APPENDIX H: GROUNDWATER IMPACT ASSESSMENT REPORT

Groundwater Complete

COZA IRON ORE (PTY) LTD
JENKINS IRON ORE PROJECT

REPORT ON GEOHYDROLOGICAL INVESTIGATION AS PART OF THE EIA AND EMP

JANUARY 2016

Contact Details:
Phone: 0844091429
Fax: 0866950191
P.O. Box 448
Riversdal
6670
gcomplete@outlook.com

Compiled by: Wiekus du Plessis, M.Sc. Geohydrology Pr.Sci.Nat.(400148/15)
Reviewed by: Gerhard Steenekamp, M.Sc. Geohydrology Pr.Sci.Nat.(400385/04)

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NEMA Regs (2014) - Appendix 6	Relevant section in report
Details of the specialist who prepared the report	Please refer to cover page of report for specialist information.
The expertise of that person to compile a specialist report including a curriculum vitae	Gerhard Steenekamp M.Sc. Geohydrology Pr.Sci.Nat.(400385/04) / Wiekus du Plessis M.Sc. Geohydrology Pr.Sci.Nat.(400148/15)
A declaration that the person is independent in a form as may be specified by the competent authority	Please refer to page 2 of report for specialist declaration.
An indication of the scope of, and the purpose for which, the report was prepared	Please refer to Section 1 in the report.
The date and season of the site investigation and the relevance of the season to the outcome of the assessment	Winter of June 2014. The season in which the site investigation was done has no influence on the outcome of study whatsoever.
A description of the methodology adopted in preparing the report or carrying out the specialised process	Please refer to Sections 1.1 and 1.2.1 in the report.
The specific identified sensitivity of the site related to the activity and its associated structures and infrastructure	Please refer to Sections 1.3 and 1.4 in the report.
An identification of any areas to be avoided, including buffers	Not applicable to groundwater study.
A map superimposing the activity including the associated structures and infrastructure on the environmental sensitivities of the site including areas to be avoided, including buffers;	Not applicable to groundwater study.
A description of any assumptions made and any uncertainties or gaps in knowledge;	Please refer to Sections 1.2.2.4, 1.2.2.5, 1.3.3.1 and 3.3.1 in the report.
A description of the findings and potential implications of such findings on the impact of the proposed activity, including identified alternatives, on the environment	Please refer to Sections 2 and 3 in the report.
Any mitigation measures for inclusion in the EMPr	Please refer to Section 2 in the report.
Any conditions for inclusion in the environmental authorisation	Please refer to Section 2 in the report.
Any monitoring requirements for inclusion in the EMPr or environmental authorisation	Please refer to Section 4 in the report.
A reasoned opinion as to whether the proposed activity or portions thereof should be authorised and	Please refer to Sections 2 and 3 in the report.
If the opinion is that the proposed activity or portions thereof should be authorised, any avoidance, management and mitigation measures that should be included in the EMPr, and where applicable, the closure plan	Please refer to Sections 2 and 4 in the report.
A description of any consultation process that was undertaken during the course of carrying out the study	Consultation with interested and affected parties was undertaken as part of the environmental impact assessment and environmental management programme process conducted by SLR Consulting (Africa) (Pty) Ltd.
A summary and copies if any comments that were received during any consultation process	Comments and responses that were raised by interested and affected parties are included in the issues table, an Appendix of the EIA report.
Any other information requested by the competent authority.	No information requested.

JENKINS IRON ORE PROJECT: REPORT ON GEOHYDROLOGICAL INVESTIGATION AS PART OF THE EIA AND EMP, JANUARY 2016

EXECUTIVE SUMMARY:

Groundwater Complete was contracted by Synergistics Environmental Services (Pty) Ltd to conduct a geohydrological study and report on findings as specialist input to the Environmental Impact Assessment (EIA) and Environmental Management Program (EMP) for their proposed Jenkins Iron Ore Project (hereinafter referred to as the Jenkins Project). The Jenkins Project area is located within the Tsantsabane Local Municipality in the Northern Cape Province, approximately 25 km south of the town of Kathu **(Figure 1)**. Several historical and active iron ore mining operations occur in the region. The most significant active mines are the Sishen (Anglo American) and Khumani (Assmang) iron ore mines approximately 12 km and 5 km north of the Jenkins Project respectively. Kolomela (Anglo American) and Beeshoek (Assmang) mines are situated approximately 50 km south of the Jenkins Project.

The focus of this investigation was centered around:

- Determining a sound baseline picture of groundwater conditions on and around the Jenkins project, followed by
- Determination of the groundwater quality and quantity impacts related to the proposed Jenkins iron ore mining activities.

Due to the project area's close proximity to operational iron ore mines to the north that are known to extract large volumes of groundwater for mine dewatering purposes, a special effort was made to:

- Delineate the extent of the existing/current groundwater level impacts (cone of depression),
- Verify if a geological structure, believed to exist between these active mines and the Jenkins Project area, is indeed a groundwater flow barrier that prevents the active mines to the north from affecting groundwater levels in the project area.

A hydrocensus and groundwater user survey was conducted on the Jenkins mining right area and surrounding properties **(Figure 3)**. A total of 52 boreholes were located of which 23 are exploration boreholes that were drilled by Coza Mining (Pty) Ltd. Twenty user boreholes (3^{rd} party) were located in the survey area, while the remaining nine boreholes are dedicated groundwater level monitoring boreholes and are the property of Assmang's Khumani Mine. Groundwater within the survey area is mainly used for domestic purposes, small scale irrigation (household gardens) and livestock watering **(Figure 4)**.

A geophysical investigation was conducted in June 2015 for the purpose of the geohydrological study to delineate geological structures such as faults and intrusive features like dolerite dykes **(Figure 6)**. The main aim of the survey was to site monitoring boreholes in areas where potential impacts from the mining related activities may occur.

The secondary aim of the investigation was also to delineate or confirm the southern boundary of the Sishen Compartment.

The southern border of the Sishen compartment was traversed five times during the geophysical survey. Despite the fact that anomalies (possible structures) were identified, two of the five traverses showed no signs of any significant geological structure. The conclusion is therefore drawn that the geophysical survey conducted for the purpose of the Jenkins Project does not entirely support Sishen's current understanding and delineation of the southern border of the compartment.

The geohydrological regime in the project area is made up of two main aquifer systems. The first, the upper, unconfined to semi-confined aquifer occurs in the weathered zone. The second aquifer is associated with fractures, fissures, joints and other discontinuities within the consolidated bedrock and associated intrusives of the Transvaal/Griqualand West Sequences.

Groundwater levels of boreholes unaffected by the Sishen mining activities to the north generally vary between ± 2 and 34 meters below surface **(Figure 12)**. Variations in groundwater levels are mainly the result of aquifer heterogeneity and significant compartmentalisation. On the other hand, boreholes believed to be affected display water levels of between ± 43 and 275 meters below surface.

Groundwater quality data is available for a total of 14 user boreholes located during the hydrocensus/user survey and two dedicated source monitoring boreholes **(Figure 25)**. Groundwater quality data were evaluated with the aid of diagnostic chemical diagrams and by comparing the inorganic concentrations to the South African National Standards for drinking water *(SANS 241:2011)*.

Summary of groundwater quality evaluation:

- Groundwater is of good quality and is suitable for human consumption according to the South African National Standards for drinking water *(SANS241:2011)*.
- Exceptions do however occur as the nitrate content measured in GP06, JKN02, ROC03, ROC06 and ROC09 exceeds the permissible SANS concentration of 11 mg/l, rendering the groundwater unfit for human consumption.
- The groundwater is mainly dominated by magnesium cations, while bicarbonate alkalinity dominates the anion content.

Acid Base Accounting (ABA) and leaching tests were performed by an accredited laboratory *(Waterlab)* on two samples collected from the drilling of exploration boreholes in the Jenkins Project area. The Modified Sobek method was used for the ABA tests, while for the leaching tests the samples were leached with distilled water as a realistic scenario expected for the project area.

The results of the ABA tests concluded that both samples collected from the Jenkins Project area are non-acid forming **(Table 12)**. The leaching tests also revealed that both the ore and waste rock from the project area are mostly inert and any leachate generated by planned ROM stockpiles and/or waste rock dumps should be of an acceptable quality **(Table 13)**. The only metal found to be present in the leachate at significant concentrations was aluminium.

The volumes of groundwater expected to discharge into the active mine workings were simulated with the numerical flow model and the results are provided in the below table:

Year	Lowest pit floor elevation	Minimum flow (m^3/d)	Maximum flow (m^3/d)
1	1280	N/A	N/A
2	1280	N/A	N/A
3	1275	N/A	N/A
4	1270	N/A	N/A
5	1260	N/A	N/A
6	1235	N/A	N/A
7	1195	160	270
8	1195	140	240
9	1195	130	230
10	1170	250	500

Note: *The highest groundwater elevation in the proposed pit area is at approximately 1227 mamsl, meaning that the water table is only expected to be intersected during/after year 7 of mining.*

A groundwater level drawdown of approximately 20 meters was simulated for the seventh year of active mining **(Figure 33)**. Maximum groundwater level impacts are expected to occur during the tenth and final year of mining and a groundwater level drawdown of ± 50 meters was simulated **(Figure 36)**. The cone of depression was simulated not to exceed the pit boundary by more than approximately 420 meters. **Except for user borehole CJBH01, which will in any case be demolished by the planned opencast workings, no other user boreholes are expected to be affected by the aquifer dewatering.**

If the proposed pit was to decant it is expected to occur at an elevation of ± 1 284 mamsl **(Figure 30)**. The most probable time it will take the backfilled void to fill with water to the decant elevation was calculated to be in the order of 160 years after active mining has ceased **(Table 9)**. An evaporation rate of approximately 962 100 m^3/y was calculated to occur from the surface of the backfilled pit, which far exceeds the expected recharge volume of ± 22 800 m^3/y. The water level within the backfilled opencast pit is therefore not expected to reach the surface and decanting should not occur.

Groundwater contamination was simulated with the mass transport model to migrate in a north/north-westerly direction away from the potential source areas. Contaminant migration was simulated not to exceed a maximum distance of approximately 300 meters in the down gradient groundwater flow direction at a time of 50 years post closure, which translates to a seepage velocity of approximately 6 meters per year **(Figure 39)**.

Except for user borehole CJBH01, which will in any case be demolished by the planned opencast workings, no other user boreholes are expected to be affected by contamination that may originate from the mining and related activities.

A total of seven monitoring boreholes were drilled on targets identified during a geophysical investigation of the project area **(Figure 40)**. Relevant information regarding the drilled monitoring boreholes is provided in the below table:

BH	Coordinates		Elevation (mamsl)	Depth (m)	Water strike (m)	Blow yield (l/h)	Water level (m)
	South	East					
JKN01	-27.92594	22.99694	1246	50	N/A	N/A	49.1
JKN02	-27.91886	22.99403	1241	50	44	4000	17.7
JKN03	-27.91430	22.98981	1236	30	22	4000	16.6
JKN04	-27.91204	23.00160	1244	75	N/A	N/A	Dry
JKN05	-27.91454	22.99980	1243	50	37	1500	21.6
JKN06	-27.91280	22.99617	1239	50	38	1000	18.9
JKN07	-27.91316	22.99618	1239	50	44	6000	18.34

Note: *Coordinates – WGS84.*

1 GENERAL DESCRIPTION OF GEOHYDROLOGY

Groundwater Complete was contracted by Synergistics Environmental Services (Pty) Ltd to conduct a geohydrological study and report on findings as specialist input to the Environmental Impact Assessment (EIA) and Environmental Management Program (EMP) for their proposed Jenkins Iron Ore Project (hereinafter referred to as the Jenkins Project). The Jenkins Project area is located within the Tsantsabane Local Municipality in the Northern Cape Province, approximately 25 km south of the town of Kathu. Several historical and active iron ore mining operations occur in the region. The most significant active mines are the Sishen (Anglo American) and Khumani (Assmang) iron ore mines approximately 12 km and 5 km north of the Jenkins Project respectively. Kolomela (Anglo American) and Beeshoek (Assmang) mines are situated approximately 50 km south of the Jenkins Project. A map of the Jenkins Project area is provided in **Figure 1**, while a regional map indicating the positions of surrounding active iron ore mines are provided in **Figure 2**.

At the Jenkins Project iron ore is proposed to be extracted by means of the opencast truck and shovel mining method on the farm Jenkins 562 as indicated in **Figure 1**. The hematite iron ore reserve is of high grade with an average iron content of approximately 62%. Topsoil will be stripped from the mine surface area and stockpiled for future rehabilitation purposes, while waste rock will be dumped at dedicated positions close to the opencast pit. Crushing and screening of the iron ore will occur on site, while blending may occur at the run-of-mine (ROM) stockpile also on the site.

The proposed Life of Mine (LOM) for the proposed Jenkins Iron Ore Project is about ten years with the highest pit bench situated at an elevation of 1 360 meters above mean sea level (mamsl) and the lowest on 1 170 mamsl. The pit will thus have a maximum depth of approximately 190 meters. An estimated 6% of the total mining rights area will be disturbed by the proposed project. Infrastructure requirements (in addition to the pit) for the Jenkins Project include:

- Primary processing plant,
- Mined ore and product stockpiles,
- Topsoil stockpile/s,
- Waste rock dump/s,
- Main power supply,
- Rail balloon and rail loading,
- Main administrative offices,
- Truck service and wash-bay,
- Explosives magazine,
- Change house,
- Store and workshop,
- Sewage treatment plant,
- Pollution control dam/s.

The focus of this investigation was centered around:

- Determining a sound <u>baseline picture of groundwater conditions</u> on and around the Jenkins project, followed by
- Determination of the <u>groundwater quality and quantity impacts</u> related to the proposed Jenkins iron ore mining activities.

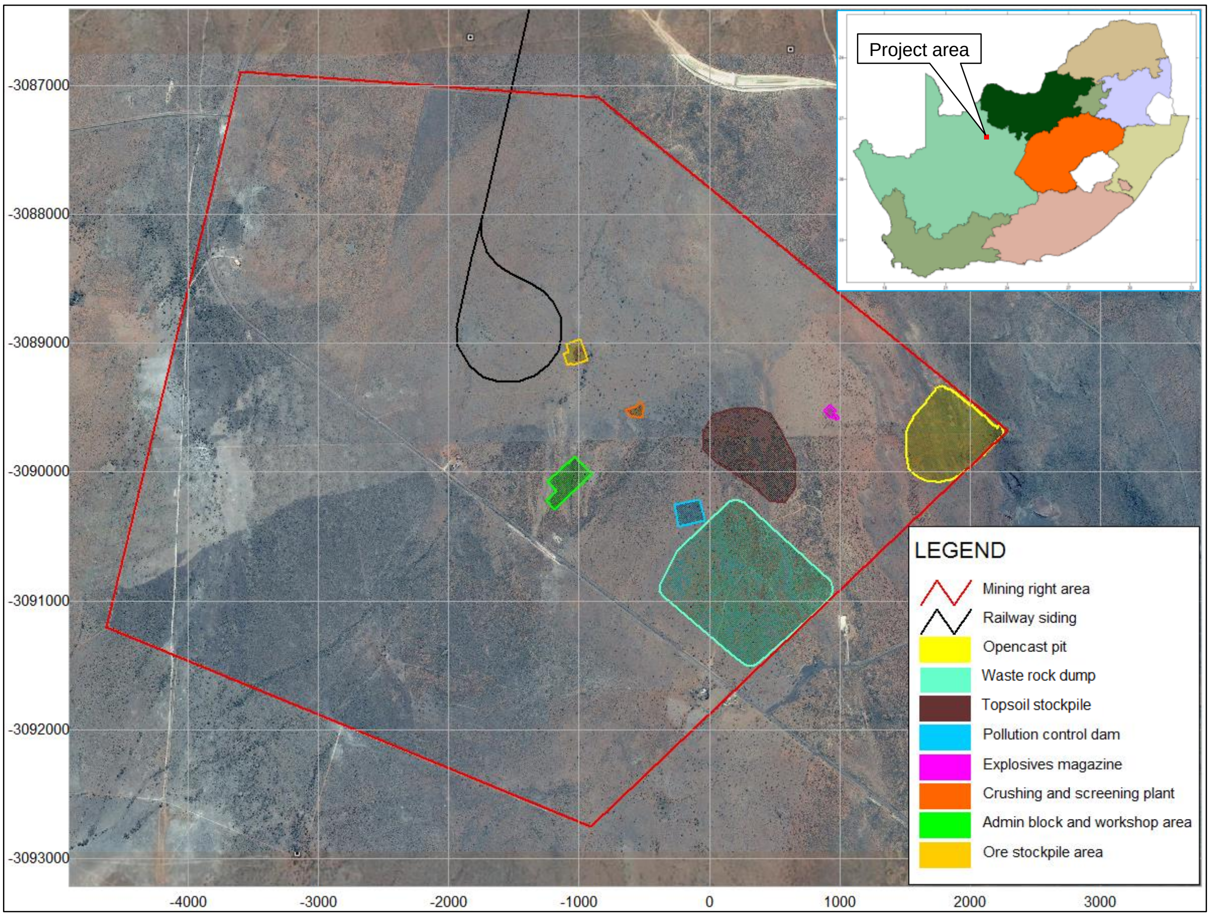


Figure 1: Locality map of the Jenkins Project area

Notes: *- All figures are provided in the WGS 84 Datum and Transverse Mercator coordinate system.*
- Grid lines provided in all figures therefore also serve as a scale bar.

