =	1.00E-07	8.18E-04	0.005
b =	0.1	3.877428	100
n =	1	2.7601214	3

Min, Max time to fit (min)

min	max
0	10000

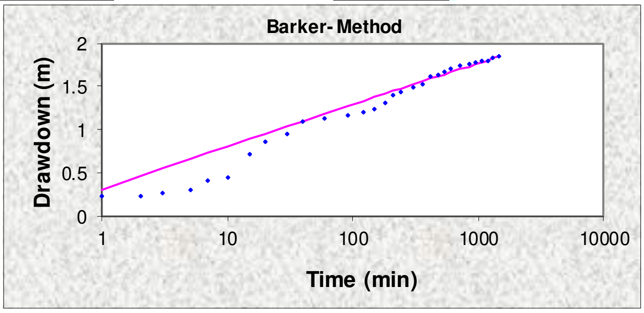
	K_f [m/d]	S_f [1/m]	b	n	N
Fit Parameters	321.00	2.00E-03	2.05	2.02	-0.0100

RMSE = 0.602327

	No boundaries	1 no-flow	2 no-flow	Closed
sWell(Extrapol.time)	3.14	6.57	8.29	10.01
Q_sust	54.48	26.00	20.62	17.08

(including influence of bh's from sust_Q sheet)

Fractal n = 2.02 **Average Q-sust (l/s)=** 29.54 std. dev = 17.02



FC - Non Linear Method to estimate Q_Sust

Top

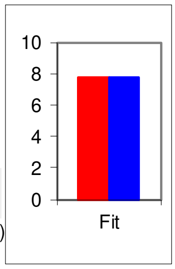
$s(t)=AQ+BQ^e(\log(t))^G+CQ^p\log(t)$

Fit stepdrawdown data first: Manual - use buttons OR : Auto - solver

comment

Extrapolation	
Ext_pol time (min)	
1051200	
Q (L/s)	Drawdown (m)
56.9	7.73

Fit graph →

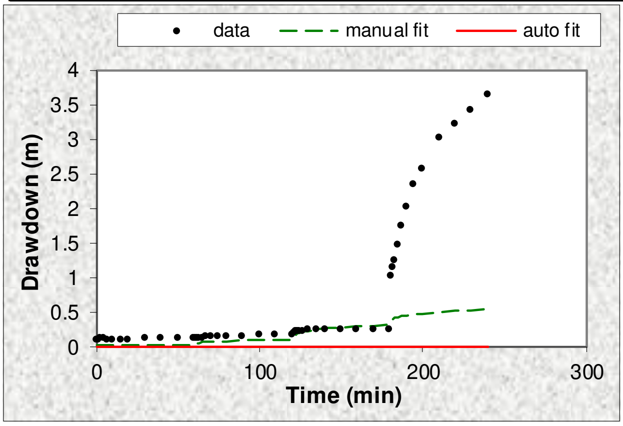


skin effect	Non-Darcian loss		Darcian loss		
A	C	p	B	n	e
8.00E-06	3.00E-08	2.02	1.00E-06	1.06	1.38
4.10E-03	2.78E-06	2.00	1.43E-03	0.00	1.00

☑ Manual param ☐ Auto fit param

(Choose which parameter set to use for Q_sust)

Available drawdown (m) =	7.7		
No boundaries	1 no-flow	2 no-flow	Closed
56.9	28.5	19.0	9.5
Q_Sust (L/s)=	23.23	std.dev = 20.49	



LBH2						
Method	**Sustainable yield (l/s)**	**Std. Dev**	**Early T (m^2/d)**	**Late T (m^2/d)**	**S**	**AD used**
Basic FC	14.32	3.98	645	585.0	2.20E-03	7.7
Advanced FC			645	585.0	1.00E-03	7.7
FC inflection point	13.01	3.75				7.7
Cooper-Jacob	25.64	16.59		630.1	9.75E-03	7.7
FC Non-Linear	23.23	20.49	1000.0		1.00E-01	7.7
Barker	29.54	17.02	K_f = 321		S_s = 2.00E-03	7.7
Average Q_sust (l/s)	**21.06**	**5.96**	b = 2.05	Fractal dimension n =	2.02	

Recommended abstraction rate (L/s)	**21.10**	for 24 hours per day
Hours per day of pumping	12	29.85 L/s for 12 hours per day
Daily volume on recommended cycle	1289.33	m3/d
Persons Served (Basic Human Needs)	51573	

LBH3

Pumping Test Data

Project Name		**Lafarge Lichtenburg Geohydrological Assessment**		JG AFRIKA EXPERIENCE QUALITY INTEGRITY / LAFARGE	
BOREHOLE NUMBER		**BH3**		**Project Reference**	5803
				Contractor	Ganu
Co-Ordinates	**South**	-26.118887°	**Final Depth**	27	**Operator**	Admire
	East	26.184489°	**Borehole Diameter**	120	**Supervision**	MN
Start Date		19-Aug-22	**Static Water Level**	19.59	**Test Pump Type**	BP90
End Date		20-Aug-22	**Available DD**	4.41	**Test Pump Depth**	24

Step Testing						**Constant Discharge Testing**								
Date	-		**Start Time**	-		**Date**	**19-Aug**	**Start Time**	**09:00**	**Water Level at Start**		**19.59**	**Observation Borehole**	
Steps			**Step Recovery**			**Contstant Discharge**				**Constant Recovery**			**ID**	
Step Number	Minutes	Draw down (S)	hh:mm:ss	Minutes	Draw down (S')	hh:mm:ss	Minutes	Draw down (S)	Rate	hh:mm:ss	Minutes	Draw down (S')	Draw down (S)	Draw down (S')
Step 1	1		0:01:00	1		0:01:00	1	0.14		0:01:00	1	2.31		
	2		0:02:00	2		0:02:00	2	0.19		0:02:00	2	1.21		
	3		0:03:00	3		0:03:00	3	0.23		0:03:00	3	0.56		
	5		0:04:00	4		0:05:00	5	0.69		0:05:00	5	0.32		
	7		0:05:00	5		0:07:00	7	1.01	20.000	0:07:00	7	0.10		
Average	10		0:07:00	7		0:10:00	10	1.50		0:10:00	10	0.00		
Rate	15		0:10:00	10		0:15:00	15	1.50		0:15:00	15			
0.860	20		0:15:00	15		0:20:00	20	2.48		0:20:00	20			
	30		0:40:00	40		0:30:00	30	2.50		0:30:00	30			
	40		0:50:00	50		0:40:00	40	2.53		0:40:00	40			
	50		1:00:00	60		1:00:00	60	2.54		1:00:00	60			
	60		1:10:00	70		1:30:00	90	2.54		1:30:00	90			
Step 2	1		1:20:00	80		2:00:00	120	2.56		2:00:00	120			
	2		1:30:00	90		2:30:00	150	2.56		2:30:00	150			
	3		1:40:00	100		3:00:00	180	2.56		3:00:00	180			
	5		1:50:00	110		3:30:00	210	2.56		3:30:00	210			
	7		2:00:00	120		4:00:00	240	2.56		4:00:00	240			
Average	10		2:30:00	150		5:00:00	300	2.56		5:00:00	300			
Rate	15		3:00:00	180		6:00:00	360	2.56		6:00:00	360			
2.080	20		3:30:00	210		7:00:00	420	2.56		7:00:00	420			
	30		4:00:00	240		8:00:00	480	2.57	20.000	8:00:00	480			
	40		4:30:00	270		9:00:00	540	2.57		9:00:00	540			
	50		5:00:00	300		10:00:00	600	2.57		10:00:00	600			
	60		5:30:00	330		12:00:00	720	2.57		12:00:00	720			
Step 3	1		6:00:00	360		14:00:00	840	2.57		14:00:00	840			
	2					16:00:00	960	2.58		16:00:00	960			
	3					18:00:00	1080	2.58		18:00:00	1080			
	5					20:00:00	1200	2.58		20:00:00	1200			
	7		**95% recovery level**		**0.00**	22:00:00	1320	2.58		22:00:00	1320			
Average	10					24:00:00	1440	2.58	20.000	24:00:00	1440			
Rate	15													
3.520	20													
	30													
	40													
	50													
	60													
Step 4	1													
	2													
	3													
	5													
	7													
Average	10													
Rate	15													
5.510	20		**Main Strike (mbgl)**		-									
	30		**Critical Depth (mbgl)**		-									
	40		FC CD Rate	Graph CD Rate	Specified CD Rate									
	50						**Average Rate**		**20.000**	**95% recovery level**		**0.13**		**0.00**
	60		-	-	-									

YIELD ANALYSIS

FC-METHOD : Estimation of the sustainable yield of a borehole

LBH3 — Main | Deriv | Inflection point method

Extrapolation time in years = (enter)	2	1051200	Extrapol.time in minutes
Effective borehole radius (r_e) = (enter)	8.00 ←	13.81	← Est. r_e / From r(e) sheet
Q (l/s) from pumping test =	20	7.67E-03	← S-late ← Change r_e
s_a (available draw dow n), sigma_s = (enter)	4.4		← Sigma_s from risk / Down
Annual effective recharge (mm) =	0	4.41	s_available w orking draw dow n(m)
t(end) and s(end) of pumping test =	1440	2.58	End time and draw dow n of test
Average maximum derivative = (enter)	0.3 ←	0.0	Estimate of average of max deriv
Average second derivative = (enter)	0.0 ←	-0.2	Estimate of average second deriv
Derivative at radial flow period = (enter)	0.06 ←	#NUM!	Read from derivative graph
	T-early[m^2/d] =	5270.40	Aqui. thick (m) 20
T and S estimates from derivatives	T-late [m^2/d] =	1054.08	Est. S-late = 1.10E-03
(To obtain correct S-value, use program RPTSOLV)	S-late =	2.20E-03	S-estimate could be w rong

BASIC SOLUTION

(Using derivatives + subjective information about boundaries)

(No values of T and S are necessary)

Maximum influence of boundaries at long time

	No boundaries	1 no-flow	2 no-flow	Closed no-flow
sWell (Extrapol.time) =	3.44	4.30	5.16	7.73
Q_sust (l/s) =	25.65	20.52	17.10	11.40
	Best case	→	→	Worst case

Average Q_sust (l/s) = 17.90

w ith standard deviation= 5.98

(If no information exists about boundaries skip advanced solution and go to final recommendation)

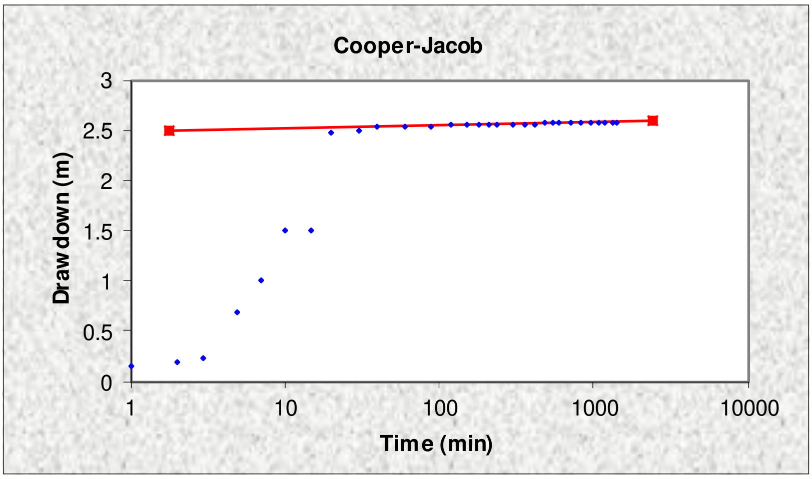
Cooper-Jacob method

Main | Theis | Cooper-Jacob 2

LBH3

T(m^2/d) =	9936.0	r_e (m)=	8.00 →
S =	1.36E-79	Q (l/s) =	20

	No boundaries	1 no-flow	2 no-flow	Closed	
Q_sust	32.86	16.43	10.85	8.22	including influence of bh's
Avg. Q_sust =	17.09	std. dev =	11.06		



FC Inflection Point method for sustainable yield estimation

back to Sust_Q sheet | **LBH3** | Main

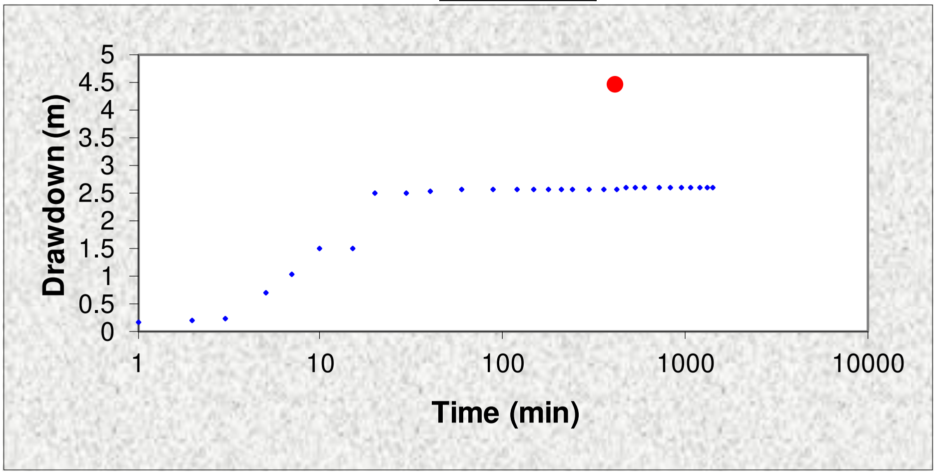
extrapolaltion time in years =	2	1051200
t(min) and s(m) at inflection point =	421.0	4.41
enter derivative value at inflection point time =	←	0.04

	No boundaries	1 no-flow	2 no-flow	Closed
sWell(Extrapol.time)	4.55	4.70	4.84	5.28
Q_sust	19.37	18.77	18.21	16.72
	Best case			Worst case

(including influence of bh's from sust_Q sheet)

Average Q-sust (l/s)= 18.24 std. dev = 1.14

421.00



Barker- Method

Main | **LBH3**

r =	8.00	Extpol. t (y)	2	avail. draw	4.41

Manual Fit — YES

K_f [m/d]	S_f [1/m]	b	n
251	2.00E-07	0.22	2.37

Automatic Fit with SOLVER — NO

	Min	Value	Max		
K_f [m/d] =	1	100	100000		
S_f [1/m] =	1.00E-07	1.00E-05	0.005	Min, Max time to fit (min)	
b =	0.1	0.2	100	min	max
n =	1	2	3	0	10000

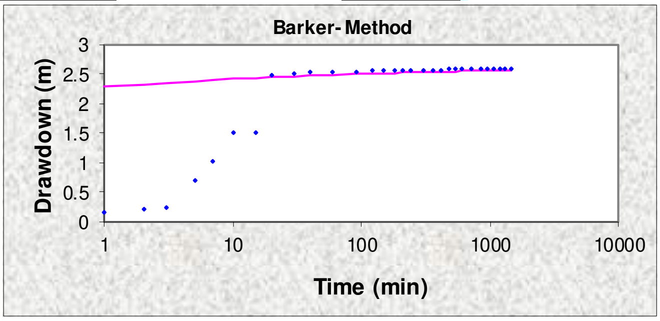
	K_f [m/d]	S_f [1/m]	b	n	N
Fit Parameters	251.00	2.00E-07	0.22	2.37	-0.1850

RMSE = 20.05481

	No boundaries	1 no-flow	2 no-flow	Closed
sWell(Extrapol.time)	2.63	4.35	5.21	6.07
Q_sust	33.54	20.29	16.94	14.54

(including influence of bh's from sust_Q sheet)

Fractal n = 2.37 **Average Q-sust (l/s)=** 21.33 std. dev = 8.48



LBH3						
Method	**Sustainable yield (l/s)**	**Std. Dev**	**Early T (m^2/d)**	**Late T (m^2/d)**	**S**	**AD used**
Basic FC	17.90	5.98	5270	1054.1	2.20E-03	4.4
Advanced FC			5270	1054.1	1.00E-03	4.4
FC inflection point	18.24	1.14				4.4
Cooper-Jacob	17.09	11.06		9936.0	1.36E-79	4.4
FC Non-Linear						4.4
Barker	21.33	8.48	K_f = 251	S_s =	2.00E-07	4.4
Average Q_sust (l/s)	**17.74**	**0.59**	b = 0.22	Fractal dimension n =	2.37	

Recommended abstraction rate (L/s)	17.10	for 24 hours per day
Hours per day of pumping	12	24.19 L/s for 12 hours per day
Daily volume on recommended cycle	1044.90	m3/d
Persons Served (Basic Human Needs)	41796	

Annexure C: Laboratory Certificate of Analysis

TALBOT
A Level 1 B-BBEE company

sanas

[007553/22], [2022/09/16]

Certificate of Analysis

Project details

Customer Details

Customer reference:	LAFARGE LICHTENBURG (5803)
Quotation number:	Q2112-066
Order number:	5803
Company name:	JG AFRIKA
Contact address:	P O BOX 2762, WESTWAY OFFICE PARK, 3635
Contact person:	MFUNDO NTUZELA

Sampling Details

Sampled by:	CUSTOMER
Sampled date:	2022/08/27
Additional customer information:	023361/22- SAMPLED BY: M NTUZELA, 023362/22- SAMPLED BY: M NTUZELA, 023363/22- SAMPLED BY: M NTUZELA, 023364/22- SAMPLED BY: M NTUZELA

Sample Details

Sample type(s):	RAW WATER SAMPLES
Date received:	2022/09/02
Delivered by:	CUSTOMER - GILLITTS DEPOT
Temperature at sample receipt (°C):	14.9

Report Details

Testing commenced:	2022/09/02
Testing completed:	2022/09/16
Report date:	2022/09/16
Our reference:	007553/22

Analytical Results

Methods	Determinands	Units	023361/22	023362/22
			LICH 0111 27.08.2022	LICH 0112 27.08.2022
Chemical				
93	Sodium	mg Na/ℓ	5.1	4.9
83A	Aluminium	µg Al/ℓ	<1	2.4
83A	Arsenic	µg As/ℓ	<1	<1
83A	Boron	µg B/ℓ	24	33
83A	Barium	µg Ba/ℓ	7.4	7.3
83A	Cadmium	µg Cd/ℓ	<1	<1
83A	Copper	µg Cu/ℓ	3.6	2.4
83A	Iron	µg Fe/ℓ	<1	<1
92	Mercury	µg Hg/ℓ	<10	<10
83A	Manganese	µg Mn/ℓ	<1	<1
83A	Nickel	µg Ni/ℓ	<1	<1
83A	Lead	µg Pb/ℓ	<1	<1
83A	Antimony	µg Sb/ℓ	<1	<1
83A	Selenium	µg Se/ℓ	<1	<1
83A	Uranium	µg U/ℓ	<1	<1
83A	Zinc	µg Zn/ℓ	5.3	2.3
83A	Total Chromium	µg Cr/ℓ	9.7	15.6
16G	Chloride	mg Cl/ℓ	7.75	7.91
135	Cyanide*	µg CN/ℓ	<20	<20
40A	Colour (True)	mg Pt-Co/ℓ	<10	<10
2A	Electrical Conductivity at 25°C	mS/m	69.8	65.2
18G	Fluoride	mg F/ℓ	0.12	0.12
64G	Total Ammonia	mg N/ℓ	<1.5	<1.5
65Gc	Nitrate	mg N/ℓ	4.14	4.1
65Gb	Nitrite	mg N/ℓ	<0.05	<0.05
Calc.	Combined Nitrate + Nitrite (sum of Ratios)*	-	0.43	0.43
4	Turbidity	NTU	0.45	0.11
1	pH at 25°C	pH units	7.3	7.1
133	Total Phenols*	µg/ℓ	2	<2
67G	Sulphate	mg SO_4/ℓ	33.6	33.6
41	Total Dissolved Solids at 180°C	mg/ℓ	360	390
Microbiological				
32	*E.coli*	MPN/100mℓ	<1 (Not detected)	<1 (Not detected)
32	Total Coliforms	MPN/100mℓ	<1 (Not detected)	<1 (Not detected)
31	Standard Plate Count	colonies/mℓ	**>1000**	109

Methods	Determinands	Units	023361/22	023362/22
			LICH 0111 27.08.2022	LICH 0112 27.08.2022
Organics				
104	Total Organic Carbon	mg C/ℓ	3.0	4.8

Methods	Determinands	Units	023363/22	023364/22
			LICH 0113 27.08.2022	LICH 0114 27.08.2022
Chemical				
93	Sodium	mg Na/ℓ	5.2	17
83A	Aluminium	µg Al/ℓ	18.9	1.4
83A	Arsenic	µg As/ℓ	<1	<1
83A	Boron	µg B/ℓ	31	40
83A	Barium	µg Ba/ℓ	11.1	66
83A	Cadmium	µg Cd/ℓ	<1	<1
83A	Copper	µg Cu/ℓ	<1	5.1
83A	Iron	µg Fe/ℓ	11.6	1.1
92	Mercury	µg Hg/ℓ	<10	<10
83A	Manganese	µg Mn/ℓ	2.9	<1
83A	Nickel	µg Ni/ℓ	1.0	<1
83A	Lead	µg Pb/ℓ	<1	<1
83A	Antimony	µg Sb/ℓ	<1	<1
83A	Selenium	µg Se/ℓ	<1	<1
83A	Uranium	µg U/ℓ	<1	<1
83A	Zinc	µg Zn/ℓ	13.4	25
83A	Total Chromium	µg Cr/ℓ	13.8	7.4
16G	Chloride	mg Cl/ℓ	8.28	13.4
135	Cyanide*	µg CN/ℓ	<20	<20
40A	Colour (True)	mg Pt-Co/ℓ	<10	<10
2A	Electrical Conductivity at 25°C	mS/m	72.4	61.8
18G	Fluoride	mg F/ℓ	0.12	0.32
64G	Total Ammonia	mg N/ℓ	<1.5	<1.5
65Gc	Nitrate	mg N/ℓ	4.62	1.51
65Gb	Nitrite	mg N/ℓ	<0.05	<0.05
Calc.	Combined Nitrate + Nitrite (sum of Ratios)*	-	0.48	0.19
4	Turbidity	NTU	0.80	0.44
1	pH at 25°C	pH units	7.1	7.1
133	Total Phenols*	µg/ℓ	7	<2
67G	Sulphate	mg SO_4/ℓ	36.9	12.6
41	Total Dissolved Solids at 180°C	mg/ℓ	468	382
Microbiological				
32	*E.coli*	MPN/100mℓ	<1 (Not detected)	<1 (Not detected)

Methods	Determinands	Units	023363/22	023364/22
			LICH 0113 27.08.2022	LICH 0114 27.08.2022
32	Total Coliforms	MPN/100mℓ	**613**	<1 (Not detected)
31	Standard Plate Count	colonies/mℓ	**>1000**	300
Organics				
104	Total Organic Carbon	mg C/ℓ	0.82	3.9

Refer to the "Notes" section at the end of this report for further explanations.