Groundwater seepage at high rates into opencast mine workings is known to be problematic in the surrounding iron ore mines (especially Sishen), hence the investigation also involved mine dewatering simulations and recommendations that will allow for safe mining conditions.

Due to the project area's close proximity to operational iron ore mines to the north that are known to extract large volumes of groundwater for mine dewatering purposes, a special effort was made to:

- Delineate the extent of the existing/current groundwater level impacts (cone of depression),
- Verify if a geological structure, believed to exist between these active mines and the Jenkins Project area, is indeed a groundwater flow barrier that prevents the active mines to the north from affecting groundwater levels in the project area.

In order to achieve these two objectives, groundwater levels from these northern mines (especially Sishen Iron Ore Mine) were evaluated and compared against ambient and site-specific groundwater level conditions measured during the hydrocensus/user survey **(Section 1.3)**.

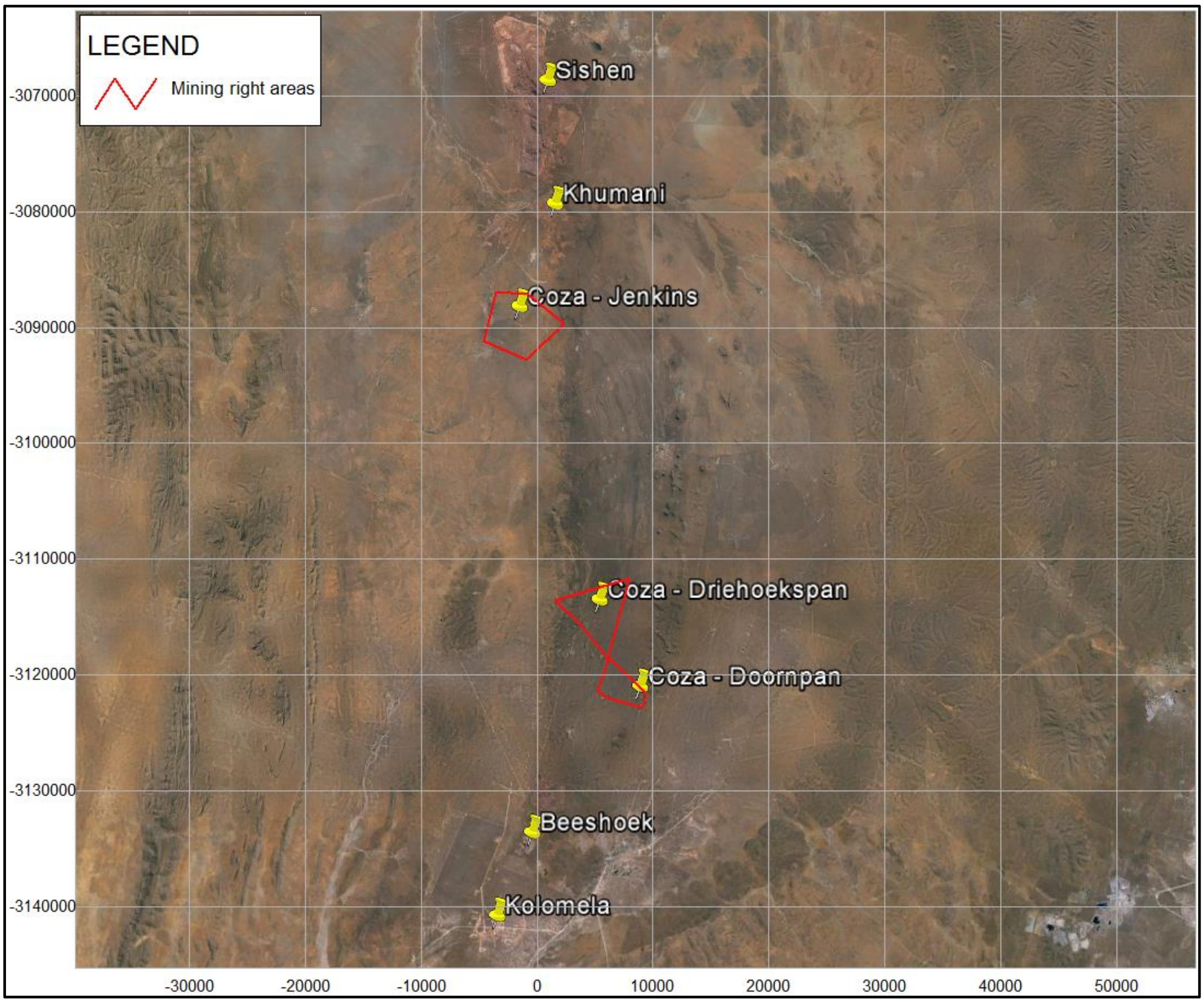


Figure 2: Positions of active iron ore mines relative to the proposed three Coza Project areas

1.1 ASSUMPTIONS AND UNCERTAINTIES

The following assumptions and uncertainties had to be dealt with during the geohydrological investigation and compilation of this specialist report:

- Numerous sources indicate a large number of geological structures (mainly dykes) to exist in the project area. Time and budget restrictions made it virtually impossible to determine the hydraulic properties of each and every structure. None the less, all dykes were simulated in the numerical flow and mass transport models.

- Aquifer delineation is conducted to show which part of the aquifer was used or considered during simulation exercises. Because the main aquifer is a fractured rock type and fractures could assume any geometry and orientation, the physical boundary or 'end' of the aquifer is very difficult to specify or quantify. No-flow boundaries were used in areas where geological information indicated dykes to occur, while general head boundaries were used to delineate the remaining model perimeter where structural information was lacking.
- Aquifer thickness in a fractured rock aquifer is virtually impossible to determine as the actual 'aquifer' consists of transmissive fractures, fissures or cracks of any orientation, extent or aperture in any of the rock types underlying the site. Therefore, an approximation can at best be made on the thickness of the aquifer.
- The groundwater level distribution throughout the project area is considered to be good. However, some areas are devoid of such information and the commonly used Bayesian interpolation method was used to estimate water levels in these areas.
- Constant rate pump tests were performed on three exploration boreholes and two user boreholes in the project area for the purpose of calculating representative aquifer parameters. Fractured rock aquifers are known for being highly heterogeneous, causing significant variations in aquifer transmissivity/storativity within relatively short distances. It is therefore difficult to determine representative values over large areas. The calculated aquifer parameters were used as indicative values only and model calibration aided in obtaining representative values.
- A secondary fractured rock aquifer (such as the one underlying the Jenkins Project area) is a highly complex system and is by no means homogeneous. Coupled with numerous model restrictions, over or under estimations of the predicted groundwater impacts should be expected (quality and quantity). The model results should therefore only be regarded as being qualitative rather than quantitative for use in planning of management and mitigation measures. The model results/predictions also need to be verified and updated regularly by means of a comprehensive groundwater monitoring program.

1.2 DESK TOP STUDY

A groundwater survey was performed for the Jenkins reserve area for which the rights have been applied for by Coza Mining (Pty) Ltd. The results of the baseline groundwater survey are presented in this chapter of the document.

Groundwater information for the survey was obtained mainly from the following sources:

- Geophysical survey of geological structures such as dykes and faults,
- Dedicated information gathering through drilling of monitoring boreholes, groundwater quality analyses, water level and aquifer test measurements in exploration boreholes,
- Baseline groundwater information gathered during the hydrocensus survey performed specifically for compilation of this EMP document.

For the purpose of the study, the groundwater information as described above was combined and interpreted in a holistic manner. The groundwater regime was evaluated using the following methodology:

- Topographical and geological maps, orthographic photographs, satellite images and geophysical surveys were used to describe the **physical properties** of the groundwater domain,

- A hydrocensus survey was conducted during which **groundwater users** around the Jenkins Project area were identified, boreholes were surveyed in terms of positions, water levels and water quality and water **uses** were determined,

- Constant rate pump and recovery tests were performed on exploration boreholes. The pump tests were used to determine the **hydraulic properties** of the saturated zone,

- User and exploration boreholes were sampled for chemical analyses to assay the groundwater **quality characteristics**,

- Groundwater **flow velocities** were calculated from first principles.

All the above data types were interpreted with appropriate techniques in each case and were used to postulate a **conceptual model** of the groundwater regime.

1.3 AMBIENT GEOHYDROLOGICAL CONDITIONS

1.3.1 GROUNDWATER USE (USER SURVEY/HYDROCENSUS RESULTS)

A hydrocensus and groundwater user survey was conducted on the Jenkins mining right area and surrounding properties. The main aims and objectives of the hydrocensus field survey were as follow:

- To locate all interested and affected parties (I&APs) pertaining to groundwater,
- To collect all relevant information from the I&APs (i.e. name, telephone number, address, etc.),
- Accurately log boreholes on the I&APs properties,
- Record all uses of all the boreholes, and
- To collect all relevant information regarding the boreholes (i.e. yield, age, depth, water level, etc.).

Summaries of the findings are provided in **Figure 4** and **Table 1**, while the complete hydrocensus report is included in **Appendix A** of the report. A total of 52 boreholes were located and their positions are indicated in **Figure 3**. Borehole ID's and detailed information is provided in the hydrocensus report.

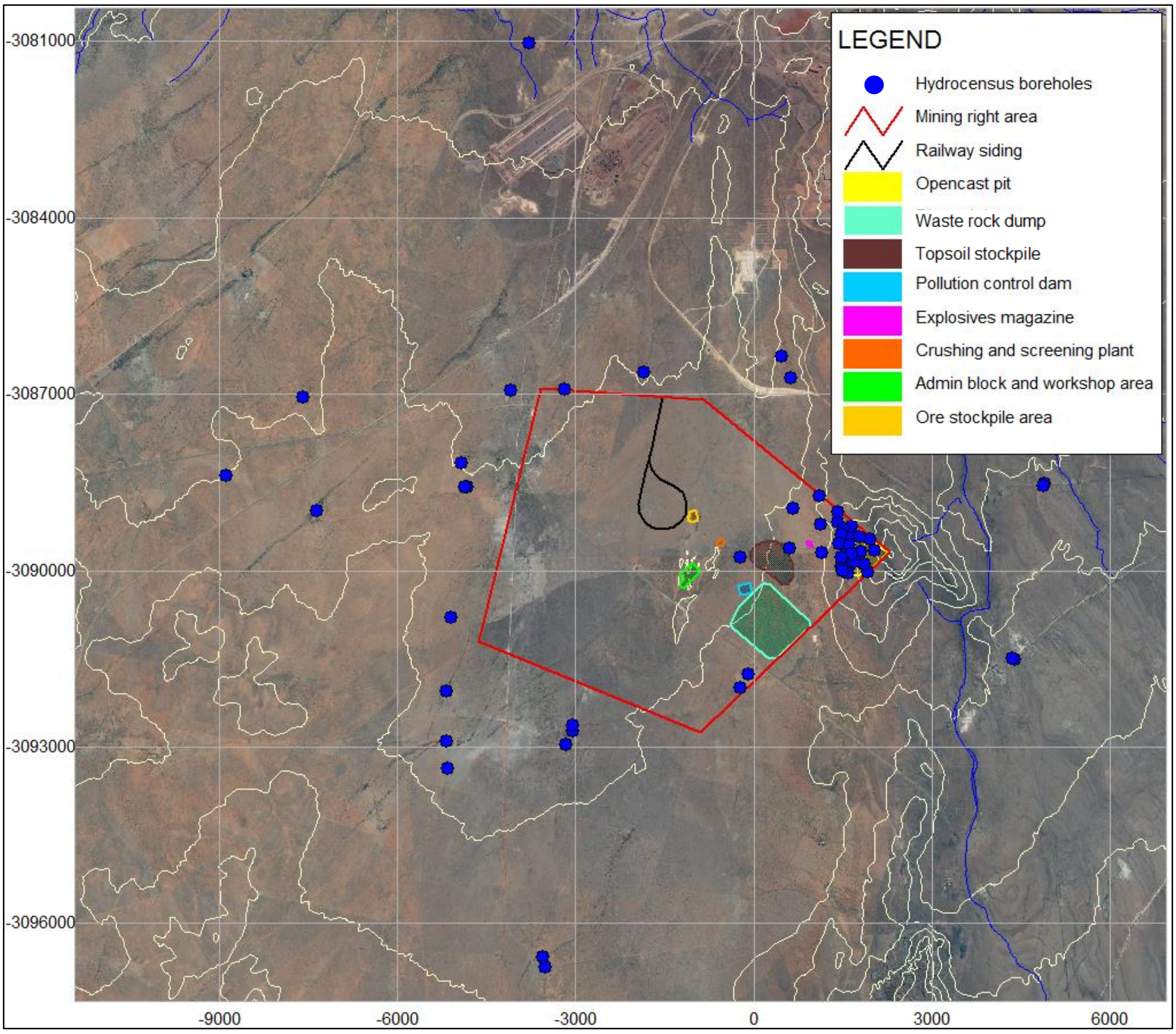


Figure 3: Boreholes recorded during the Jenkins user survey

Figure 4 shows that 23 of the 52 boreholes located during the hydrocensus are exploration boreholes that were drilled by Coza Mining (Pty) Ltd, while 20 user boreholes (3rd party) were located in the survey area. Groundwater within the survey area is mainly used for domestic purposes, small scale irrigation (household gardens) and livestock watering. The remaining nine boreholes are dedicated groundwater level monitoring boreholes and are the property of Assmang's Khumani Mine, which is located approximately 5 km north of the Jenkins Project.

Yield information could only be obtained for four boreholes and varied between approximately 1 500 l/h and 3 000 l/h **(Appendix A)**. Widespread pollution or depletion of the groundwater resource will impact negatively on:

- The groundwater **resource itself** and interrelations with other natural resources (e.g. rivers and streams), and
- **The users** that depend on groundwater as **sole source** of domestic water as well as for livestock and gardening.