Where the laboratory reporting limit for a test is higher than the required specification limit, the raw data is reviewed and the detection limit highlighted in bold font if outside of specification.

Specific Observations

1. The parameters tested on the samples submitted (lab numbers 023362/22 & 023364/22) conform to the SANS 241:2015 requirements for drinking water.

2. The parameters tested on the sample submitted (lab number 023361/22) conform to the SANS 241:2015 requirements for drinking water, with the exception of standard plate count.

- A standard plate count exceeding 1000 counts per ml indicates failure in the system and if any form of disinfection is currently being undertaken this should be investigated.

3. The parameters tested on the sample submitted (lab number 023363/22) conform to the SANS 241:2015 requirements for drinking water, with the exception of total coliforms & standard plate count.

- The presence of coliforms shows contamination from soil or vegetation which may become more serious after rain. The water is of doubtful quality and cannot be recommended for drinking unless properly disinfected.

Quality Assurance

Technical signatories

Inorganic Chemistry: Sipho Ngabhi	Microbiology: Olivia Magaya	Organic Chemistry: Lungani Ziqubu

Notes to this report

Limitations

This report shall not be reproduced except in full without prior written approval of the laboratory.
Results in this report relate only to the samples as taken, and the condition received by the laboratory.
Any opinions and interpretations expressed herein are outside the scope of SANAS accreditation.
The decision rule applicable to this laboratory is available on request.
Sample preparation may require filtration, dilution, digestion or similar. Final results are reported accordingly.
Where the laboratory has undertaken the sampling, the location of sampling and sampling plan are available on request. Talbot Laboratories is guided by the National Standards SANS 5667-3:2006 Part 3 Guidance on the Preservation and Handling of Water Samples; SANS 5667-1:2008 Part 1 Guidance on the Design of Sampling Programmes and Sampling Techniques and SANS 5667-2:1991 Part 2: Guidance on Sampling Techniques.
Customers to contact Talbot Laboratories for further information.

Uncertainty of measurement

Talbot Laboratories' Uncertainty of Measurement (UoM) values are:

- Identified for relevant tests.
- Calculated as a percentage of the respective results.
- Applicable to total, dissolved and acid soluble metals for ICP element analyses.
- Available upon request.

Analysis explanatory notes

Tests may be marked as follows:

^	Tests conducted at our Port Elizabeth satellite laboratory.
*	Tests not included in our Schedule of Accreditation and therefore that are not SANAS accredited.
#	Tests that have been sub-contracted to a peer laboratory.
NR	Not required -shown, for example, where the schedule of analysis varied between samples.
σ	Field sampling point on-site results.
a	Testing has deviated from Method.

Appendix 1: Specifications - SANS 241-1:2015 RECOMMENDED LIMITS

Reported Determinands	Limits	Reported Determinands	Limits
E.coli	0 Count/100mℓ (0 MPN/100mℓ)	Zinc	≤5000 µg/l (≤5 mg/ℓ)
Faecal Coliforms	0 Count/100mℓ (0 MPN/100mℓ)	Antimony	≤20 µg/ℓ (≤0.02 mg/ℓ)
Cryptosporidium species	Not Detected	Arsenic	≤10 µg/ℓ (≤0.01 mg/ℓ)
Giardia species	Not Detected	Barium	≤700 µg/ℓ (≤0.7 mg/ℓ)
Total Coliforms	≤10 Count/100mℓ (10 MPN/100mℓ)	Boron	≤2400 µg/ℓ (≤2.4 mg/ℓ)
Standard Plate Count	≤1000 Count/1mℓ	Cadmium	≤3 µg/ℓ (≤0.003 mg/ℓ)
Somatic Coliphages	Not Detected	Total Chromium	≤50 µg/ℓ (≤0.05 mg/ℓ)
Cytopathogenic viruses	Not detected	Copper	≤2000 µg/ℓ (≤2 mg/ℓ)
Enteric Virus (Sub#)	Not Detected	Cyanide	≤200 µg/ℓ (≤0.2 mg/ℓ)
Colour	≤15 mg/ℓ Pt-Co	Iron	Chronic: ≤ 2000 µg/ℓ (≤2 mg/ℓ)
Electrical Conductivity	≤170 mS/m	Iron	Aesthetic: ≤ 300 µg/ℓ (≤0.3 mg/ℓ)
Total Dissolved Solids at 180°C	≤1200 mg/ℓ	Lead	≤10 µg/ℓ (≤0.01 mg/ℓ)
Turbidity	Operational ≤1 NTU	Manganese	Chronic: ≤ 400 µg/ℓ (≤0.4 mg/ℓ)
Turbidity	Aesthetic ≤5 NTU	Manganese	Aesthetic: ≤100 µg/ℓ (≤0.1 mg/ℓ)
pH	≥ 5 to ≤ 9.7	Mercury	≤6 µg/ℓ (≤0.006 mg/ℓ)
Odour	Inoffensive	Nickel	≤70 µg/ℓ (≤0.07 mg/ℓ)
Free Chlorine	≤5 mg/ℓ	Selenium	≤40 µg/ℓ (≤0.04 mg/ℓ)
Monochloramine	≤3000 µg/ℓ (≤3 mg/ℓ)	Uranium	≤30 µg/ℓ (≤0.03 mg/ℓ)
Nitrate	≤11 mg/ℓ	Aluminium	≤300 µg/ℓ (≤0.3 mg/ℓ)
Nitrite	≤0.9 mg/ℓ	Total Organic Carbon	≤10 mg/ℓ
Combined Nitrate plus Nitrite (sum of Ratios)	≤1	Chloroform	≤300 µg/ℓ (≤0.3 mg/ℓ)
Sulphate	Acute: ≤ 500 mg/ℓ	Bromoform	≤100 µg/ℓ (≤0.1 mg/ℓ)
Sulphate	Aesthetic: ≤ 250 mg/ℓ	Dibromochloromethane	≤100 µg/ℓ (≤0.1 mg/ℓ)
Fluoride	≤1500 µg/ℓ (≤1.5 mg/ℓ)	Bromodichloromethane	≤60 µg/ℓ (≤0.06 mg/ℓ)
Ammonia	≤1.5 mg/ℓ	Trihalomethanes Ratio	≤1
Chloride	≤ 300 mg/ℓ	Microcystins	≤1 µg/ℓ
Sodium	≤200 mg/ℓ	Phenols	≤10 µg/ℓ (≤0.01 mg/ℓ)

End of Report

Annexure D: Summary Hydrocensus and Resource Photographs

National Groundwater Archive Resources

SORT	Key	SITE	IDENTIFIER	COUNT	LAT	LONG	COORDMETHOD	ACCURACY	STATUS1	STATUS2	PURPOSE	EQUIPMENT	WLMIN	WLMAX	ABSTRACTION	YIELD	DEPTH	STRIKEDEPTH
25	1	Cement Plant	1137	343	-26.16719	26.16632	Map Estimated	100	Unused: Abandoned		Monitoring		12.56	16.58			30	
26	2	Cement Plant	20-00076	2	-26.11028	26.17126	GPS	100	In Use: Unknown	Unused: Standby	Production							
27	3	Cement Plant	20-00077	1	-26.10808	26.17104	GPS	100	Unused: Dry - Unknown		Production							
28	4	Cement Plant	20-00078	1	-26.11578	26.16678	GPS	100	In Use: Unknown									
29	5	Cement Plant	20-00079	1	-26.11092	26.16778	GPS	100	In Use: Unknown		Production							
30	6	Cement Plant	20-00080	1	-26.11194	26.16903	GPS	100	In Use: Unknown		Production				53121			
31	7	Cement Plant	20-00081	2	-26.09968	26.16553	GPS	100	In Use: Unknown	Unused: Irreparably Destroyed	Production				338054			
32	8	Cement Plant	20-00082	2	-26.09920	26.16768	GPS	100	In Use: Unknown	Unused: Irreparably Destroyed	Production							
33	9	Cement Plant	20-00083	1	-26.09753	26.15942	GPS	100	In Use: Unknown		Production				71288			
38	10	Cement Plant	20-00091	1	-26.10022	26.16750	GPS	100	In Use: Unknown		Production							
39	11	Cement Plant	20-00093	1	-26.10086	26.16686	GPS	100	In Use: Unknown		Monitoring							
41	12	Cement Plant	20-00098	2	-26.09299	26.15575	GPS	100	Unused: Irreparably Destroyed	Unused: Standby	Production							
47	13	Cement Plant	20-00106	1	-26.09722	26.15950	GPS	100	In Use: Unknown		Monitoring							
48	14	Cement Plant	20-00107	1	-26.11889	26.18489	GPS	100	In Use: Unknown		Monitoring							
49	15	Cement Plant	20-00108	1	-26.13381	26.16367	GPS	100	In Use: Unknown		Exploration							
54	16	Cement Plant	2624DC00042	161	-26.10160	26.16661	Map Estimated	100	In Use: Unknown		Monitoring		19.12	25.99		0	30	
133	17	Cement Plant	2626AA00008	24	-26.09218	26.17049	Map Estimated	100	Unused: Monitoring		Monitoring		12.55	13.64		0	20	
134	18	Cement Plant	2626AA00009	17	-26.10052	26.16632	Map Estimated	100	Unused: Monitoring		Monitoring		12.35	16.53		0	32.35	
135	19	Cement Plant	2626AA00011	900	-26.12521	26.14907	Map Estimated	100	In Use: Unknown	Unused: Monitoring	Monitoring		0.48	33.3		0.85	35	
137	20	Cement Plant	2626AA00016	1	-26.12158	26.14688	Map Estimated	100	Status Not Selected							0		
138	21	Cement Plant	2626AA00017	136	-26.15052	26.14965	Map Estimated	100	Unused: Abandoned		Monitoring		8.3	15.9		0	30	
139	22	Cement Plant	2626AA00018	928	-26.18614	26.17767	GPS	5	In Use: Unknown	Unused: Irreparably Destroyed	Monitoring		7.72	23.33		0	24	
140	23	Cement Plant	2626AA00019	445	-26.18336	26.16987	Map Estimated	100	In Use: Unknown		Monitoring		8	25.69		0	27	
157	24	Cement Plant	2626AA00214	375	-26.16719	26.19965	Map Estimated	100	Unused: Abandoned		Monitoring		3.1	7.99		0	17.99	
158	25	Cement Plant	2626AA00217	18	-26.11719	26.21910	Map Estimated	100	Unused: Monitoring		Monitoring		9.3	10.76		0	20.76	
159	26	Cement Plant	2626AA00218	2	-26.15163	26.20021	Map Estimated	100	In Use: Unknown					15		3	48	
160	27	Cement Plant	2626AA00219	2	-26.15163	26.18354	Map Estimated	100	In Use: Unknown					30		12	78	
162	28	Cement Plant	2626AA00223	1	-26.12488	26.14859	Map Estimated	100	Status Not Selected							0		
163	29	Cement Plant	2626AA00229	93	-26.14802	26.13937	Map Estimated	100	Unused: Abandoned		Monitoring		0.3	5.79		0	20	
164	30	Cement Plant	2626AA00230	1	-26.09941	26.16771	Map Estimated	100	Status Not Selected			Submersible Pump				0		
167	31	Cement Plant	2626AA00233	1	-26.15052	26.16632	Map Estimated	100	Status Not Selected		Monitoring					0		
168	32	Cement Plant	2626AA00234	1	-26.15053	26.16632	Map Estimated	100	Status Not Selected		Monitoring					0		
169	33	Cement Plant	2626AA00235	1	-26.15054	26.16632	Map Estimated	100	Status Not Selected		Monitoring					0		
170	34	Cement Plant	2626AA00236	1	-26.15055	26.16632	Map Estimated	100	Status Not Selected		Monitoring					0		
171	35	Cement Plant	2626AA00238	1	-26.15052	26.16633	Map Estimated	100	Status Not Selected		Monitoring					0		
172	36	Cement Plant	2626AA00239	1	-26.15053	26.16632	Map Estimated	100	Status Not Selected		Monitoring					0		
179	37	Cement Plant	2626AA00259	1	-26.11719	26.18576	Map Estimated	100	Status Not Selected					3.2		0	30.78	
180	38	Cement Plant	2626AA00260	2	-26.11725	26.22055	Map Estimated	100	Status Not Selected					10.97		4.3	35.97	
181	39	Cement Plant	2626AA00261	1	-26.11724	26.22054	Map Estimated	100	Status Not Selected					9.14		0.09	74.98	
182	40	Cement Plant	2626AA00262	1	-26.11723	26.22053	Map Estimated	100	Status Not Selected					12.19		0	60.96	
183	41	Cement Plant	2626AA00263	1	-26.11722	26.22052	Map Estimated	100	Status Not Selected					13.72		0	35.05	
184	42	Cement Plant	2626AA00264	2	-26.11721	26.22051	Map Estimated	100	Status Not Selected					4.27		0.5	69.49	
185	43	Cement Plant	2626AA00265	2	-26.11720	26.22050	Map Estimated	100	Status Not Selected					13.72		0.7	53.34	
186	44	Cement Plant	2626AA00266	1	-26.11719	26.22049	Map Estimated	100	Status Not Selected					7.62		0.03	71.63	
187	45	Cement Plant	2626AA00267	1	-26.11719	26.21632	Map Estimated	100	Status Not Selected							0	23.77	
188	46	Cement Plant	2626AA00268	1	-26.11720	26.21633	Map Estimated	100	Status Not Selected					14.63		0.08	49.07	
189	47	Cement Plant	2626AA00269	1	-26.11721	26.21634	Map Estimated	100	Status Not Selected					12.95		0	56.69	
190	48	Cement Plant	2626AA00270	1	-26.11722	26.21635	Map Estimated	100	Status Not Selected					14.48		0	45.72	
191	49	Cement Plant	2626AA00271	2	-26.11723	26.21636	Map Estimated	100	Status Not Selected					11.89		5.1	20.73	
192	50	Cement Plant	2626AA00272	1	-26.11724	26.21637	Map Estimated	100	Status Not Selected					10.67		0	46.02	