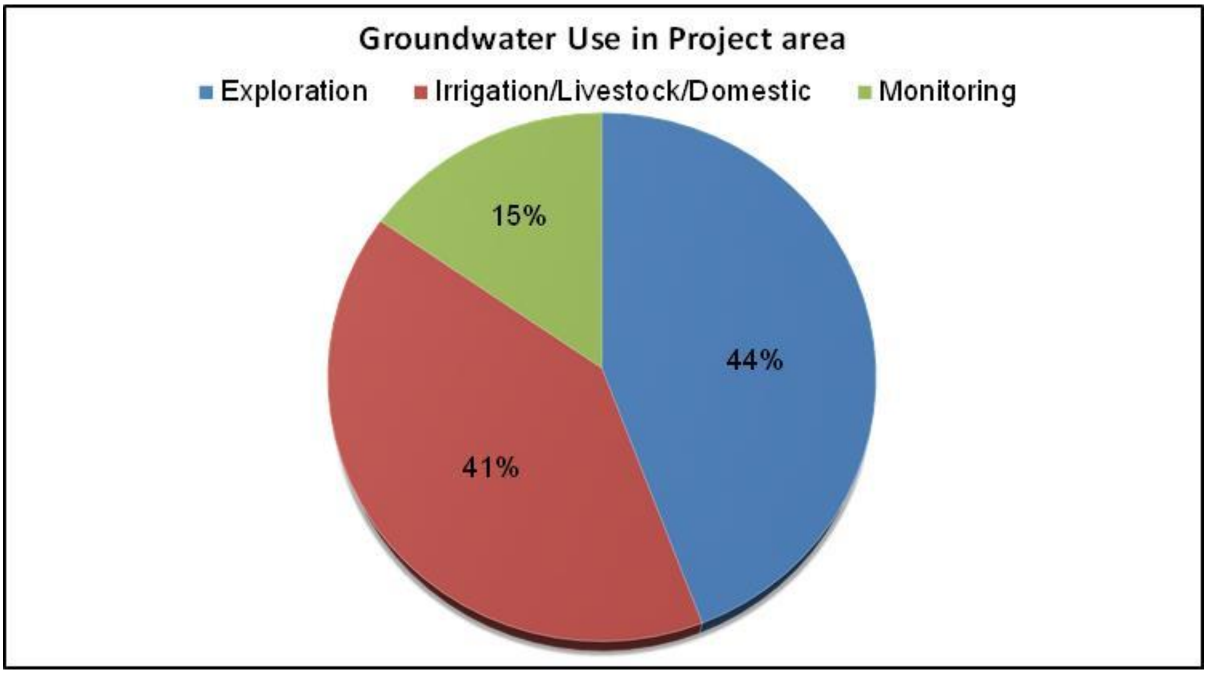


Figure 4: Results of groundwater user survey

Table 1: Summary of hydrocensus and groundwater user survey

BH	Coordinates		Elevation	Depth	Water level	Owner	Comment	Sampled
	South	East						
MAC01	-27.91051	23.04963	1254.00	80	8.9	Assmang	None	Yes
MAC02	-27.91082	23.04951	1254.00	237	8.7	Assmang	None	Yes
MAC03	-27.93744	23.04451	1279.00	90	-	Assmang	Probe on borehole	No
MAC04	-27.93728	23.04429	1279.00	106	-	Assmang	Probe on borehole	No
MAC09	-27.89091	23.00488	1231.00	68	13.6	Assmang	Submersible pump	No
MOKGANENG	-27.89423	23.00630	1235.00	130	21.4	Assmang	None	No
PBW01	-27.84286	22.96164	1201.00	39.5	7.7	Assmang	Submersible pump	No
WGK09	-27.89605	22.96769	1223.00	60	17.5	Assmang	None	Yes
WGK12	-27.89337	22.98133	1224.00	60	20.9	Assmang	None	Yes
CJBH01	-27.92297	23.01644	1294.00	-	80.6	Coza Mining (Pty) Ltd	Submersible pump	No
CJBH02	-27.92176	22.99778	1244.00	-	-	Coza Mining (Pty) Ltd	Windmill blocking access	No
CJBH03	-27.94182	22.99780	1250.00	54	13.2	Coza Mining (Pty) Ltd	Submersible pump	Yes
CJBH04	-27.93983	22.99918	1251.00	-	-	Coza Mining (Pty) Ltd	Windmill blocking access	No
PC-A21	-27.91238	23.01132	1258.00	92	-	Coza Mining (Pty) Ltd	Borehole blocked at 13m	No
PC-A25	-27.91679	23.01151	1254.00	113	-	Coza Mining (Pty) Ltd	Welded shut	No
PC-A29	-27.92116	23.01157	1259.00	68	-	Coza Mining (Pty) Ltd	Welded shut	No
PC-A32	-27.92040	23.00625	1251.00	99	-	Coza Mining (Pty) Ltd	Welded shut	No
PC-A33	-27.91438	23.00682	1245.00	119	-	Coza Mining (Pty) Ltd	Welded shut	No
RC-JNR02	-27.91893	23.01990	1327.00	93	-	Coza Mining (Pty) Ltd	Dry at 103m	No
RC-JNR12	-27.91842	23.01645	1294.00	134	-	Coza Mining (Pty) Ltd	Dry/Blocked at 16m	No
RC-JNR15	-27.91632	23.01434	1272.00	132	14.0	Coza Mining (Pty) Ltd	None	No
RC-JNR19	-27.92324	23.01504	1277.00	177	-	Coza Mining (Pty) Ltd	Dry/Blocked at 9.5m	No
RC-JNR20	-27.92075	23.02067	1340.00	122	121.3	Coza Mining (Pty) Ltd	None	No
RC-JNR27	-27.91865	23.01817	1316.00	168	109.1	Coza Mining (Pty) Ltd	None	No
RC-JNR29	-27.92402	23.01946	1322.00	158	101.9	Coza Mining (Pty) Ltd	None	No
RC-JNR31	-27.92282	23.01885	1320.00	104	-	Coza Mining (Pty) Ltd	Borehole deeper than 150m	No
RC-JNR35	-27.91703	23.01675	1302.00	170	88.4	Coza Mining (Pty) Ltd	None	No
RC-JNR41	-27.92249	23.01727	1299.00	108	81.0	Coza Mining (Pty) Ltd	None	No
RC-JNR43	-27.92424	23.01623	1285.00	145	-	Coza Mining (Pty) Ltd	Dry/Blocked at 89.4m	No

BH	Coordinates		Elevation	Depth	Water level	Owner	Comment	Sampled
	South	East						
RC-JNR46	-27.92086	23.01823	1312.00	163	89.2	Coza Mining (Pty) Ltd	None	No
RC-JNR54	-27.91479	23.01441	1275.00	158	61.7	Coza Mining (Pty) Ltd	None	No
RC-JNR55	-27.91826	23.01501	1278.00	153	68.1	Coza Mining (Pty) Ltd	None	No
RC-JNR56	-27.91975	23.01456	1277.00	123	43.0	Coza Mining (Pty) Ltd	None	No
RC-JNR58	-27.91997	23.01630	1293.00	130	66.4	Coza Mining (Pty) Ltd	None	No
RC-JNR60	-27.92127	23.01676	1296.00	119	79.1	Coza Mining (Pty) Ltd	None	No
RC-JNR63	-27.92182	23.01496	1271.00	103	63.9	Coza Mining (Pty) Ltd	None	No
GP01	-27.98470	22.96437	1261.00	32	22.0	Danelle Family Trust	Windmill	Yes
GP02	-27.98305	22.96396	1261.00	-	19.1	Danelle Family Trust	Windmill	Yes
GP03	-27.95054	22.96783	1246.00	19	18.4	Danelle Family Trust	Windmill	No
GP04	-27.94843	22.96906	1244.00	-	-	Danelle Family Trust	Probe on borehole	No
GP05	-27.94758	22.96915	1244.00	150	17.5	Danelle Family Trust	No pump on borehole	Yes
GP06	-27.94242	22.94755	1243.00	-	15.1	Danelle Family Trust	Windmill	Yes
GP07	-27.95003	22.94744	1243.00	-	-	Danelle Family Trust	Monopump	No
GP08	-27.95419	22.94774	1244.00	21.5	17.8	Danelle Family Trust	Windmill	No
ROC01	-27.91095	22.95095	1231.00	-	-	Roscoe Farm	Solar pump obstruction	No
ROC02	-27.93102	22.94825	1239.00	29.5	19.1	Roscoe Farm	Windmill	No
ROC03	-27.91095	22.95063	1231.00	26.5	20.2	Roscoe Farm	Windmill	Yes
ROC05	-27.90738	22.95014	1229.00	23.5	18.0	Roscoe Farm	Windmill	No
ROC06	-27.91472	22.92540	1236.00	-	-	Roscoe Farm	Windmill blocking access	Yes
ROC07	-27.90915	22.90977	1228.00	21.5	-	Roscoe Farm	Windmill	Yes
ROC08	-27.89714	22.92297	1224.00	55	24.5	Roscoe Farm	Windmill	Yes
ROC09	-27.89623	22.95847	1222.00	21	16.9	Roscoe Farm	Windmill	Yes

Note: *Coordinates – WGS84.*

1.3.2 GROUNDWATER ZONE

The following aspects typically delineate the applicable "groundwater zone":

- The thickness, soil characteristics, infiltration rate and water bearing properties of the unsaturated zone,
- The geological properties and dimensions of each unit in the geological column that could potentially be impacted upon by groundwater contamination. This includes rock type, thickness of aquifer(s) and confining units, aerial distribution, structural configuration, storativity, water levels, infiltration or leakage rate, if appropriate,
- Aquifer recharge and discharge rates,
- The direction and rate of groundwater movement in potentially impacted units,
- Groundwater and surface water relationships,
- Background water quality of potentially impacted units,
- Potential sources and types of contamination.

1.3.2.1 UNSATURATED ZONE

Soil development in the project area is relatively poor and soils are mostly limited to Kalahari sands and calcrete or a combination thereof. The soil horizon in the vicinity of the proposed pit consists mostly of the saprolite type with very little or no actual soil fraction. The unsaturated zone consists of calcrete or sandy alluvium of the Kalahari quaternary deposit type. Weathered calcrete and wind-transported sand of Kalahari-type occurs in depressions and topographical lower lying areas. The latter areas are also the only places where any degree of cultivation and crop irrigation is possible but such is virtually non-existent in the Jenkins region due to the hot and dry climate. The unsaturated zone may impact on the aquifer in terms of both groundwater quality and quantity.

The permeability and thickness of the unsaturated zone are some of the main factors determining the infiltration rate, the amount of runoff and consequently the effective recharge percentage of rainfall to the aquifer.

The type of material forming the unsaturated zone as well as the permeability and texture will significantly influence the mass transport of surface contamination to the underlying aquifer(s). Factors like ion exchange, retardation, bio-degradation and dispersion all play a role in the unsaturated zone.

The thickness of the unsaturated zone was determined by subtracting the pre-mining static water levels in the project area from the topography. Water level measurements in purpose-drilled monitoring boreholes, boreholes of users in the area as well as in exploration boreholes showed that the depth to water level, and thus the unsaturated zone, generally varies between ± 2 and 275 meters below surface **(Figures 12** and **13)**.

Although the calcrete is very hard and seemingly impermeable at surface, studies at the nearby mining operations have shown that infiltration rates through the unsaturated zone are high in places. Small cracks and openings cause high surface water infiltration areas that allow for significant recharge ratios under favorable conditions.

1.3.2.2 GEOLOGY OF THE PROJECT AREA

Regional Geology:

Iron ore in the wider project area is preserved in chemical and clastic sediments of the Proterozoic Transvaal Supergroup. These sediments define the western margin of the Kaapvaal Craton in the Northern Cape Province. The stratigraphy has been deformed by thrusting from the west and has also undergone extensive karstification. The thrusting has produced a series of open, north south plunging, anticlines, synclines and grabens. Karstification has been responsible for the development of deep sinkholes. The iron ore in the project area has been preserved from erosion as low hills due to high hardness. The iron ore deposits that are actively mined in the area are all located on the Maremane anticline structure.

The Transvaal Supergroup lithologies have been deposited on a basement of Archaean granite gneisses and greenstones, and/or lavas of the Ventersdorp Supergroup. In the Jenkins region, the oldest rocks of the Transvaal Supergroup form a carbonate platform sequence (dolomites with minor limestone, chert and shale) known as the Campbell Rand Subgroup. The upper part of the Transvaal Supergroup comprises a banded iron formation unit, the Asbestos Hills Subgroup, which has been conformably deposited on carbonates of the Campbell Rand Subgroup. The upper portion of the banded iron formations has in places been supergene-enriched to ore grade, i.e. Fe ≥ 60%. The ores found within this Subgroup comprise the bulk of the higher-grade iron ores in the region.

An altered, intrusive sill (originally of gabbroic composition) usually separates the ore bodies from the underlying host iron formation. It intruded into the Transvaal Supergroup in late Proterozoic times. A thick sequence of younger clastic sediments (shale’s, quartzite’s and conglomerates) belonging to the Gamagara Subgroup unconformably overlies the banded iron formations. Some of the conglomerates consist almost entirely of hematite and are of lower-grade ore quality.

The unconformity separating the iron formations from the overlying clastic sediments represents a period of folding, uplift and erosion. At the time, dissolution and karstification took place in the upper dolomitic units. A residual dissolution breccia, referred to as the ‘Manganese Marker’ or ‘Wolhaarkop Breccia’, developed between the basal dolomites and overlying banded iron formations. This breccia is known to contain/yield vast volumes of groundwater. In places, deep sinkholes developed in the dolomites, into which the overlying iron formation and mineralized iron ore bodies collapsed. The sinkholes are considered to have resulted from a combination of folding and collapse of overlying iron-bearing strata. At Jenkins, however, the iron ore has been preserved through resistance to weathering and occurs as part of a low hill similar to adjacent deposits such as the Mokaning reserves of Assmang’s Khumani Mine.

Diamictite of the Makganyene Formation and lava belonging to the Ongeluk Formation have been thrusted over the Gamagara sediments. It is now preserved only within the larger synclinal structures. A considerable portion of the upper parts of the stratigraphy have been eroded during Dwyka glaciation and re-deposited as tillite.

The entire, folded sequence was later truncated by Tertiary erosion. A thick (10 to around 60 m) blanket of calcrete, dolocrete, clays and pebble layers belonging to the Kalahari Supergroup was unconformably deposited over the older lithologies.

Site Specific Geology *(PGS Heritage, 2013)*:
According to Moen *(Moen HFG, 1977)* the farm Jenkins is underlain by rocks of the Gamagara Subgroup (Vg), Asbestos Hills Subgroup as well as rocks of the Lime Acres Member of the Ghaap Plato Formation (Vgl) of the Campbell Rand Subgroup. The rocks of the Gamagara Subgroup underlie the eastern corner of the Jenkins farm. This subgroup consists of quartzites, conglomerates, flagstones and shales and constitutes the base of the Postmasburg Group.

Lenticular basal conglomerates contain pebbles of jasper and banded iron stone and are completely ferruginised in places. The shales contain lenses of conglomerate and are also locally ferruginised or manganised. Ferruginous flagstone and white, purple and brown quartzites form the top of the Subgroup.

Rocks of the Lime Acres Member of the Ghaap Plato Formation of the Campbell Rand Subgroup consist of dolomitic limestone with subordinate coarsely crystalline dolomite and chert with lenses of limestone. Stromatolitic puckered limestone consisting of alternating dark and light bands can be found. Lenticular bodies of limestone occurring in the dolomite are probably the result of irregular dolomitisation of the original limestone.

A simplified geological map of the Jenkins Project area is provided in **Figure 5**.

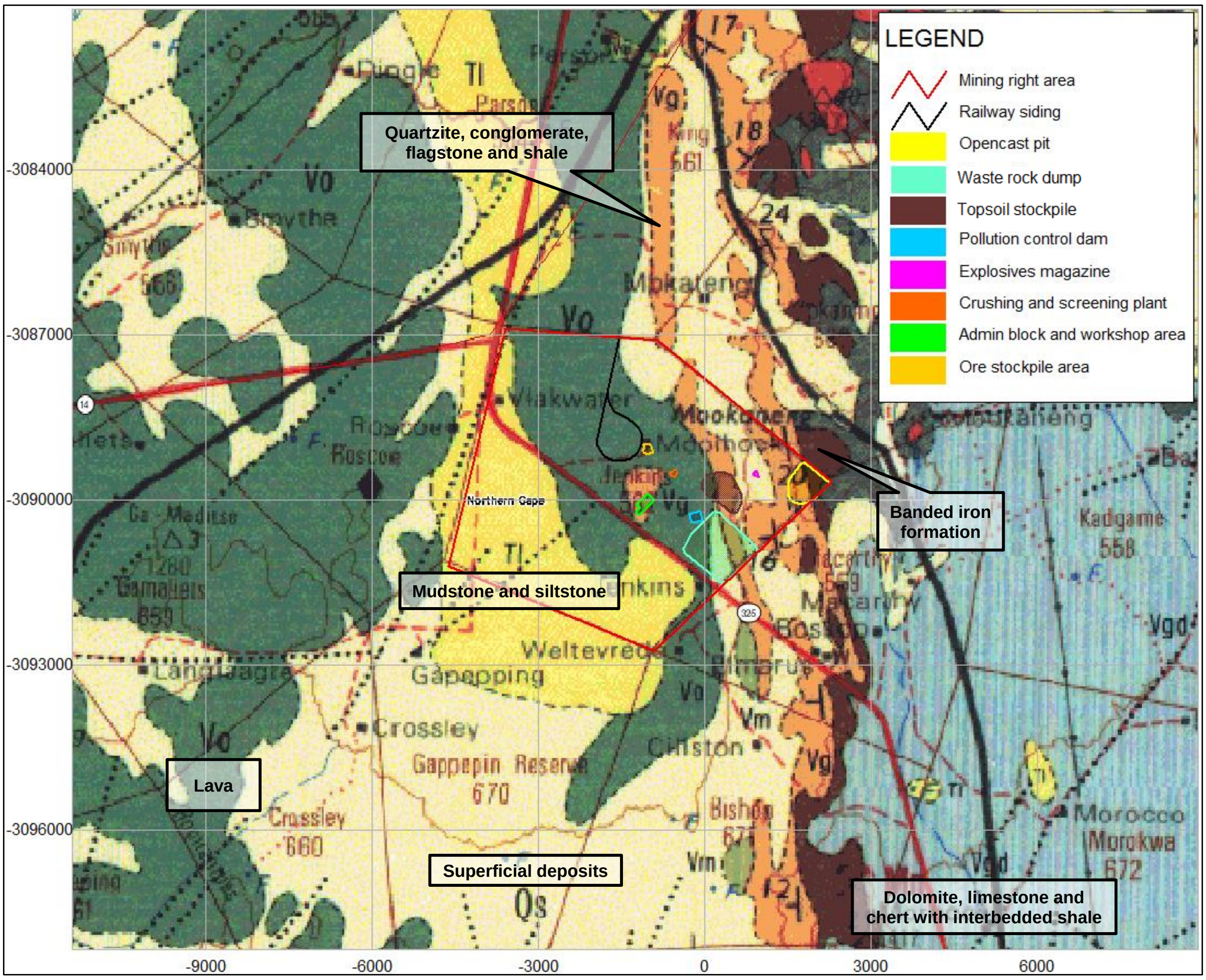


Figure 5: Simplified geological map (1:250 000) of the Jenkins Project area

1.3.2.3 GEOPHYSICAL INVESTIGATION

A geophysical investigation was conducted in June 2015 for the purpose of the geohydrological study to delineate geological structures such as faults and intrusive features like dolerite dykes. The main aim of the survey was to site monitoring boreholes in areas where potential impacts from the mining related activities may occur. The secondary aim was also to delineate or confirm the southern boundary of the Sishen Compartment.

Geological structures such as dykes and faults are generally targeted when drilling for groundwater, as they are considered to act as preferred pathways for groundwater flow and mass transport (contamination). Dykes are widespread throughout the study area and some of the more prominent ones are easily identifiable on aerial and satellite imagery. Fractures are typically formed along the sides of a dyke due to rapid cooling during the intrusion process. These fractures are wholly responsible for most dykes being able to hold significant volumes of groundwater and also to act as preferred pathways. However, these fractures are generally superficial and do not affect the structural integrity of the dyke.

This means that a dyke may also act as an effective barrier for the flow of groundwater perpendicular to its strike. In an area, such as the project area, where numerous dykes occur in various strike directions, groundwater compartments are formed, which may be independent from one another with regards to groundwater hydraulics and chemistry.

A combination of magnetic and electro-magnetic methods was used during the survey and the geophysical line survey graphs are provided in **Appendix B**.

During the survey of twelve traverses a total of 16 anomalies were identified and their positions are indicated in **Figure 6**. These traverses were mainly concentrated along the southern border of the Sishen compartment as well as geological structures that were identified remotely on satellite images. The southern border is defined by a geological structure located approximately 600 meters north of the proposed Jenkins pit and has a strike of west-east **(Figure 7)**. This structure is believed to be a dolerite dyke and may therefore act as a barrier between groundwater level impacts caused by the mines to the north and the Jenkins Project area located south of the dyke.

The southern border of the Sishen compartment was traversed five times during the geophysical survey. Despite the fact that anomalies (possible structures) were identified, two of the five traverses (Lines 6 and 9 in **Appendix B**) showed no signs of any significant geological structure. The conclusion is therefore drawn that the geophysical survey conducted for the purpose of the Jenkins Project does not entirely support Sishen's current understanding and delineation of the southern border of the compartment. As will however be seen in the discussion of water level distribution, some geological feature does form a barrier that prevents the southward extension of the Sishen depression cone. From the geophysical investigation it seems that the boundary may be formed by a dipping geological contact in the area rather than a sub-vertical dolerite dyke.

A total of seven monitoring boreholes were drilled on anomalies identified during the geophysical survey. Please refer to **Section 4** of the report for a full discussion on the drilling results and proposed monitoring program.

Information gained from the drilling of the monitoring boreholes as well as pump tests performed in the project area was used in the postulation of a conceptual model and the construction and calibration of numerical flow and mass transport models.

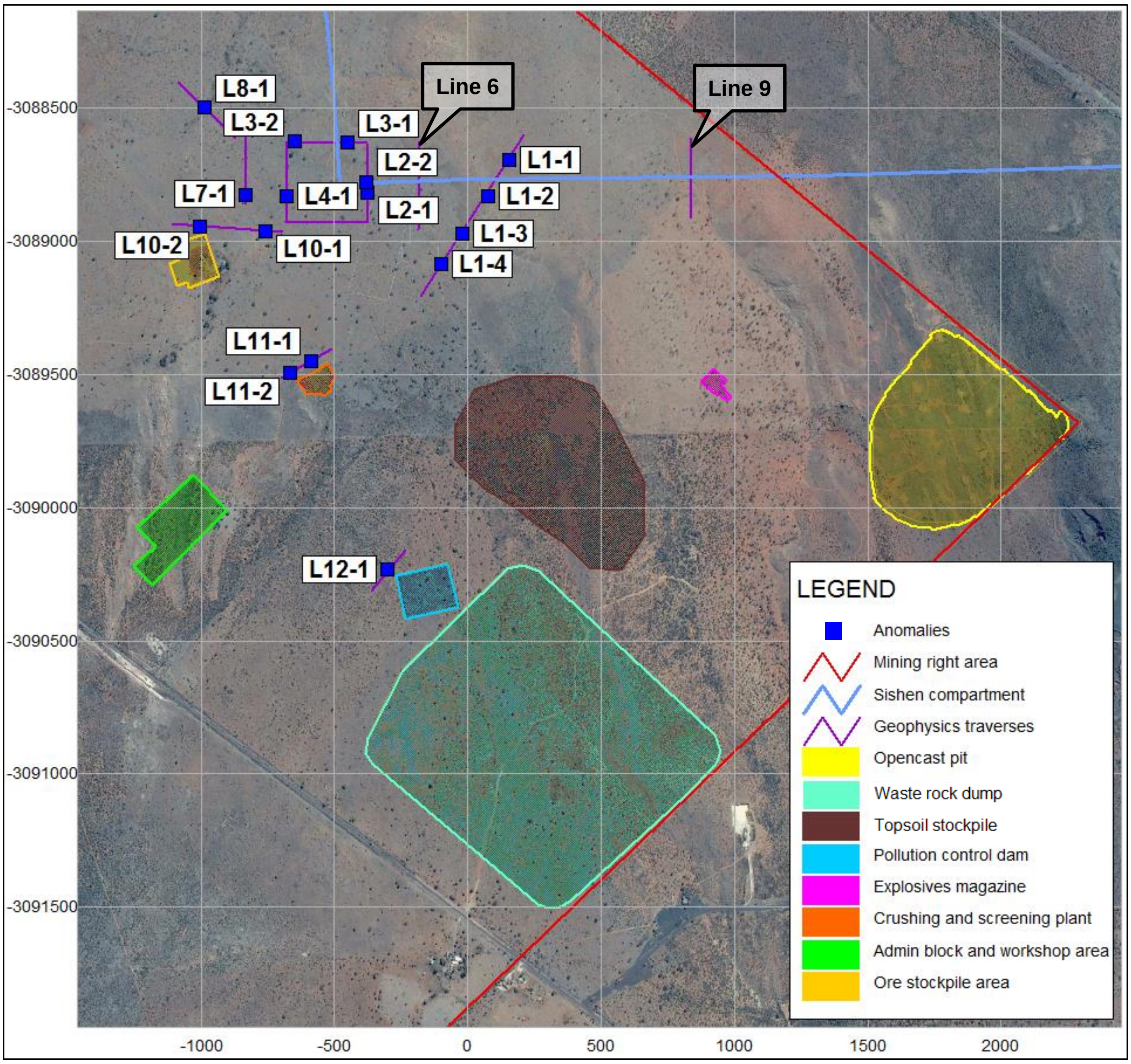


Figure 6: Positions of anomalies identified during geophysical survey

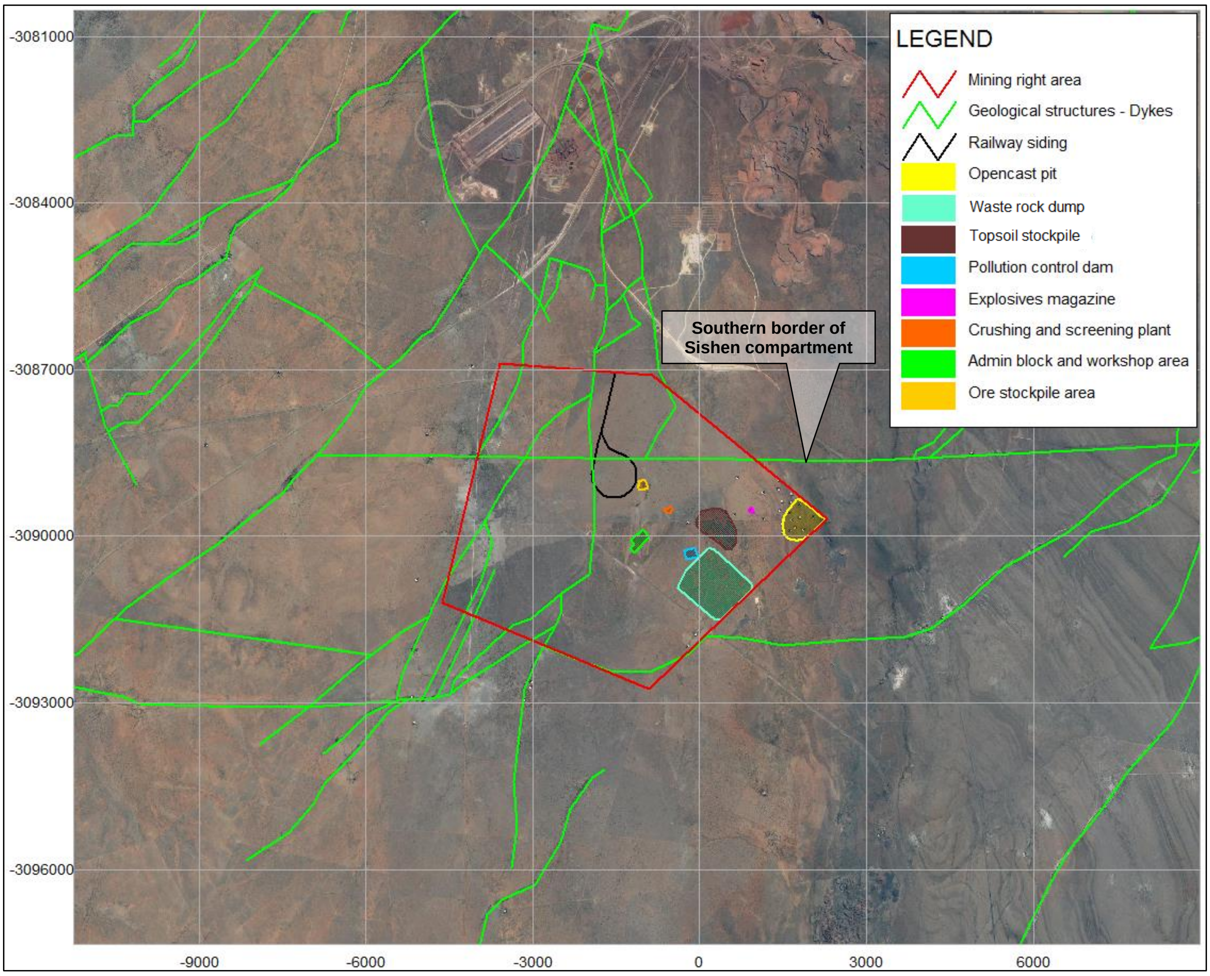


Figure 7: Occurrence of dykes within project area and immediate surroundings

1.3.2.4 AQUIFER DELINEATION

Aquifer delineation is conducted to show which part of the aquifer was used or considered during simulation exercises (numerical modeling). Because the main aquifer is a fractured rock type and fractures could assume any geometry and orientation, the physical boundary or 'end' of the aquifer is very difficult to specify or quantify. More appropriately, the aquifer boundary conditions that were considered during numerical model simulations are described below.

No-flow boundaries in a model, as in nature, are groundwater divides (topographic high or low areas/lines) and geological structures (dykes) across which no groundwater flow is possible.

Constant head boundaries are positions or areas where the groundwater level is fixed numerically/mathematically at a certain elevation and cannot change (perennial rivers/streams or dams/pans). No such boundaries were simulated due to the absence of such features in the Jenkins/Sishen region.

General head boundaries are boundaries through which groundwater movement is possible. The rate at which the groundwater will move through the boundary depends on the groundwater gradients as well as the hydraulic conductivities on opposite sides of the boundary position.

General head boundaries in combination with no-flow boundaries were used as model boundaries in the regional model constructed to include the proposed Jenkins mining area **(Figure 8)**. General head boundaries were applied in some areas as a result of the absence of prominent/confirmed no-flow and/or constant head boundaries within the immediate vicinity of the project area. The boundaries were constructed far enough away from the planned mining activities to ensure that they do not influence the groundwater flow and mass transport simulations discussed in **Sections 3.3.1** and **3.3.2** respectively.

To the experienced modeler the question will immediately arise as to why the Jenkins area is situated close to the southern boundary of the large model grid. The reason for this is simply the fact that mine dewatering at Sishen Mine has caused significant dewatering that extends in a north-south elongated compartment right down to the Jenkins area. These dewatering effects dominate the groundwater flow in the entire region (Sishen Mine, Khumani Mine and the Jenkins area) and had to be incorporated in the Jenkins model simulation.