SORT	Key	SITE	IDENTIFIER	COUNT	LAT	LONG	COORDMETHOD	ACCURACY	STATUS1	STATUS2	PURPOSE	EQUIPMENT	WLMIN	WLMAX	ABSTRACTION	YIELD	DEPTH	STRIKEDEPTH
193	51	Cement Plant	2626AA00273	1	-26.11725	26.21638	Map Estimated	100	Status Not Selected					19.2		0	49.07	
194	52	Cement Plant	2626AA00274	1	-26.11726	26.21639	Map Estimated	100	Status Not Selected							0	222.5	
195	53	Cement Plant	2626AA00275	1	-26.11727	26.21640	Map Estimated	100	Status Not Selected					27.43		0.06	47.55	
196	54	Cement Plant	2626AA00276	2	-26.11728	26.21641	Map Estimated	100	Status Not Selected					18.29		0.4	59.44	
197	55	Cement Plant	2626AA00277	1	-26.11729	26.21642	Map Estimated	100	Status Not Selected							0	45.72	
198	56	Cement Plant	2626AA00278	1	-26.11730	26.21643	Map Estimated	100	Status Not Selected					18.29		0.06	95.1	
199	57	Cement Plant	2626AA00279	2	-26.11731	26.21644	Map Estimated	100	Status Not Selected					12.19		0.4	112.78	
200	58	Cement Plant	2626AA00280	1	-26.11732	26.21645	Map Estimated	100	Status Not Selected							0	48.77	
201	59	Cement Plant	2626AA00281	1	-26.11733	26.21646	Map Estimated	100	Status Not Selected					10.06		0	36.88	
202	60	Cement Plant	2626AA00282	2	-26.11736	26.21649	Map Estimated	100	Status Not Selected					12.8		3.8	41.76	
203	61	Cement Plant	2626AA00283	1	-26.11737	26.21650	Map Estimated	100	Status Not Selected					14.63		0.04	37.8	
204	62	Cement Plant	2626AA00284	1	-26.11738	26.21651	Map Estimated	100	Status Not Selected					11.58		0	73.15	
205	63	Cement Plant	2626AA00285	2	-26.11739	26.21652	Map Estimated	100	Status Not Selected					13.41		0.4	65.84	
206	64	Cement Plant	2626AA00286	1	-26.11740	26.21653	Map Estimated	100	Status Not Selected							0	48.77	
207	65	Cement Plant	2626AA00287	1	-26.11741	26.21654	Map Estimated	100	Status Not Selected					14.33		0	23.47	
208	66	Cement Plant	2626AA00288	1	-26.11742	26.21655	Map Estimated	100	Status Not Selected					13.72		0	29.57	
209	67	Cement Plant	2626AA00328	1	-26.16720	26.16633	Map Estimated	100	Status Not Selected					46.63		0.04	46.63	
210	68	Cement Plant	2626AA00329	1	-26.16719	26.16632	Map Estimated	100	Status Not Selected					36.58		0.08	99.97	
211	69	Cement Plant	2626AA00335	1	-26.16720	26.16633	Map Estimated	100	Status Not Selected							0	41.76	
212	70	Cement Plant	2626AA00336	1	-26.16719	26.16632	Map Estimated	100	Status Not Selected					54.86		0	65.84	
213	71	Cement Plant	2626AA00354	1	-26.11721	26.22051	Map Estimated	100	Status Not Selected					15.24			36.27	30.48
214	72	Cement Plant	2626AA00355	2	-26.11720	26.22050	Map Estimated	100	Status Not Selected					6.71		0.3	64.01	
215	73	Cement Plant	2626AA00356	2	-26.11719	26.22049	Map Estimated	100	Status Not Selected					15.24		1.1	55.47	
217	74	Cement Plant	2626AA00405	1	-26.14777	26.14968	Map Estimated	100	Status Not Selected							0	26.7	
218	75	Cement Plant	2626AA00406	1	-26.14776	26.14967	Map Estimated	100	Status Not Selected							0	27.7	
219	76	Cement Plant	2626AA00407	1	-26.14775	26.14966	Map Estimated	100	Status Not Selected							0	29	
220	77	Cement Plant	2626AA00408	1	-26.14774	26.14965	Map Estimated	100	Status Not Selected							0	27	
221	78	Cement Plant	2626AA00435	1	-26.14775	26.14966	Map Estimated	100	Status Not Selected							0	78.33	
222	79	Cement Plant	2626AA00436	1	-26.14774	26.14965	Map Estimated	100	Status Not Selected							0	42.67	
223	80	Cement Plant	2626AA00437	1	-26.16740	26.16653	Map Estimated	100	Status Not Selected					4.57			49.68	39.62
224	81	Cement Plant	2626AA00438	1	-26.16739	26.16652	Map Estimated	100	Status Not Selected					3.05		0	54.25	
225	82	Cement Plant	2626AA00439	1	-26.16738	26.16651	Map Estimated	100	Status Not Selected					6.1			65.23	57.91
226	83	Cement Plant	2626AA00440	1	-26.16737	26.16650	Map Estimated	100	Status Not Selected					18.9			60.96	35.36
227	84	Cement Plant	2626AA00441	1	-26.16736	26.16649	Map Estimated	100	Status Not Selected					7.62		0.09	33.53	
228	85	Cement Plant	2626AA00442	1	-26.16735	26.16648	Map Estimated	100	Status Not Selected					2.44		0	17.37	
229	86	Cement Plant	2626AA00443	1	-26.16734	26.16647	Map Estimated	100	Status Not Selected					4.88		0	51.82	
230	87	Cement Plant	2626AA00444	1	-26.16733	26.16646	Map Estimated	100	Status Not Selected					12.19		0	16.46	
231	88	Cement Plant	2626AA00445	1	-26.16732	26.16645	Map Estimated	100	Status Not Selected					7.62			54.86	51.82
232	89	Cement Plant	2626AA00446	1	-26.16731	26.16644	Map Estimated	100	Status Not Selected					7.92		0	37.19	
233	90	Cement Plant	2626AA00447	1	-26.16730	26.16643	Map Estimated	100	Status Not Selected							0	45.11	
234	91	Cement Plant	2626AA00448	1	-26.16729	26.16642	Map Estimated	100	Status Not Selected							0.06	28.96	
235	92	Cement Plant	2626AA00449	1	-26.16728	26.16641	Map Estimated	100	Status Not Selected					0.91		0	21.34	
236	93	Cement Plant	2626AA00450	1	-26.16727	26.16640	Map Estimated	100	Status Not Selected					6.1		0	129.24	
237	94	Cement Plant	2626AA00451	1	-26.16726	26.16639	Map Estimated	100	Status Not Selected					1.68		0	32.31	
238	95	Cement Plant	2626AA00452	1	-26.16725	26.16638	Map Estimated	100	Status Not Selected					4.88		0	31.7	
239	96	Cement Plant	2626AA00453	1	-26.16724	26.16637	Map Estimated	100	Status Not Selected					0.61		0	21.34	
240	97	Cement Plant	2626AA00454	1	-26.16721	26.16634	Map Estimated	100	Status Not Selected							0	40	
241	98	Cement Plant	2626AA00455	1	-26.16720	26.16633	Map Estimated	100	Status Not Selected					18		0.01	40	
242	99	Cement Plant	2626AA00456	1	-26.16719	26.16632	Map Estimated	100	Status Not Selected					18		0	35	
243	100	Cement Plant	2626AA00457	1	-26.11721	26.22051	Map Estimated	100	Status Not Selected					7.92			50.29	45.72

SORT	Key	SITE	IDENTIFIER	COUNT	LAT	LONG	COORDMETHOD	ACCURACY	STATUS1	STATUS2	PURPOSE	EQUIPMENT	WLMIN	WLMAX	ABSTRACTION	YIELD	DEPTH	STRIKEDEPTH
244	101	Cement Plant	2626AA00458	2	-26.11720	26.22050	Map Estimated	100	Status Not Selected					15.85		0.5	45.11	
245	102	Cement Plant	2626AA00459	1	-26.11719	26.22049	Map Estimated	100	Status Not Selected					6.1		0	34.75	
246	103	Cement Plant	2626AA00464	1	-26.14778	26.14969	Map Estimated	100	Status Not Selected							0	62	
248	104	Cement Plant	2626AA00472	1	-26.10658	26.19723	GPS	10	Status Not Selected			Mono Type Pump				0		
249	105	Cement Plant	2626AA00473	1	-26.09156	26.19456	GPS	10	Status Not Selected			Mono Type Pump				0		
254	106	Cement Plant	2626AD00015	1	-26.11719	26.21632	Map Estimated	100	Status Not Selected					3.35		1.82	23.46	
255	107	Cement Plant	31385	1	-26.14779	26.14970	Map Estimated	100	Status Not Selected							0	8	
258	108	Cement Plant	35030	1	-26.12802	26.16882	Map Estimated	100	Status Not Selected					5.37		0	50	

Field Verified Resource Photos

(1) LBH1

(2) LBH2

(3) LBH3

(4) LBH10

(5) LBH11

(6) LBH12

 (7) LBH13	 (8) LBH14
 (9) LBH15	 (10) LBH16
 (11) LBH17	No Photo (12) LBH18

 (13) LBH19	 (14) LBH20
 (15) LBH21	 (16) LBH22
 (17) LBH23	 (18) LBH24

 (19) LBH25	 (20) LBH26
 (21) LBH27	No Photo (22) LBH31
No Photo (23) LBH32	No Photo (24) LBH33
No Photo (25) LBH34	 (26) LBH35
No Photo (27) LBH36	No Photo (28) LBH37

 (29) LBH38	 (30) LBH39
 (31) LBH40	 (32) LBH41
 (33) LBH42	No Photo (34) LBH43

 (35) LBH44	 (36) LBH45
No Photo (37) LBH46	No Photo (38) LBH47
No Photo (39) LBH48	 (40) LBH49

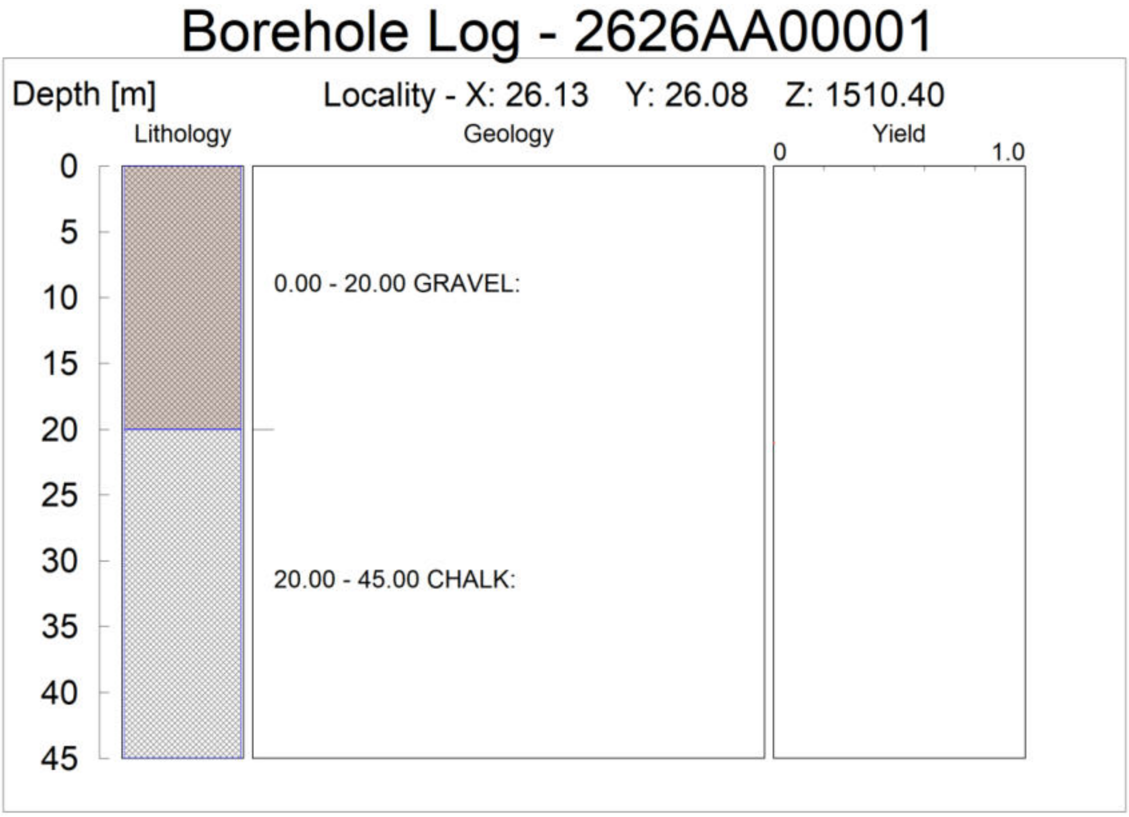
<table>
<tr><td>
(41) LBH50</td><td>
(42) LBH51</td></tr>
<tr><td>
(43) LBH52</td><td>
(44) LBH53</td></tr>
<tr><td>
(45) LBH54</td><td>No Photo
(46) LBH55</td></tr>
</table>

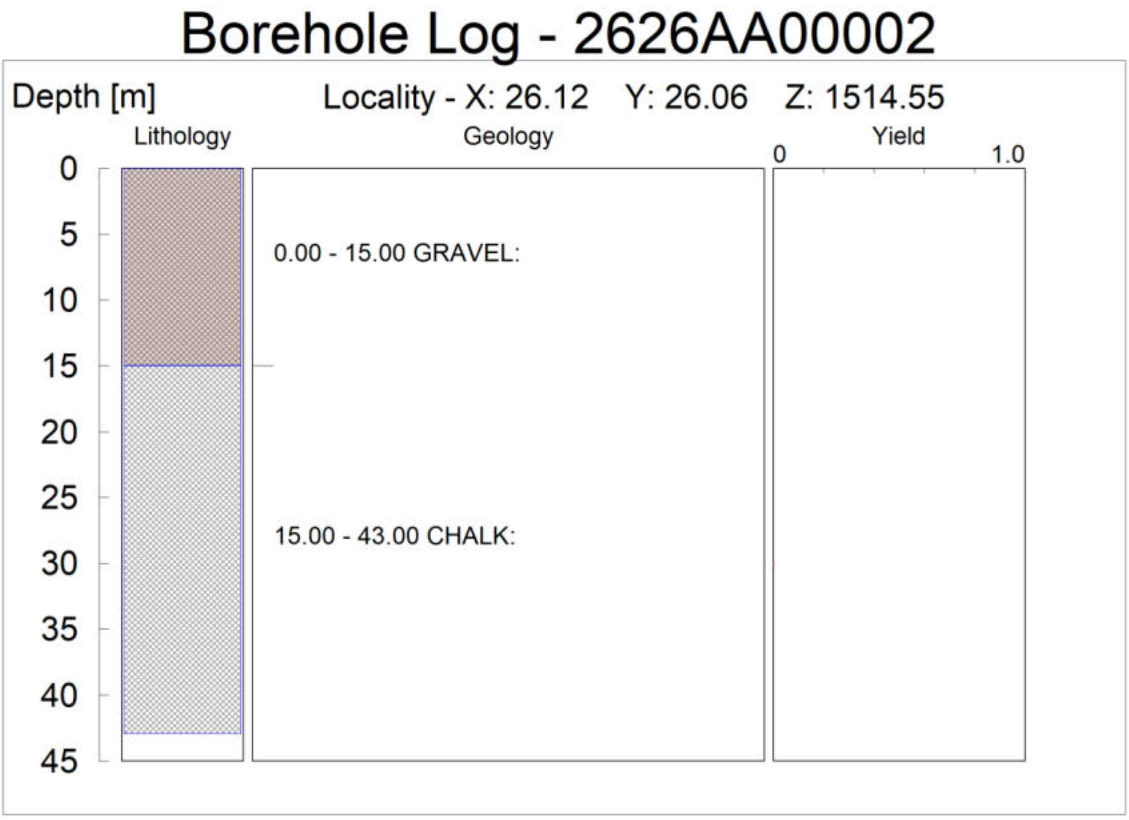
 (47) LBH56	 (48) LBH57
 (49) LBH58	 (50) LBH59