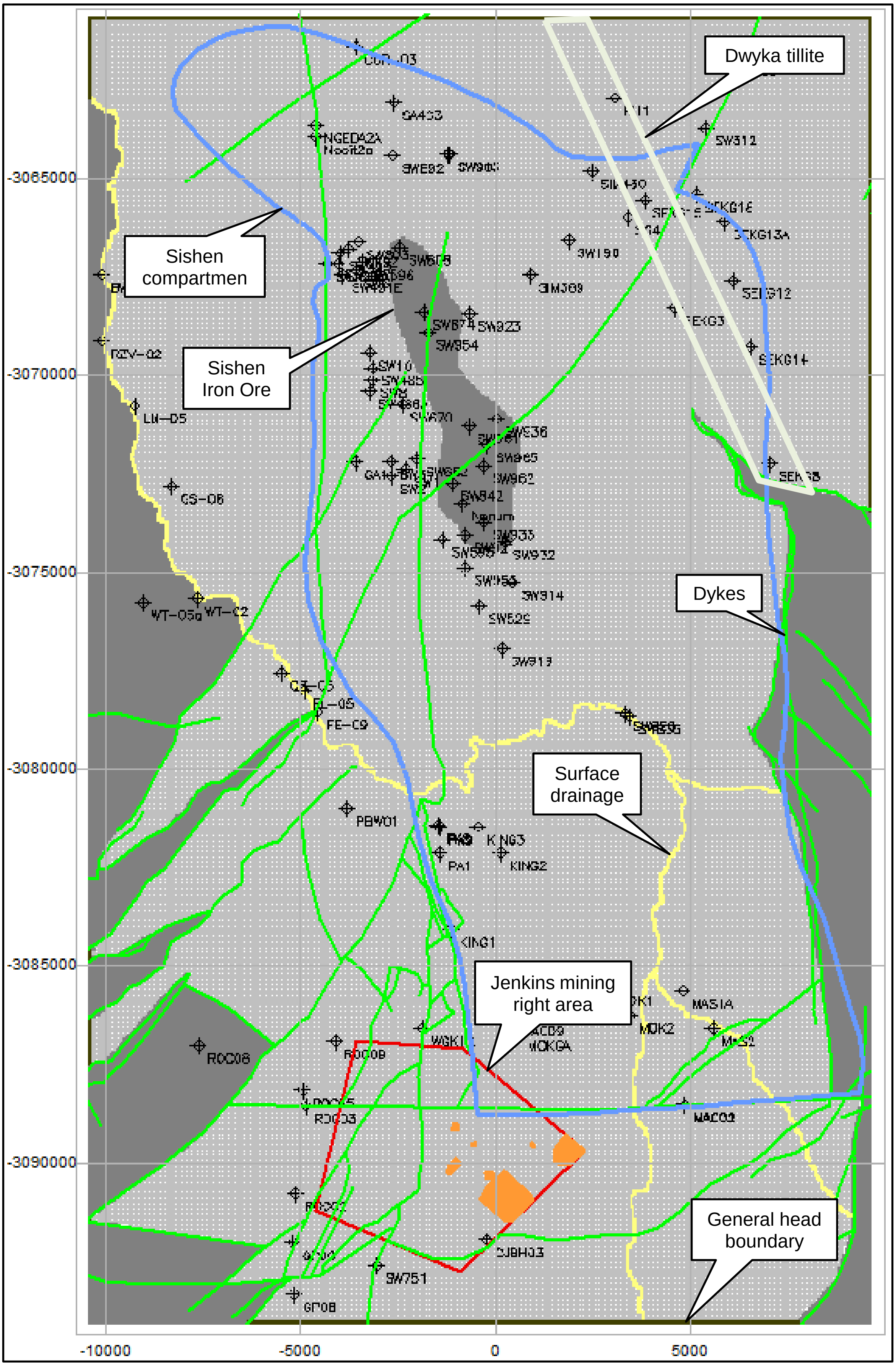


Figure 8: Regional numerical model grid

1.3.2.5 AQUIFER THICKNESS

Aquifer thickness in a fractured rock aquifer is virtually impossible to determine as the actual 'aquifer' consists of fractures with any orientation, dip, strike or aperture. Considering the fact that the actual 'aquifer' consists of transmissive fractures, fissures or cracks of any orientation, extent of aperture in any of the rock types underlying the site, an approximation can at best be made on the thickness of the aquifer.

Aquifer thickness for the project area is therefore considered to be the difference between the static groundwater level and the deepest water yielding fracture. Numerous water-yielding fractures were intersected in different geological units during the drilling of monitoring boreholes in the project area. Such fractures occurred at depths varying between ± 22 and 44 meters below surface. The aquifer thickness in the Jenkins Project area is therefore expected to vary between approximately 5 and 30 meters.

Please note that the estimation of the aquifer thickness includes both the shallow weathered zone aquifer and deeper fractured rock aquifer as additional drilling data is required to make a clear distinction. It is also the experience of Groundwater Complete that there is often not a clear layer or formation that separates the shallow and deeper aquifer. The distinction is mainly made based on the degree of primary or secondary porosity of the aquifer(s) due to weathering.

1.3.2.6 GENERALISED CONCEPTUAL MODEL

In order to predict the movement of water and mass in the subsurface, a conceptual geohydrological model of the area was formulated. The basis of such a model is the structural geological make-up of the project area. A conceptual model can therefore be described as being the holistic understanding of the integral workings of the geohydrological regime as well as the interactions it may have with other natural systems (i.e. surface water environment).

The geohydrological regime in the project area is made up of two main aquifer systems. The first, the upper, unconfined to semi-confined aquifer occurs in the weathered zone. The aquifer is usually developed on the contact between the weathered zone at surface and the underlying un-weathered clay or hard rock formations. Although relative low yields occur in this shallow aquifer, it is developed widely throughout most of the project area and has been the sole reliable source of water supply to most of the farms in the area for more than a century. Yields of up to 2 liters per second occur in this aquifer with a shallow water table and spring formation common, especially in the lower-lying topography.

The second aquifer is associated with fractures, fissures, joints and other discontinuities within the consolidated bedrock and associated intrusives of the Transvaal/Griqualand West Sequences. The aquifer occurs at depths of more than 50 meters below surface in the project area. It is semi-confined and has greatly varying yields that are directly associated with the geology and geological structure.

The aquifer yield may be as high as 40 liters per second and more in mainly the chert breccia (Manganese Marker) and iron ore formations. Contrary to general beliefs, the dolomite in the mining area is not a significant aquifer and yields of no more than 2 to 4 liters per second have been recorded. The dolomite is however considered to have good storage properties for groundwater.

Mining in the Jenkins mine boundary area will penetrate both the calcrete and deeper bedrock aquifers and the physical structure of these two aquifers will be destroyed in the pit. The shallow aquifer is mostly absent at the position of the proposed Jenkins pit due to the hill-like topography where the ore body occurs.

Water entering the system will migrate vertically downwards until a more impervious layer that forms a perched aquifer is encountered. Over the longer term (after a year and more) it is likely that the majority of recharge water will migrate downwards into the saturated zone of the deeper solid bedrock aquifer. From there it will migrate in the direction of the hydraulic gradient until it eventually reaches discharge areas.

With the dewatering foreseen for the proposed Jenkins pit, significant groundwater gradients will be created towards the pit and groundwater flow directions will change towards this area. The local change in groundwater flow directions is caused by the formation of a cone of depression due to mine dewatering. **Please note that the pit floor is expected to intersect the water table during year seven of mining and only thereafter will the groundwater gradients be affected. The groundwater influx is not expected to exceed ± 500 m^3/d, or 5.8 l/s at the time of mine closure.** The concept of mine dewatering and subsequent formation of a depression cone is illustrated in **Figure 9**.

The lateral rate of migration usually exceeds the vertical rate, especially in a predominantly sedimentary rock environment where the layers are more or less horizontal. In the project area horizontal movement would be strongly determined by the presence, extent and orientation of the highly transmissive chert breccia and iron ore formation. Given the general north-south orientation of these transmissive deposits/formations, the impact of dewatering is also expected to be orientated as such, i.e. the cone of depression is expected to be elongated in a north-south direction.

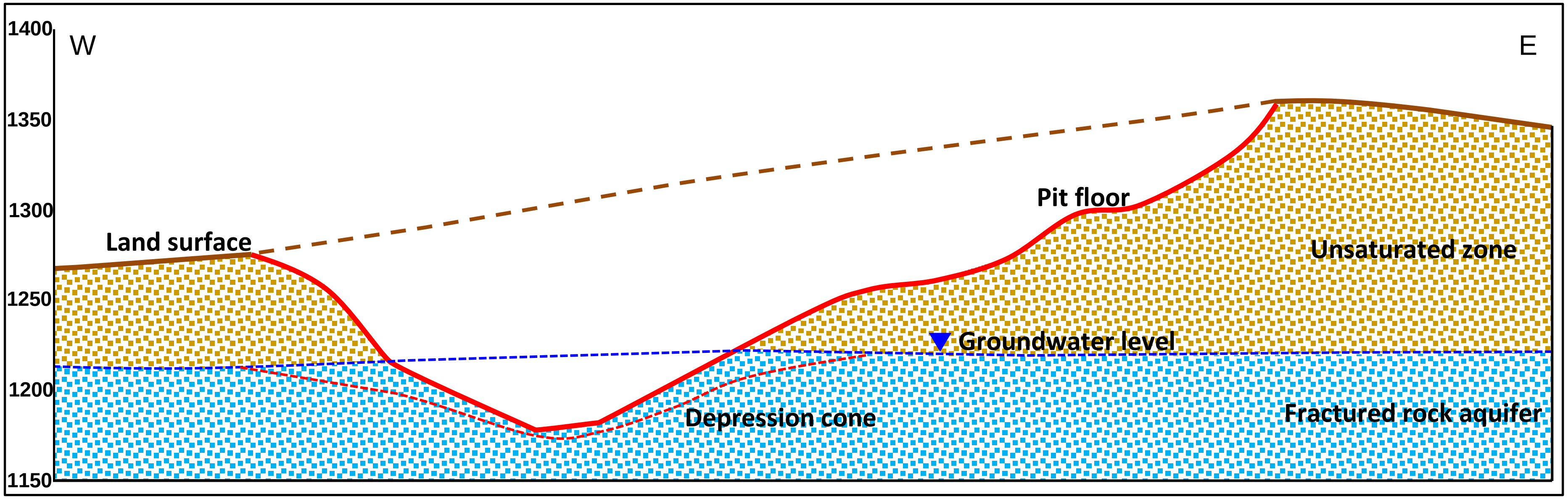


Figure 9: Section through proposed Jenkins pit

Please note that although the section is extended in the vertical dimension and not drawn to scale it is based on actual elevations of the surface topography, the measured (current) static water level and the proposed final pit shell geometry. The position of the above section is indicated in **Figure 30** with the use of a dashed line.

1.3.3 PRESENCE OF BOREHOLES AND SPRINGS

As mentioned earlier, a hydrocensus and groundwater user survey was conducted on the Jenkins mining right area and surrounding properties **(Table 1)**. The survey area was extended because the radius of influence depends strongly on geological structures such as faults and dykes (preferred groundwater flow paths), groundwater gradients, nearby mining operations and the presence of other groundwater production boreholes or dewatering from mining in the area.

Different types of groundwater information was obtained for a total of 52 points during the groundwater user survey conducted for the Jenkins Project. The water supply source of nearby users was sampled and analyzed for macro element inorganic chemistry.

No springs were recorded in the area under investigation. Springs in a semi-confined or confined fractured rock aquifer usually occur where structural discontinuities in the aquifer bisect the confining layer/material and a fracture or fracture system reaches the surface. For a spring to occur, the water level or piezometric head at that point in the aquifer must be higher than the land surface.

Although the natural trend for the groundwater level or piezometric head is to follow the surface topography, the water level is the closest to surface in the topographic low-lying areas. For this reason, springs will mostly occur in these areas, or at least on the slopes of hills. In perched and confined aquifers however, groundwater or piezometric levels may also be high in topographic higher lying areas with subsequent spring formation.

1.4 GROUNDWATER FLOW EVALUATION

1.4.1 DEPTH TO WATER LEVEL

Groundwater level information was obtained from the following sources:

- Newly drilled source monitoring boreholes,
- Surrounding groundwater user boreholes,
- Exploration boreholes, and
- Dedicated groundwater level monitoring boreholes drilled and monitored by Sishen Iron Ore Mine and Khumani Mine

Large volumes of groundwater are being extracted by the Sishen Iron Ore Mine for mine dewatering purposes. In accordance with DWAF regulations a comprehensive monitoring program has been established to monitor groundwater level response to the dewatering activities as well as to define the influenced area (cone of depression). The Sishen Iron Ore Mine is located approximately 12 kilometers north of the Jenkins Project area and the depression cone created by the extensive mine dewatering activities is known to extend in a north-south direction. A comprehensive assessment of not only the local but also regional groundwater level conditions was deemed necessary in an attempt to define the area influenced by the existing iron ore mines.

This information plays a vital role in the conceptual understanding of the geohydrological system underlying the project area and also in the construction of an encompassing numerical flow model. Mine dewatering may influence the Jenkins Project area in more than one way, namely:

- The direction of groundwater migration in the saturated zone may change,
- Groundwater gradients may increase, which will also lead to an increase in the groundwater flow velocity.

Sishen Iron Ore Mine was approached by Groundwater Complete and after being informed of the situation provided groundwater level monitoring data as well as a map indicating aquifer boundaries believed to define the aquifer compartment in which mining occurs **(Figures 12** and **13)**.

A graph of borehole collar elevation versus groundwater level elevation is presented in **Figure 11**. This graph was used to distinguish between groundwater levels that are affected by the existing mining activities (boreholes in red zone) and those that are unaffected (plot on linear trendline). A linear correlation of approximately 97% was achieved for boreholes unaffected by mining activities **(Figure 11)**.

Based on this distinction, thematic water level maps are provided in **Figures 12** and **13** for both groups of boreholes. These water levels are essential as they enabled distinction between impacted water levels (in the Sishen compartment or otherwise) and natural steady state water levels. The latter were used in the generation of static groundwater level elevations with the use of the Bayesian interpolation method and steady state numerical groundwater flow model calibration **(Figure 14)**, i.e. water level elevations before the effect of Sishen Mine dewatering. The water level elevations that deviated from the relationship meant that they were impacted and therefore helped in defining the Sishen compartment or other impacted boreholes.

Groundwater levels of boreholes unaffected by the mining activities generally vary between ± 2 and 34 meters below surface **(Figure 12)**. Variations in groundwater levels are mainly the result of aquifer heterogeneity and significant compartmentalisation. On the other hand, boreholes believed to be affected display water levels of between ± 43 and 275 meters below surface **(Figure 13)**.

The hematite iron ore and chert breccia are characterised by significant fracturing and are roughly orientated in a north-south direction. The dewatering activities of the Sishen Iron Ore Mine therefore occur in aquifer host rock characterised by high transmissivities, causing the depression cone to extend in a north-south direction over a large area (total distance of ± 23 kilometers from north to south). The effect that aquifer transmissivity has on the extent of groundwater level impacts (depression cone) is illustrated in **Figure 10**.

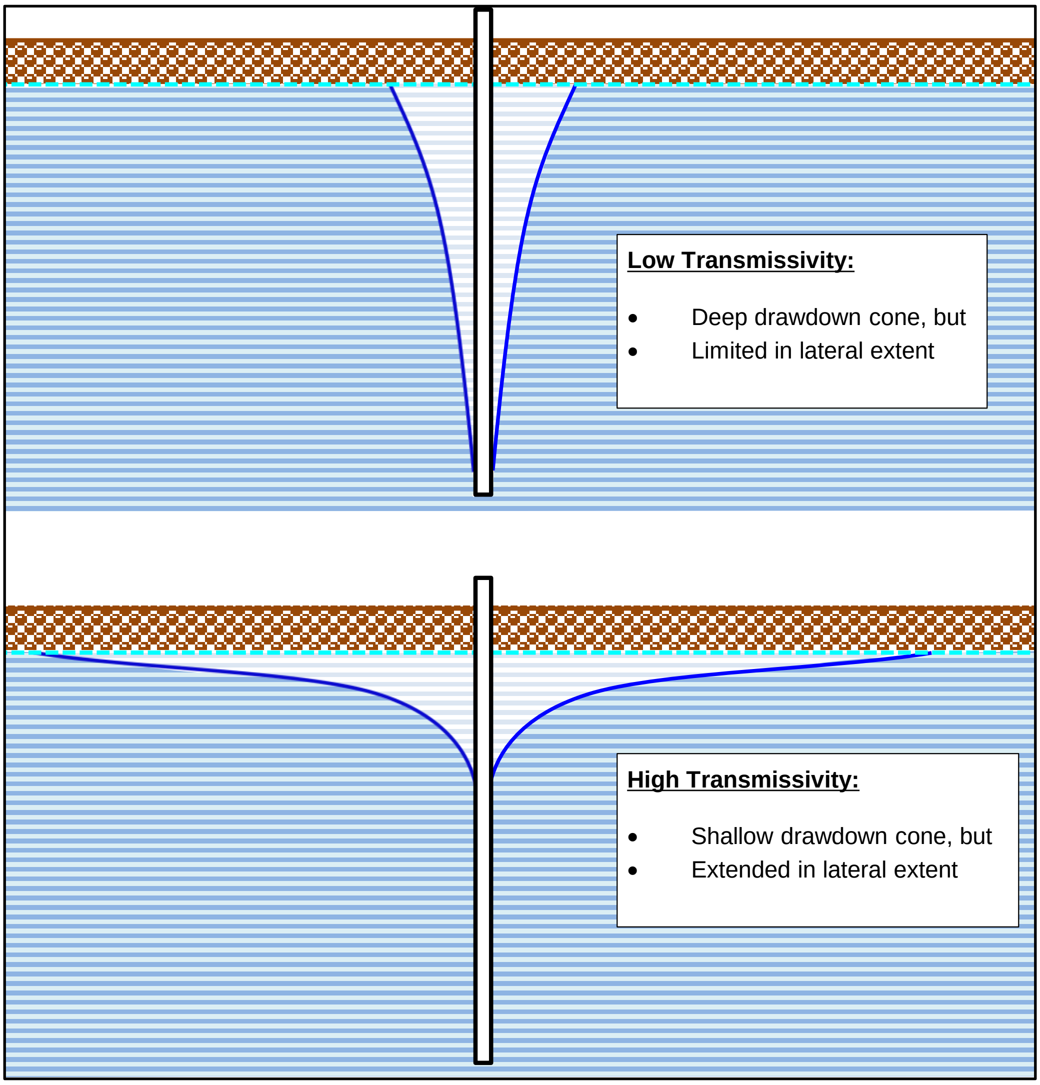


Figure 10: Effect of aquifer transmissivity on depression cone

A static groundwater elevation contour map for the project area is provided in **Figure 14**. The map was generated by means of a numerical flow model, which was calibrated using groundwater level information from approximately 200 boreholes located in the modelled area. The map represents current groundwater level conditions and shows the area believed to be affected by the Sishen dewatering activities, i.e. depression cone. **The interpolated potentiometric surface of the water levels is bound to contain local over- or under estimations of the actual water levels but is representative of the general regional trend of the static groundwater level.**

The highest static water level elevation in the model area is approximately 1 280 mamsl and occurs in the topographically higher region towards the south-east of the mining right application area **(Figure 14)**. The lowest static water level elevation **where no impact from abstraction/dewatering occurs** is at approximately 1 120 mamsl in the north-western down gradient direction towards the Ga-Mogara River.

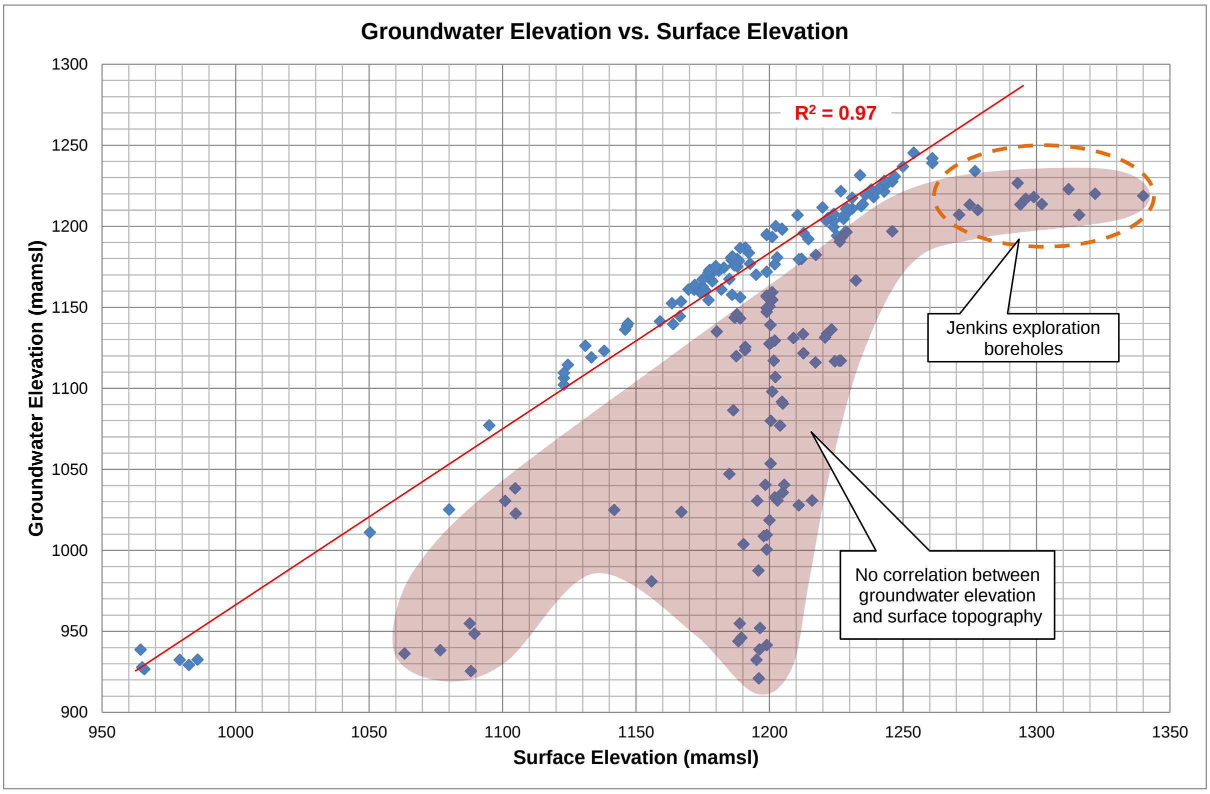


Figure 11: Relationship between surface and water level elevation

Please note that the static water levels of the Jenkins exploration boreholes plot outside the linear trendline **(Figure 11)**, meaning their groundwater levels do not follow the surface topography. This natural tendency for groundwater levels to follow the surface topography can be disturbed by means of groundwater abstraction or artificial aquifer recharge. Groundwater levels are also known to deviate from this relationship in mountainous areas or steeper topographies, where water levels are generally much deeper in comparison to lower lying topographies and valleys. We consider the plot positions of Jenkins exploration boreholes on the above graph to be the result of sudden changes in the surface topography rather than groundwater abstraction/dewatering at Sishen.

Conceptual groundwater flow directions within the project area are indicated in **Figure 14** with the use of blue arrows. The natural groundwater flow direction from the Jenkins mining right area is expected to be towards the north and eventually north-west in the direction of the Ga-Magara River. Groundwater will follow the natural groundwater gradient towards the north until it reaches the depression cone created by the Sishen dewatering activities. From here we expect groundwater seepage to deviate from its natural flow path and continue in a more or less northerly direction until it eventually reaches the Sishen Pit or dewatering boreholes.

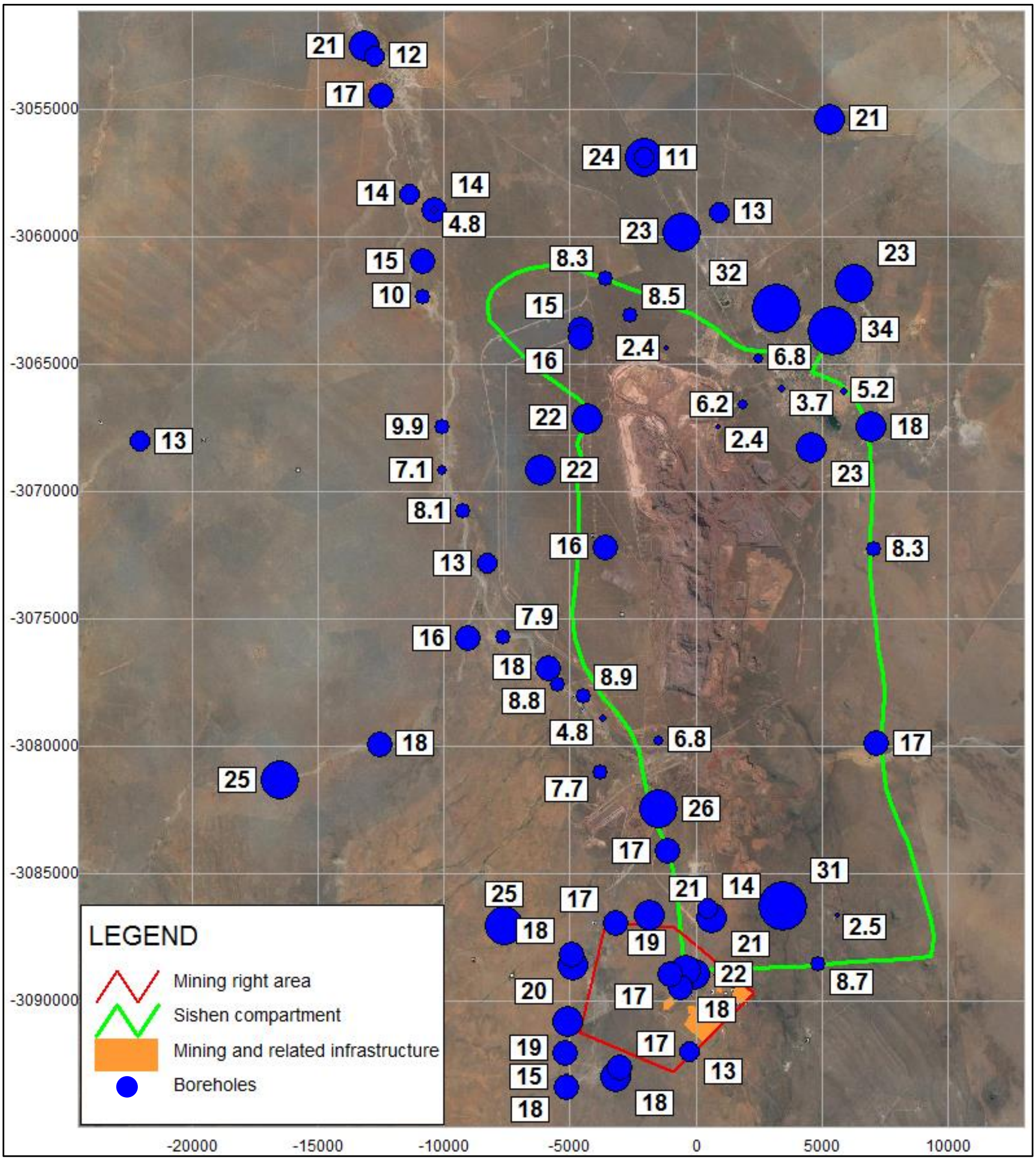


Figure 12: Thematic map of groundwater levels unaffected by mining activities

Notes:
- *The numbers in the above figure indicate the groundwater level depth below surface in meters,*
- *The size of the blue circles is directly proportional to the groundwater level depth, hence the largest circle represents the deepest water level,*
- *All boreholes indicated in above figure show good correlation between groundwater elevation and surface topography **(Figure 11)**.*

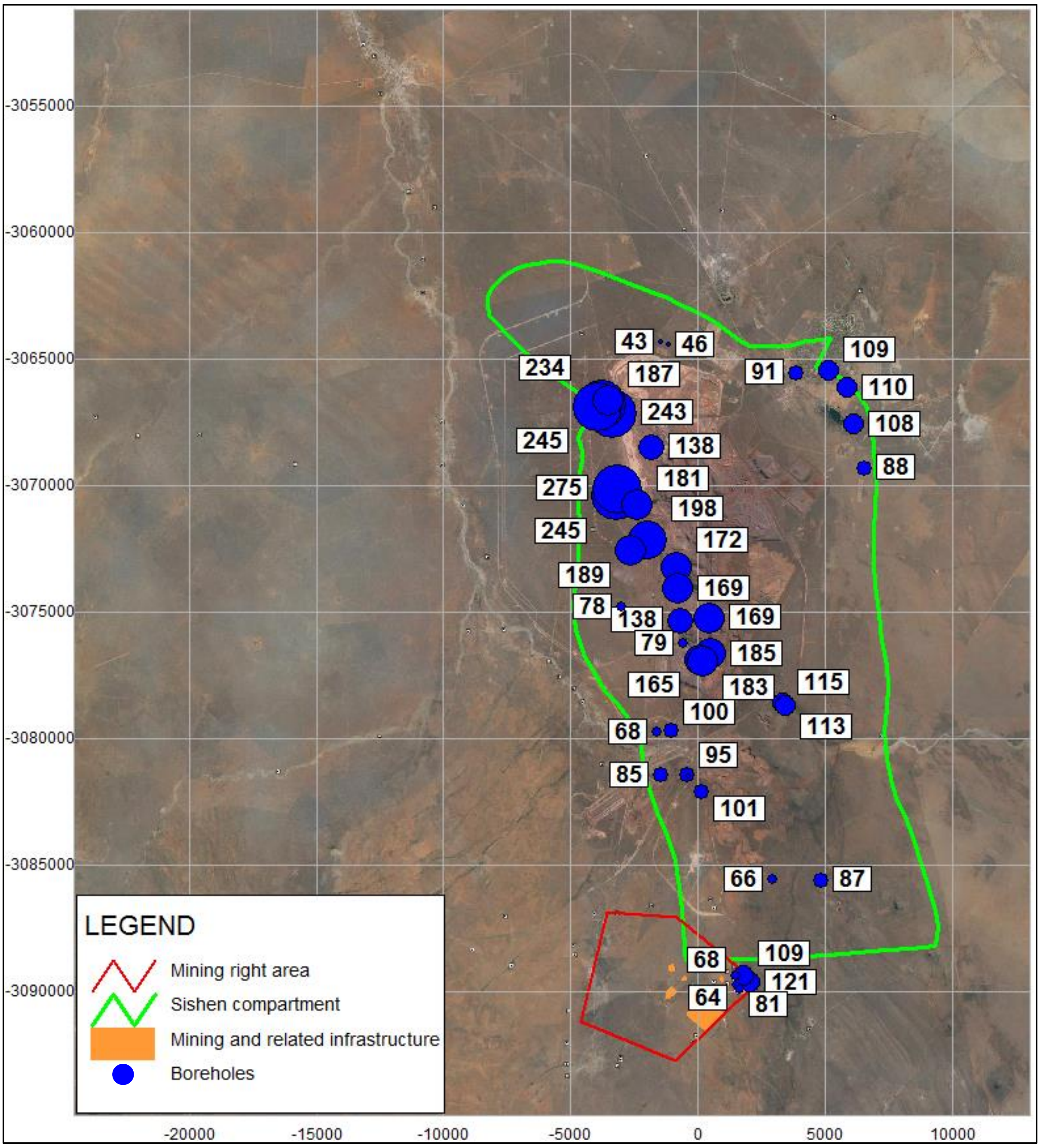


Figure 13: Thematic map of groundwater levels affected by mining activities

Notes: *All boreholes indicated in the above figure show poor correlation between groundwater elevation and surface topography* ***(Figure 11)****.*

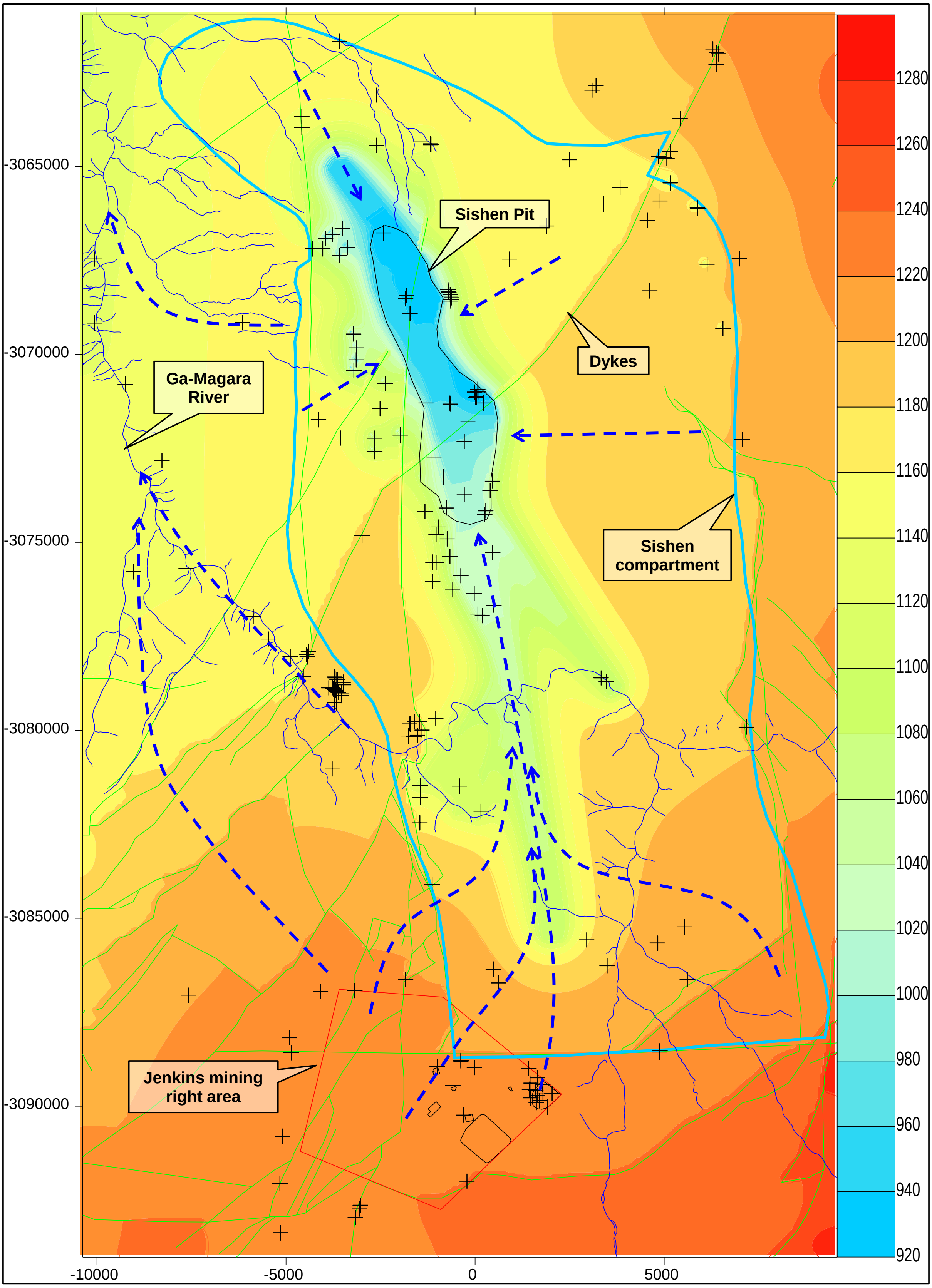


Figure 14: Groundwater elevation contour map of the project area and immediate surroundings (mamsl)

1.4.2 FLOW GRADIENTS

Contours of the static water levels or piezometric heads in and around the project area are indicated in **Figure 14**. Path lines or flow lines of groundwater particles are lines perpendicular to the contours, as indicated with arrows. Flow occurs faster where contours are closer together and gradients are thus steeper.