 (51) LBH60	 (52) LBH61
 (53) LBH62	 Not listed
 Not listed	 Not listed

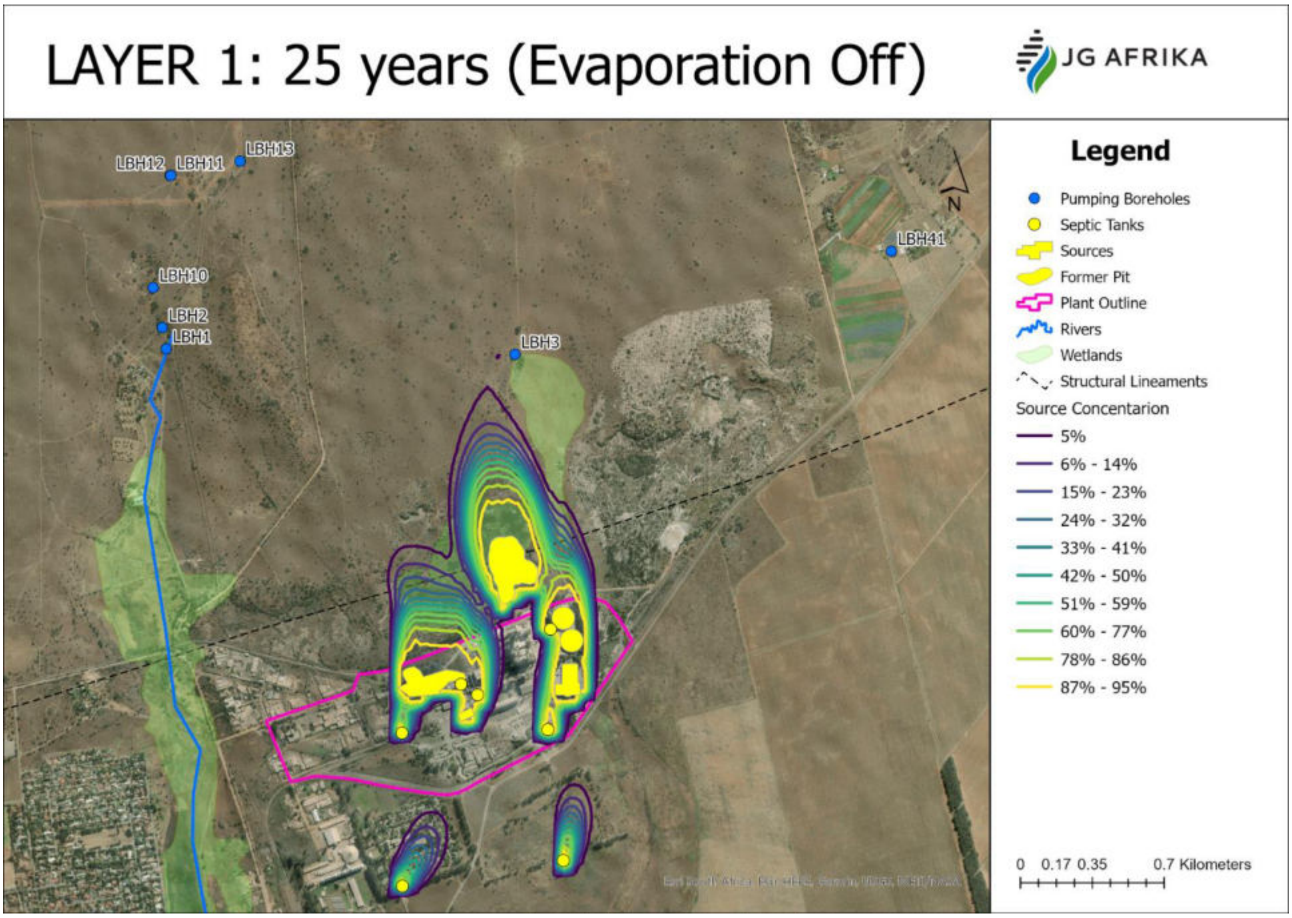
 Not listed	

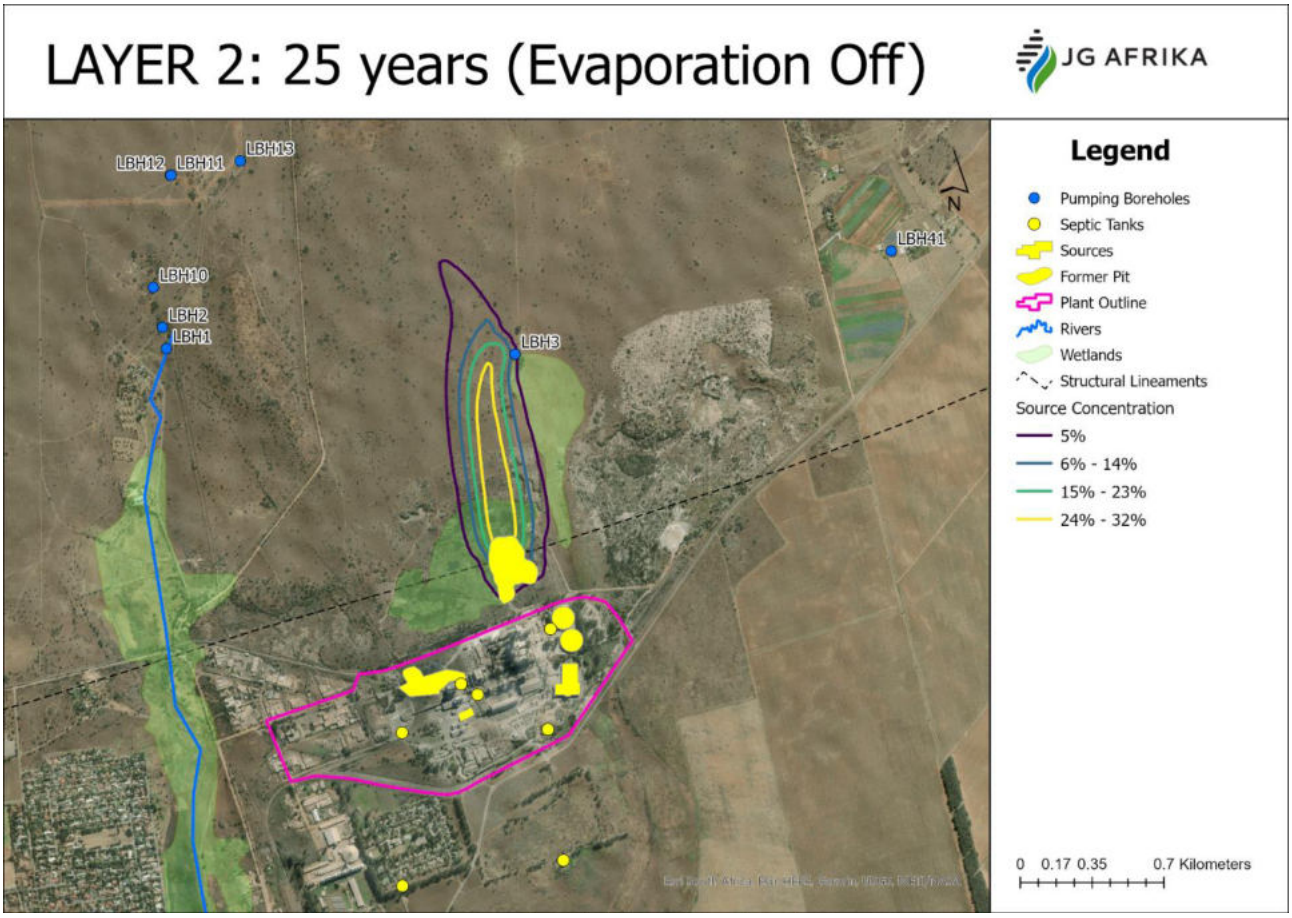
Annexure E: Borehole Logs for Model Layer Interpolation

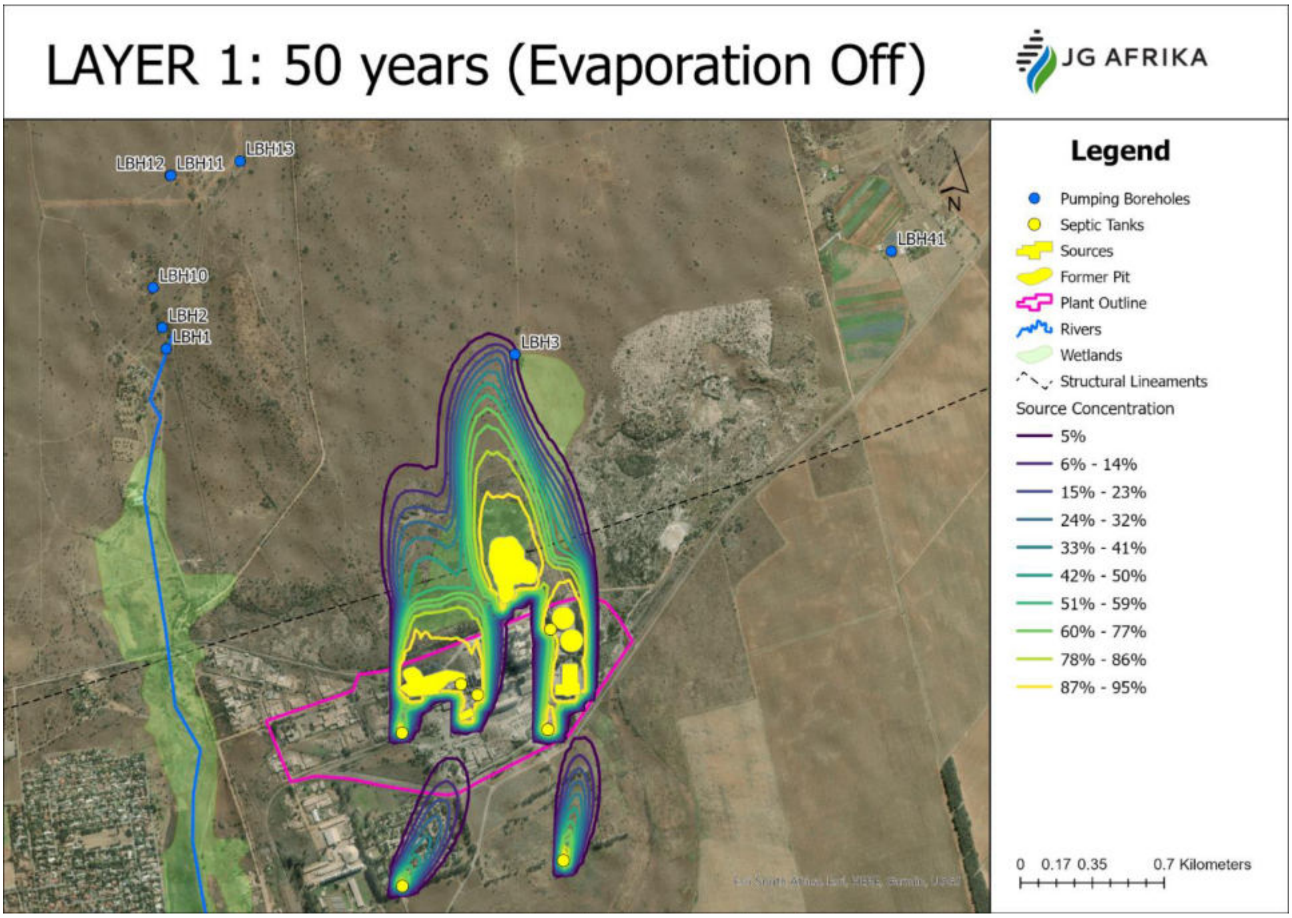

Borehole Log - 2626AA00001
Depth [m]
Locality - X: 26.13 Y: 26.08 Z: 1510.40
Lithology
Geology
Yield
0
1.0
0
5
10
15
20
25
30
35
40
45
0.00 - 20.00 GRAVEL:
20.00 - 45.00 CHALK:

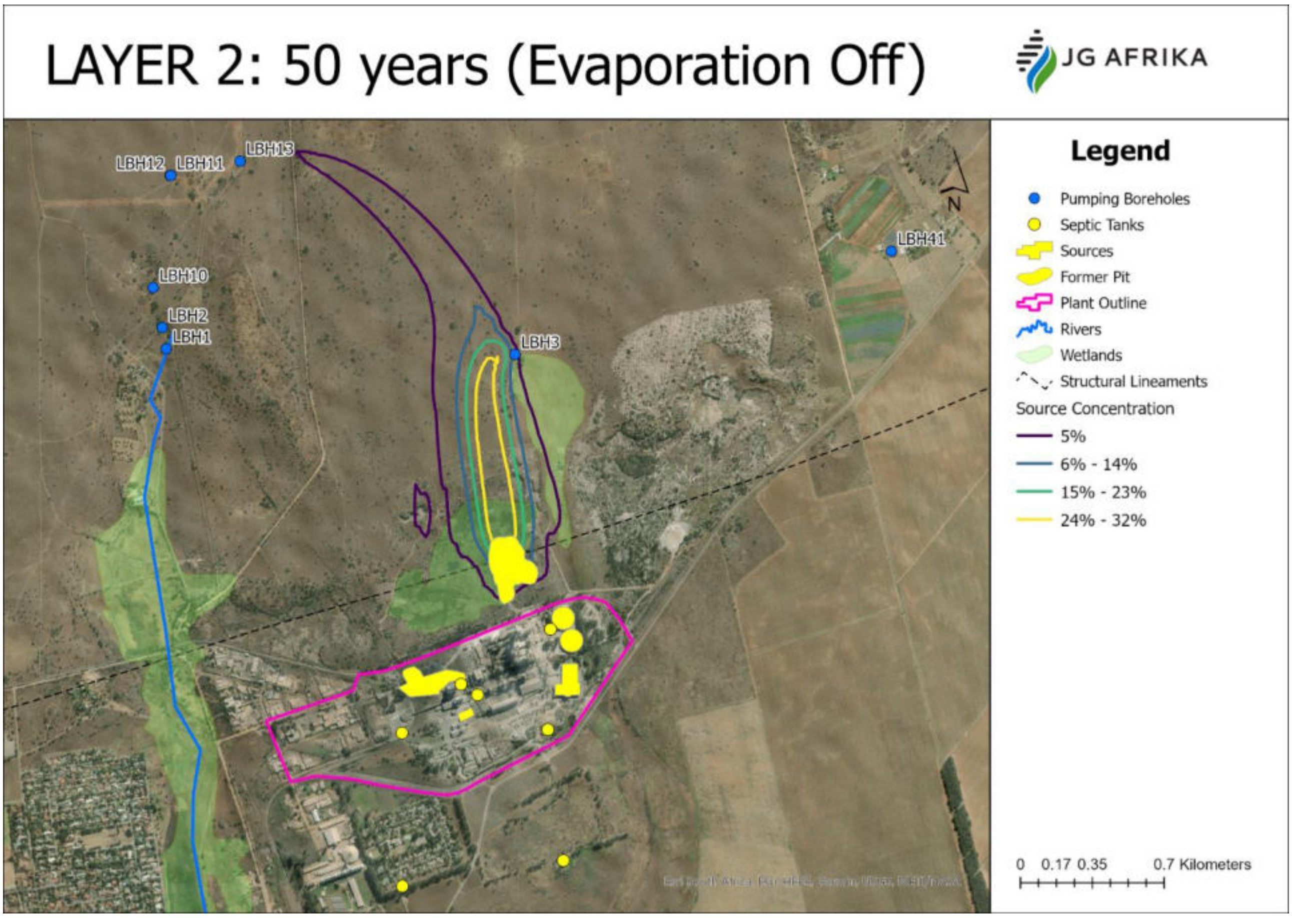

Borehole Log - 2626AA00002
Depth [m]
Locality - X: 26.12 Y: 26.06 Z: 1514.55
Lithology
Geology
Yield
0
1.0
0
5
10
15
20
25
30
35
40
45
0.00 - 15.00 GRAVEL:
15.00 - 43.00 CHALK:

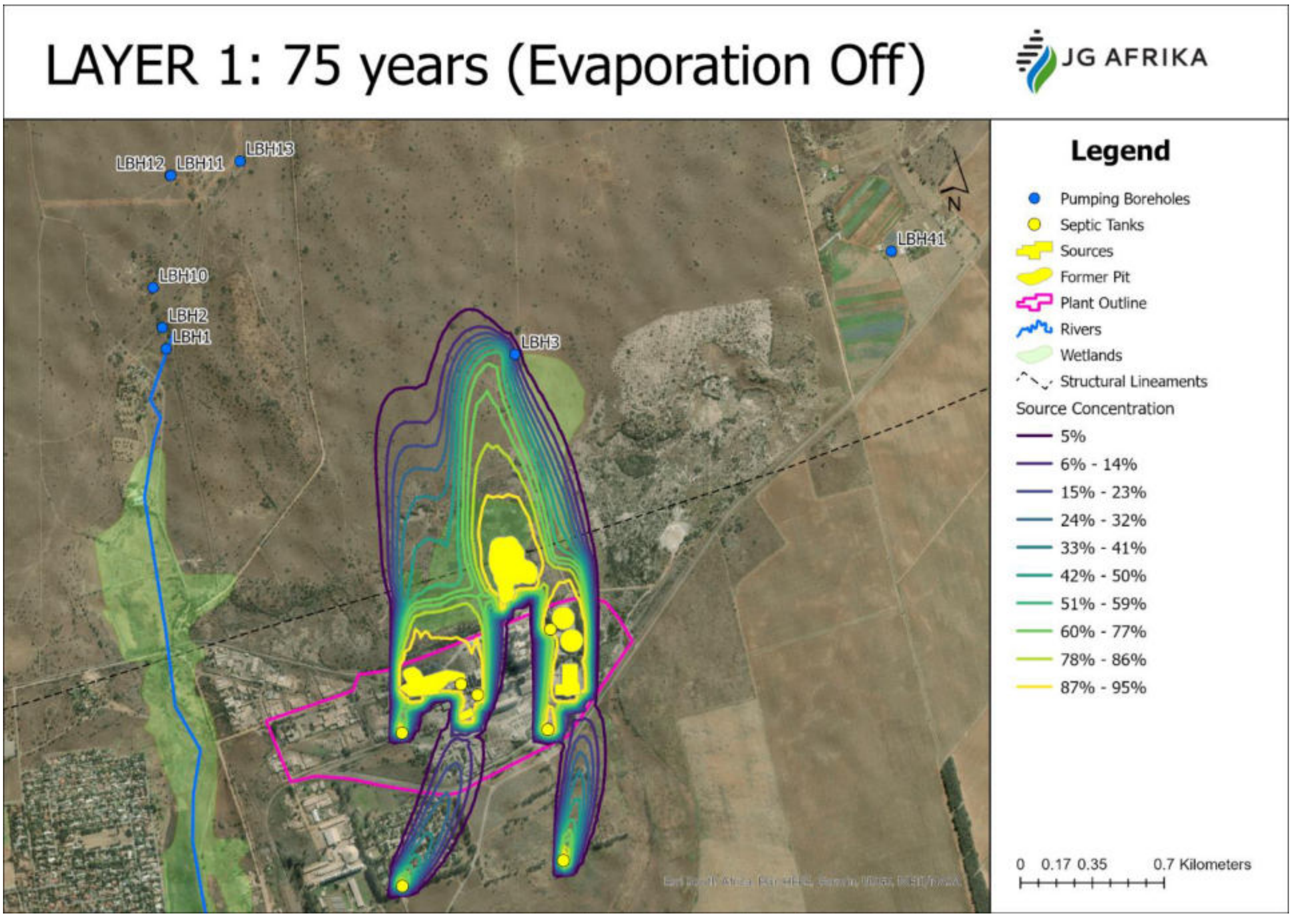
Annexure F: Mass Transport Model Results – Evaporation Off

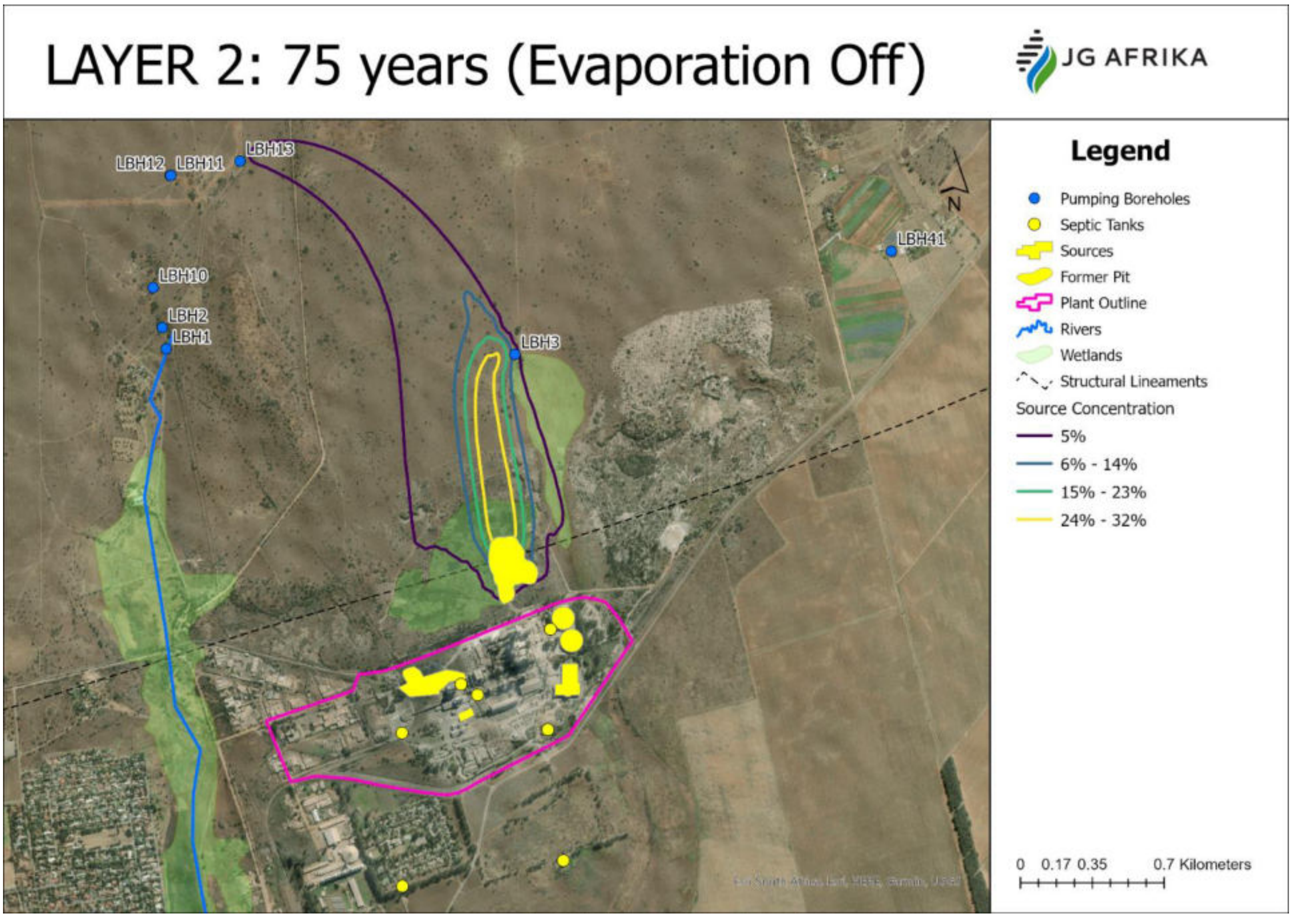

LAYER 1: 25 years (Evaporation Off)
JG AFRIKA
Legend
Pumping Boreholes
Septic Tanks
Sources
Former Pit
Plant Outline
Rivers
Wetlands
Structural Lineaments
Source Concentration
5%
6% - 14%
15% - 23%
24% - 32%
33% - 41%
42% - 50%
51% - 59%
60% - 77%
78% - 86%
87% - 95%
0 0.17 0.35 0.7 Kilometers
N
LBH12
LBH11
LBH13
LBH10
LBH2
LBH1
LBH3
LBH41