Under steady state conditions groundwater seepage rates are highest on the relatively steeper sloping hillocks where groundwater gradients are steepest. Seepage rates on the other hand are much lower in the flat plains/plateaus and valley bottoms. These phenomena do not feature very clearly in the Jenkins area since the groundwater level distribution is totally dominated by the cone-of-depression formed in the Sishen Compartment to the north of Jenkins.

The groundwater gradient is obtained by the following formula:

$$i = dH / dL$$

Where:

i = *Hydraulic gradient*
dH = *Head difference*
dL = *Lateral distance over which gradient is measured*

Average groundwater gradients were calculated with the above formula from the water level elevation data **(Figure 11)**. By substituting the hydraulic head difference over lateral distance a hydraulic gradient of approximately 1.6% northwards was calculated for the proposed Jenkins mining area.

1.4.3 AQUIFER TYPES AND YIELD

Information from exploration boreholes indicates the presence of two possible aquifer types in the project area. For the purpose of this study an aquifer is defined as a geological formation or group of formations that can yield groundwater in economically useable quantities. Aquifer classification according to the Parsons Classification system is summarised in **Table 2**.

The **first aquifer** is a shallow, **semi-confined or unconfined aquifer** within the upper 7 to 30 meters of the geological profile. This aquifer often develops on the contact zone between the weathered zone at surface and fresh hard rock formation. Farmers in the region use this aquifer widely for domestic and livestock water supply. Borehole yields in the shallow aquifer generally vary from 0.2 to approximately 2 l/s. Where consideration of the shallow aquifer system becomes important is during seepage estimations into voids and mass transport simulations from mine-induced contamination sources, because a significant lateral seepage component often occurs. According to the Parsons Classification system the aquifer is usually regarded as a minor or even a non-aquifer system.

The **second aquifer** is the deeper, **secondary porosity hard rock aquifer** that occurs at depths usually exceeding 30 meters below surface and will be the major aquifer system in the affected groundwater zone. Fracturing in the aquifer usually occurs in the chert breccia (Manganese Marker), banded iron formation and to a lesser extent the underlying dolomite at depths of between ± 30 and 160 m below surface. Yields in the aquifer may vary from 1 to more than 40 l/s. Fracturing is usually concentrated near the haematite ore bodies where mineralization and preservation of ore occurred through folding, thrusting, fracturing and sinkhole formation/slumping.

This aquifer system usually displays semi-confined or confined characteristics with piezometric heads often significantly higher than the water-bearing fracture position. The fractures may occur in any of the co-existing host rocks due to different tectonic, structural and depositional processes. According to the Parsons Classification system the aquifer could be regarded as a major aquifer system.

Table 2: Parsons Aquifer Classification *(Parsons, 1995)*

Sole Aquifer System	An aquifer that is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. Aquifer yields and natural water quality are immaterial.
Major Aquifer System	Highly permeable formation, 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 (less than 150 mS/m).
Minor Aquifer System	These can be fractured or potentially fractured rocks that do not have a primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large volumes of water, they are important both for local suppliers and in supplying base flow for rivers.
Non-Aquifer System	These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks, although impermeable, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.
Special Aquifer System	An aquifer designated as such by the Minister of Water Affairs, after due process.

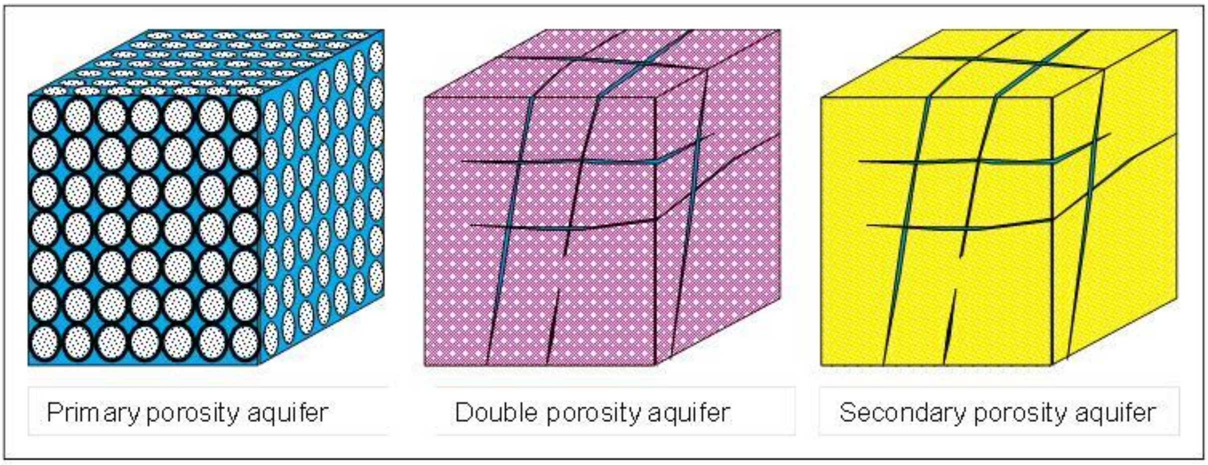


Figure 15: Types of aquifers based on porosity

Notable is the fact that although all seven boreholes drilled for monitoring purposes intersected dolomite, **no significant blow yield** was recorded (please refer to **Table 19** for more information on monitoring boreholes). Dolomite, a rock type usually considered a host rock for major aquifers, is in this case considered rather a subordinate aquifer with high storage properties for groundwater, but not highly transmissive. The younger banded iron formation and chert breccia, on the other hand, are highly transmissive due to fracturing, but the groundwater storage coefficients are much lower. The same phenomenon is also experienced at other iron ore mines in South Africa (e.g. Sishen, Kolomela, Thabazimbi) in the same geological environment.

Pump tests were performed on five boreholes of which the positions are indicated in **Figure 16**. These pump tests were performed with the main aim of determining the transmissivity and storage characteristics of the solid geological formation – the so-called aquifer matrix. Pump tests are performed instead of the more commonly used slug tests because of the much improved accuracy obtained with the pump tests, resulting in much more reliable aquifer parameters calculated from the tests. The tests results (calculated aquifer parameters) are provided in **Table 4**.

1.4.3.1 AQUIFER TRANSMISSIVITY AND STORATIVITY

Constant rate pump tests were performed on three exploration boreholes and two user boreholes and their positions are indicated below in **Figure 15**. A summary of the pump tests is provided in **Table 3**, while aquifer parameters calculated from the tests are provided in **Table 4**.

A pump test basically involves the abstraction of groundwater from a borehole by means of a pump (submersible- or mono pump) at a known rate. Measurements of the decreasing water level within the borehole are taken at predetermined intervals, which are generally short at the start of the test and increase as the test progresses. After the test has been completed and the pump has been shut down, measurements are also taken of the water level as it starts to recover/rise in the borehole again.

This water level vs. time data is then analysed with software developed specifically for pump tests and aquifer parameters such as transmissivity/hydraulic conductivity and storage coefficient are calculated for both the matrix- and fracture flow stages. The aquifer parameters can then be used to calculate the long term sustainable rate at which groundwater can be extracted from the borehole.

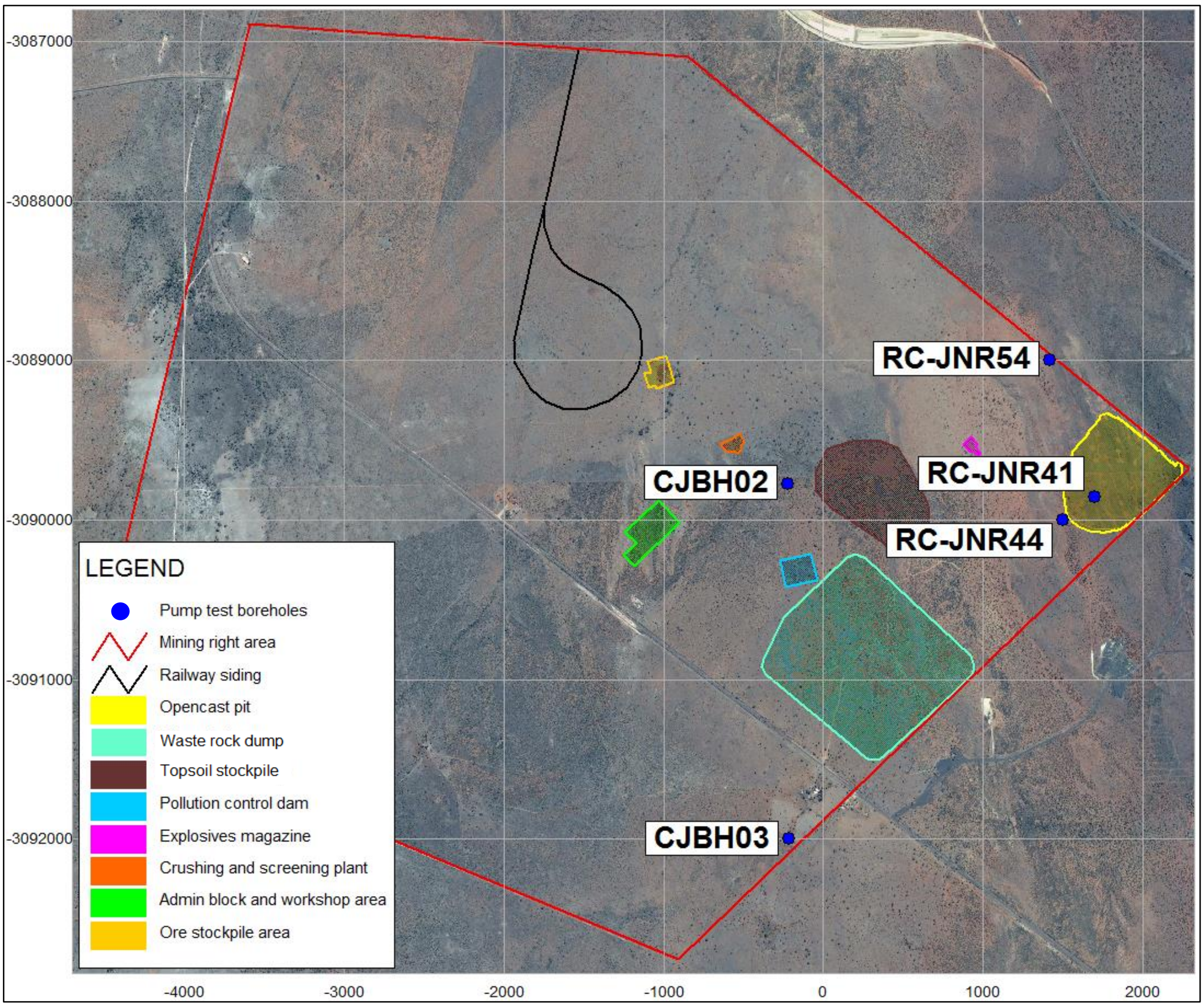


Figure 16: Positions of pump test boreholes

Table 3: Summary of pump tests

BH	BH depth	Static WL	Pump duration	Pump rate	Drawdown	Recovery
Unit	*m*	*mamsl*	*min*	*l/s*	*m*	*%*
CJBH02	48	18.0	600	3.00	7.8	95% after 600 min
CJBH03	54	12.6	600	2.50	2.8	95% after 240 min
RC-JNR41	108	81.6	15	0.20	15.7	42% after 7 min
RC-JNR44	>100	58.4	40	0.24	19.7	56% after 7 min
RC-JNR54	158	64.2	120	0.15	16.1	92% after 360 min

Aquifer transmissivity is defined as a measure of the amount of water that could be transmitted horizontally through a unit width of aquifer by the full-saturated thickness of the aquifer under a hydraulic gradient of 1. Transmissivity is the product of the aquifer thickness and the hydraulic conductivity of the aquifer, usually expressed as m^2/day (Length^2/Time).

Storativity (or the storage coefficient) is the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in piezometric head. Storativity (a dimensionless quantity) cannot be measured with a high degree of accuracy in slug tests or even in conventional pumping tests. It has been calculated by numerous different methods with the results published widely and a value of 0.002 to 0.01 is taken as representative for the proposed mining area. The storage coefficient values calculated from the Jenkins pump tests proved to be in this order of magnitude.

The pump test data was analysed with the AQTESOLV Professional software package, which offers a wide range of mathematical equations/solutions for the calculation of aquifer parameters. The time-water level data collected during the constant rate pump test is plotted on a log-linear graph. A straight line can then be fitted to the different flow stages on the graph (process known as curve matching) and the aquifer transmissivity and storativity is calculated in accordance with the preselected analytical equation. All aquifer parameters provided in this report were calculated with the *Cooper-Jacob (1946)* equation. Examples of curve matching are provided in **Figures 17** to **20**, which illustrate aquifer parameters calculated for both the matrix- and fracture flow stages.

It is important to note that the *Cooper-Jacob* approximation algorithm for pump test analysis was designed for pump tests interpretation in a primary porosity aquifer environment with the following assumptions:

- The aquifer is a homogeneous medium,
- Of infinite extent,
- No recharge is considered, and
- An observation borehole is used for water level recording at a distance from the pumped borehole.

Although few of these assumptions apply at the project area, the method could still be used as long as the assumptions and 'shortcomings' are recognized and taken into account. It is for this reason that not one straight line is fitted but two different lines are fitted for the fracture and matrix flow periods respectively.

Fractured rock aquifers are known for being highly heterogeneous, causing significant variations in aquifer transmissivity/storativity within relatively short distances. It is therefore also difficult to determine representative values over large areas. Because aquifer hydraulic parameters (like most geological parameters) usually display a log-normal distribution it is an accepted approach to calculate the harmonic or geometric mean in preference to the arithmetic mean. A generally accepted approach for calculating a representative hydraulic conductivity for an aquifer is to take the average of the harmonic and geometric means.

Aquifer parameters calculated from the five pump tests are provided in **Table 4** and vary significantly from one borehole to another. The process discussed above was therefore not used to calculate an average transmissivity and storativity for the aquifer regime as it would only be of academic value and not representative of the wider project area. The aquifer parameters were used as indicative values only and model calibration aided in obtaining representative aquifer parameter values.

Table 4: Aquifer parameters calculated from pump tests

BH	Tf	Tm	Sf	Sm
CJBH02	84.6	31.4	1.1E-9	0.02
CJBH03	48.0	9.7	-	-
RC-JNR41	-	0.3	-	0.03
RC-JNR44	-	0.5	-	0.04
RC-JNR54	-	0.5	-	0.003

Note:

Tf – Fracture transmissivity (m^2/d),
Tm – Matrix transmissivity (m^2/d),
Sf – Fracture storativity/storage coefficient (dimensionless quantity),
Sm – Matrix storativity/storage coefficient (dimensionless quantity).