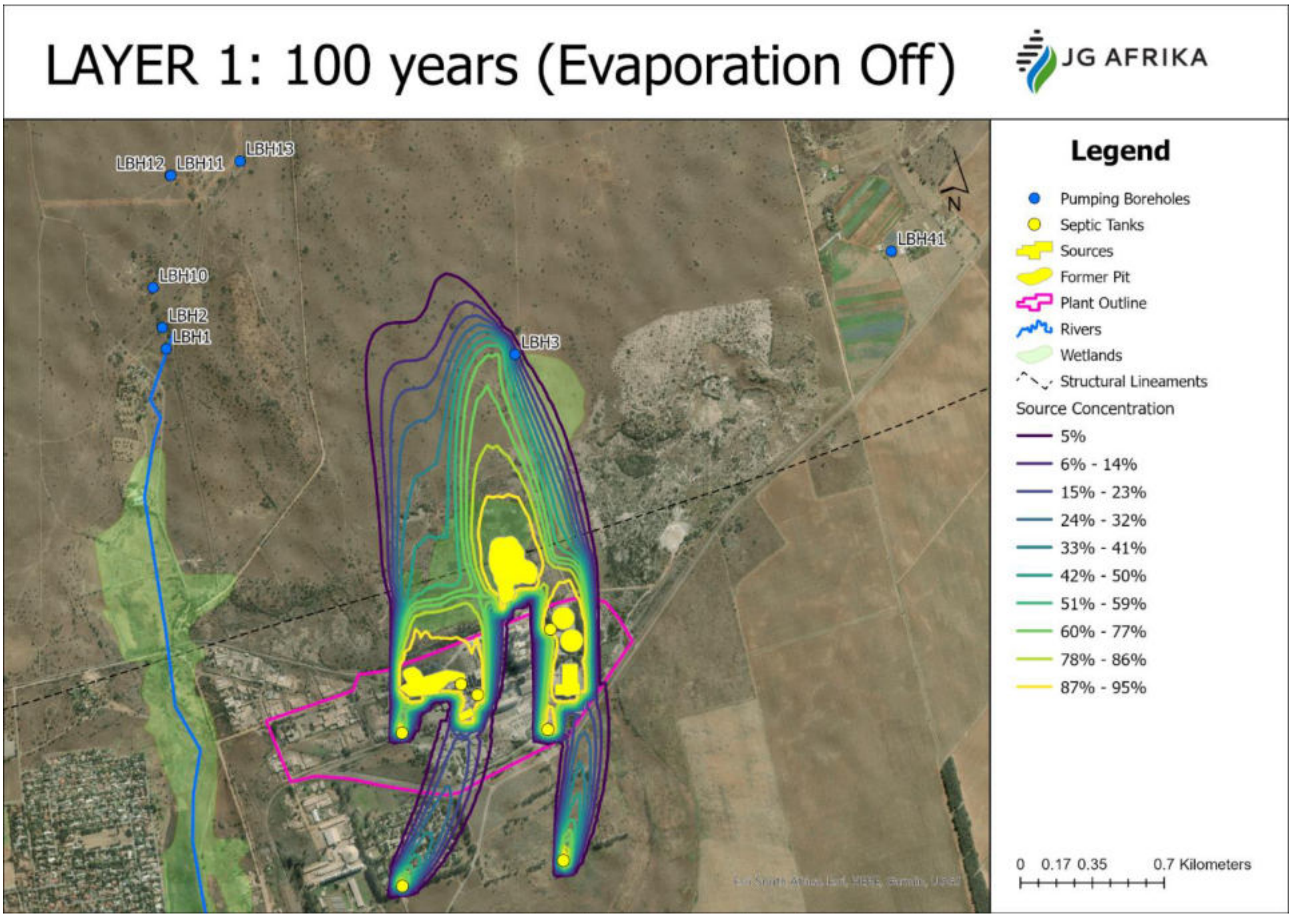

LAYER 2: 25 years (Evaporation Off)
JG AFRIKA
Legend
Pumping Boreholes
Septic Tanks
Sources
Former Pit
Plant Outline
Rivers
Wetlands
Structural Lineaments
Source Concentration
5%
6% - 14%
15% - 23%
24% - 32%
0 0.17 0.35 0.7 Kilometers
N
LBH12
LBH11
LBH13
LBH10
LBH2
LBH1
LBH3
LBH41

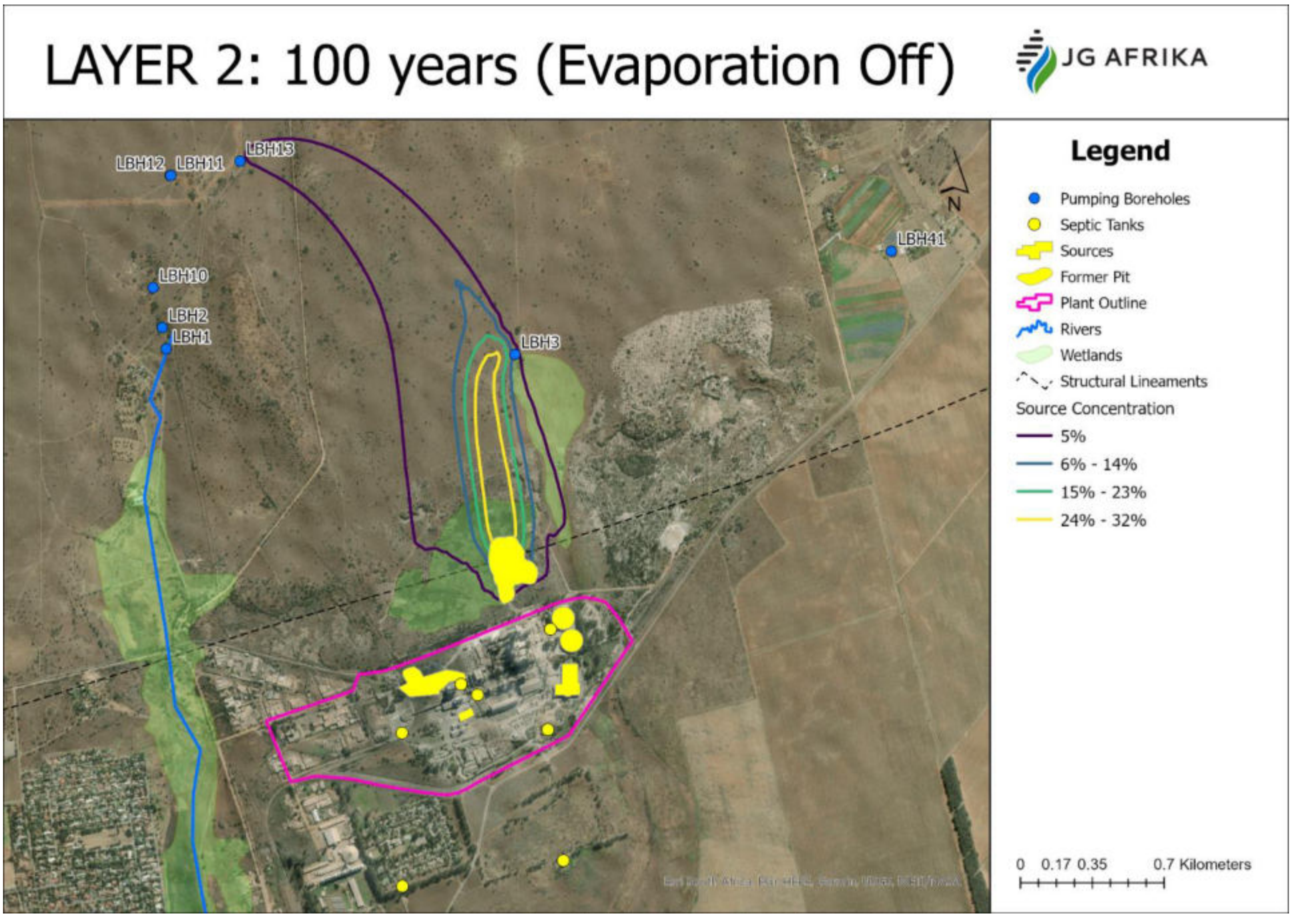

LAYER 1: 50 years (Evaporation Off)
JG AFRIKA
LBH12
LBH11
LBH13
LBH10
LBH2
LBH1
LBH3
LBH41
N
Legend
Pumping Boreholes
Septic Tanks
Sources
Former Pit
Plant Outline
Rivers
Wetlands
Structural Lineaments
Source Concentration
5%
6% - 14%
15% - 23%
24% - 32%
33% - 41%
42% - 50%
51% - 59%
60% - 77%
78% - 86%
87% - 95%
0 0.17 0.35 0.7 Kilometers


LAYER 2: 50 years (Evaporation Off)
JG AFRIKA
LBH12
LBH11
LBH13
LBH10
LBH2
LBH1
LBH3
LBH41
N
Legend
Pumping Boreholes
Septic Tanks
Sources
Former Pit
Plant Outline
Rivers
Wetlands
Structural Lineaments
Source Concentration
5%
6% - 14%
15% - 23%
24% - 32%
0 0.17 0.35 0.7 Kilometers


LAYER 1: 75 years (Evaporation Off)
JG AFRIKA
LBH12
LBH11
LBH13
LBH10
LBH2
LBH1
LBH3
LBH41
N
Legend
Pumping Boreholes
Septic Tanks
Sources
Former Pit
Plant Outline
Rivers
Wetlands
Structural Lineaments
Source Concentration
5%
6% - 14%
15% - 23%
24% - 32%
33% - 41%
42% - 50%
51% - 59%
60% - 77%
78% - 86%
87% - 95%
0 0.17 0.35 0.7 Kilometers


LAYER 2: 75 years (Evaporation Off)
JG AFRIKA
LBH12
LBH11
LBH13
LBH10
LBH2
LBH1
LBH3
LBH41
N
Legend
Pumping Boreholes
Septic Tanks
Sources
Former Pit
Plant Outline
Rivers
Wetlands
Structural Lineaments
Source Concentration
5%
6% - 14%
15% - 23%
24% - 32%
0 0.17 0.35 0.7 Kilometers


LAYER 1: 100 years (Evaporation Off)
JG AFRIKA
LBH12
LBH11
LBH13
LBH10
LBH2
LBH1
LBH3
LBH41
N
Legend
Pumping Boreholes
Septic Tanks
Sources
Former Pit
Plant Outline
Rivers
Wetlands
Structural Lineaments
Source Concentration
5%
6% - 14%
15% - 23%
24% - 32%
33% - 41%
42% - 50%
51% - 59%
60% - 77%
78% - 86%
87% - 95%
0 0.17 0.35 0.7 Kilometers


LAYER 2: 100 years (Evaporation Off)
JG AFRIKA
LBH12
LBH11
LBH13
LBH10
LBH2
LBH1
LBH3
LBH41
N
Legend
Pumping Boreholes
Septic Tanks
Sources
Former Pit
Plant Outline
Rivers
Wetlands
Structural Lineaments
Source Concentration
5%
6% - 14%
15% - 23%
24% - 32%
0 0.17 0.35 0.7 Kilometers

Annexure G: Quantitative Environmental Risk Assessment (ERA) Guideline

Ref: Department of Water Affairs	February 2010
Operational Guideline: Integrated Water and Waste Management Plan	

In terms of a quantitative environmental risk assessment (ERA), the assessment will be based on:

- Probability of occurrence which describes the likelihood of the impact actually occurring and is indicated as:-
  - Improbable, where the likelihood of the impact is very low;
  - Probable, where there is a distinct possibility of the impact to occur;
  - Highly probable, where it very likely that the impact will occur;
  - Definite, where the impact will occur regardless any management measure.
- Consequence of occurrence in terms of:
  - Nature of the impact;
  - Extent of the impact, either local, regional, national or across international borders;
  - Duration of the impact, either short term (0-5 years), medium term (6-15 years) or long-term (the impact will cease after the operational life of the activity) or permanent, where mitigation measures by natural processes or human intervention will not occur;
  - Intensity of the impact, either being low, medium or high effect on the natural, cultural and social functions and processes.
- Significance level of the risk posed by the water use, which is determined through a synthesis of the probability of occurrence and consequence of occurrence.

The applicant will have to rank the risks based on the quantitative assessment as described above into high, medium, or low risks. Management measures need to be identified to mitigate, prevent and /or reduce the risk. These measures will primarily be focussed on the risks identified as high in the ranking matrix, but will also include measures for medium and low risks. The management measures will be taken forward in the IWMP as part of the water use authorisation process.

In order to assess each of the factors for each impact the ranking scales as contained in Table 7-1 could be used. Once the factors had been ranked for each impact, the environmental significance of each impact could be assessed by applying the following formula:

SP = (magnitude + duration + scale) x probability

where SP is defined as significance points.

Table 7-1: Ranking Scales for ERA

PROBABILITY = P 5 – Definite / don't know 4 – High probable 3 – Medium probability 2 – low [probability 1 – Improbable 0 - None	**DURATION** = D 5 – Permanent 4 – Long-term ceases with operational life) 3 – Medium-term (5 – 15 years) 2 – Short-term (0-5 years) 1 - Immediate
SCALE = S 5 – International 4 – National 3 – Regional 2 – Local 1 – Site 0 – None	**MAGNITUDE** = M 10 – Very high / Don't know 8 – High 6 – Moderate 4 – Low 2 – Minor

The maximum value of significance points (SP) is 100. Environmental effects could therefore be rated as either high (H), moderate (M), or low (L) significance on the following basis:

- More than 60 points indicates high (H) environmental significance
- Between 30 – 60 points indicate moderate (M) environmental significance
- Less than 30 points indicates low (L) environmental significance.