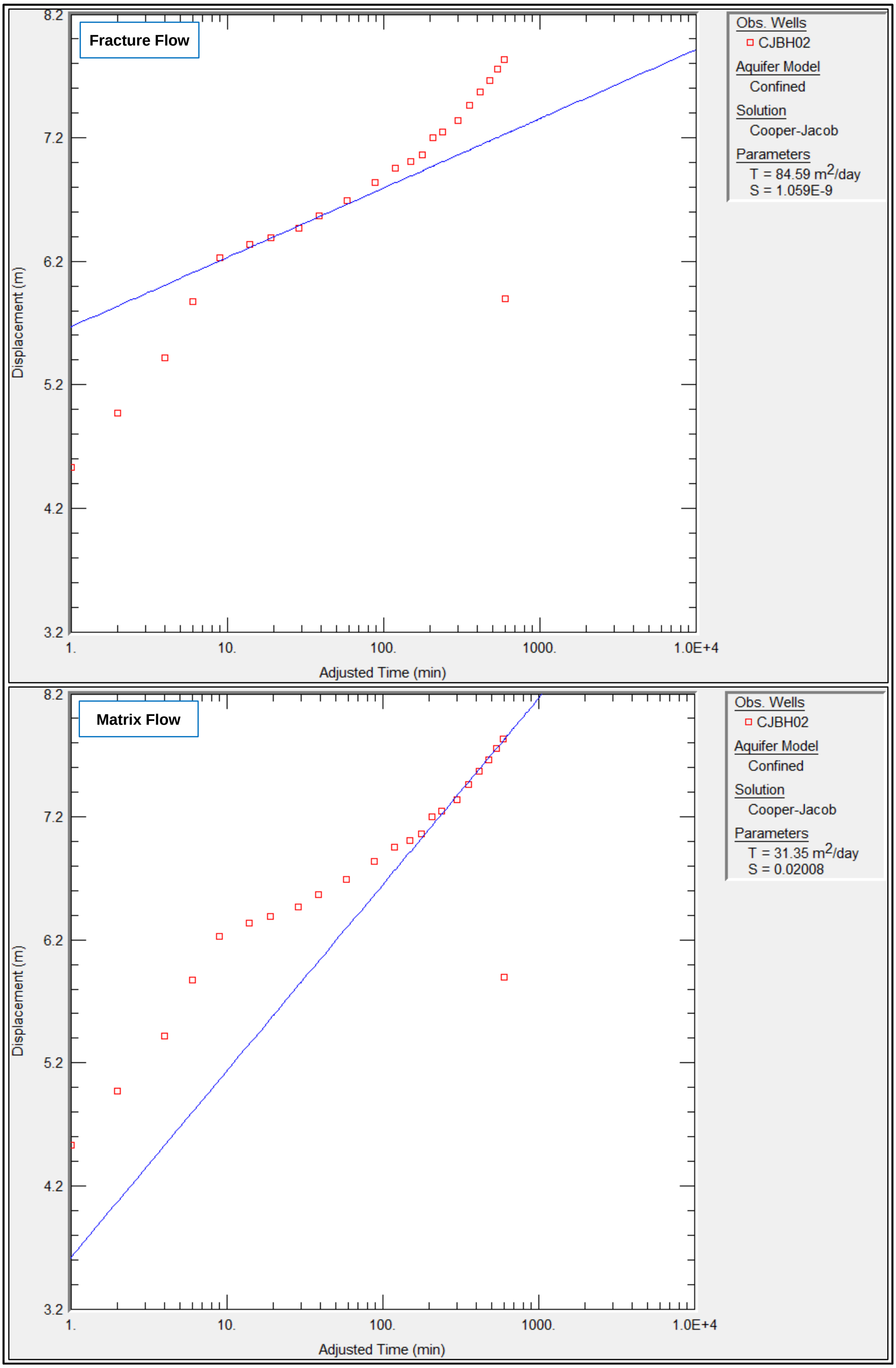


Figure 17: Analysis of pump test for borehole CJBH02

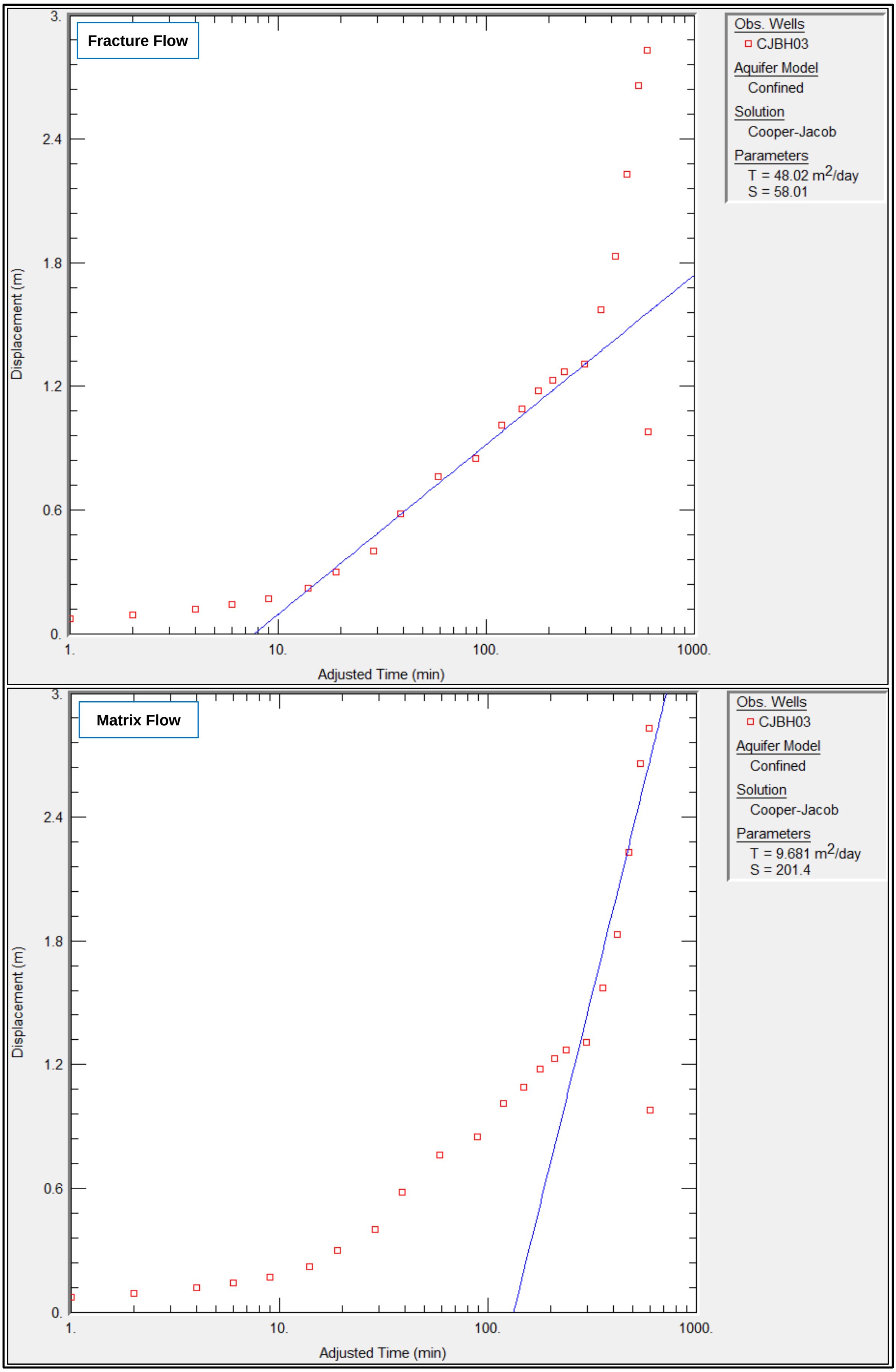


Figure 18: Analysis of pump test for borehole CJBH03

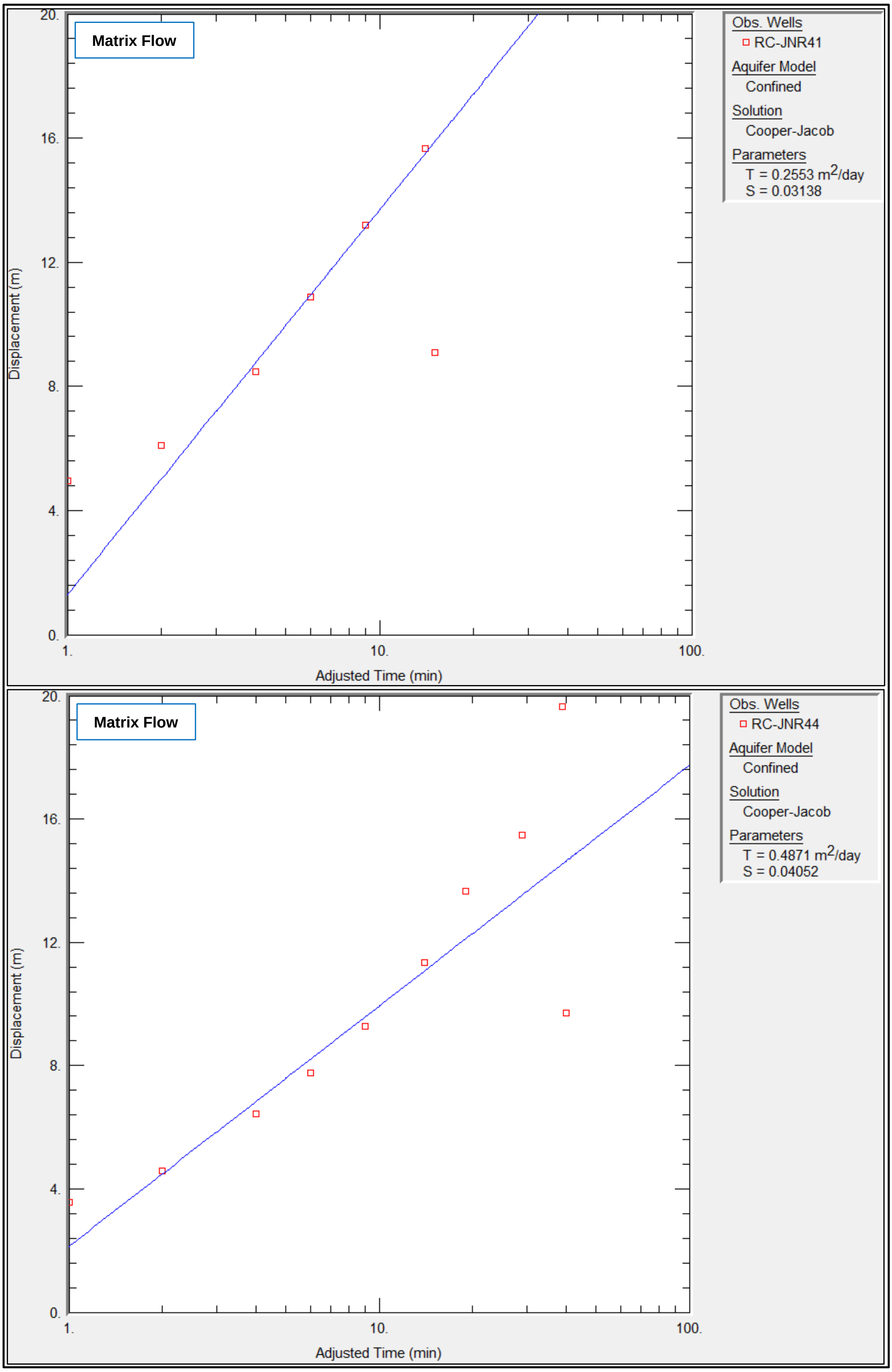


Figure 19: Analysis of pump test for boreholes RC-JNR41 and RC-JNR44

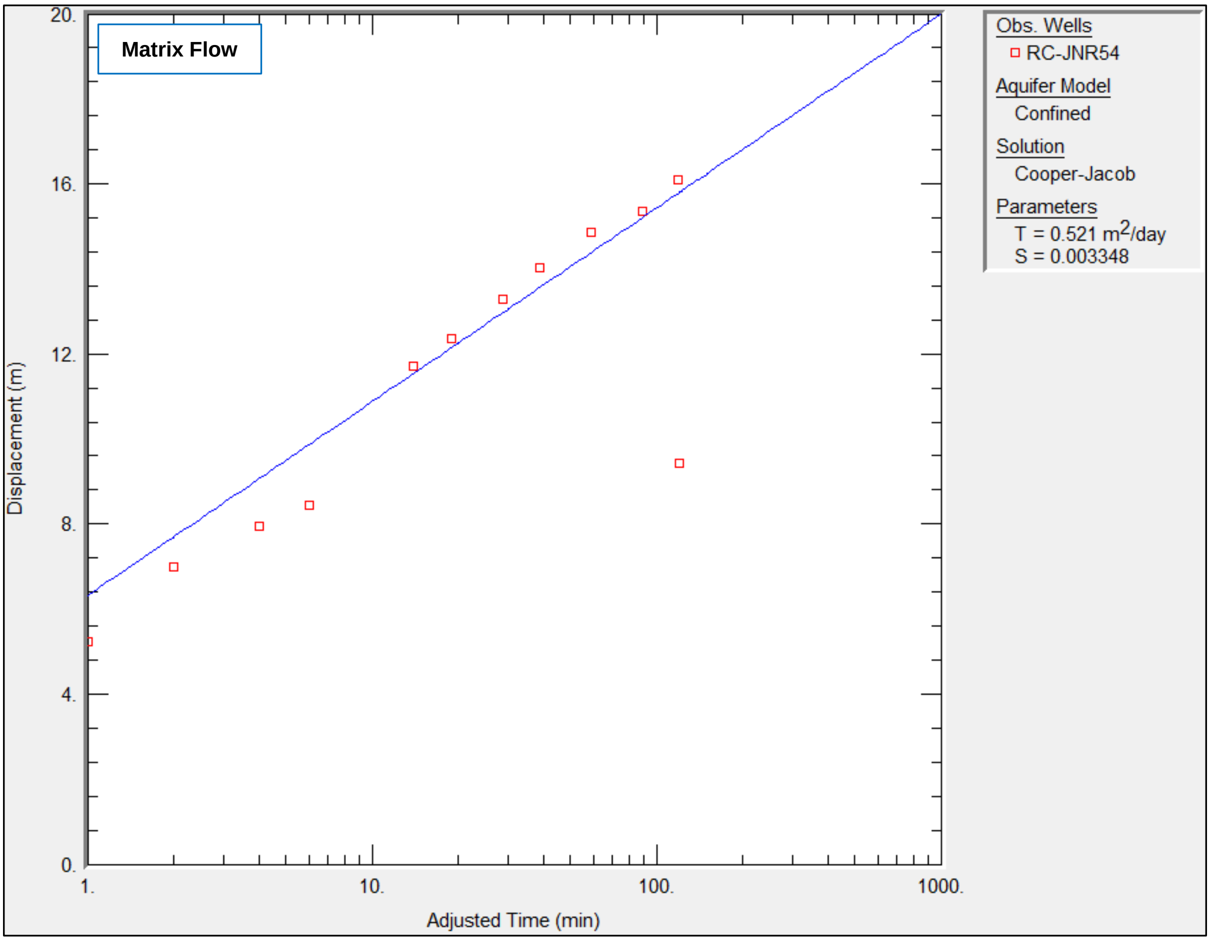


Figure 20: Analysis of pump test for borehole RC-JNR54

1.4.3.2 AQUIFER RECHARGE AND DISCHARGE RATES

According to **Figure 23** the mean annual recharge to the aquifer underlying the project area is approximately 8 mm, which based on an average rainfall of between 200 and 400 mm/a **(Figure 21)** translates to a recharge percentage varying between 2 to 4%. This recharge is slightly higher in comparison to Karoo type aquifers (typically between 1 and 3%) found over large parts of South Africa. The main reasons for the higher effective recharge percentage are:

- The dolomitic aquifers occurring over large portions of the project area,
- Kalahari sand and transmissive calcrete cover where outcrop does not occur, and
- Very low clay content of soils that are present, allowing for easier infiltration.

Where outcrop occurs, the effective recharge percentage can be slightly higher while in low-lying topographies where discharge generally occurs and thicker sediment deposition, the effective recharge will be lower or even zero. Based on this estimate, the annual recharge to the Jenkins mining right area is in the order of 204 000 m^3.

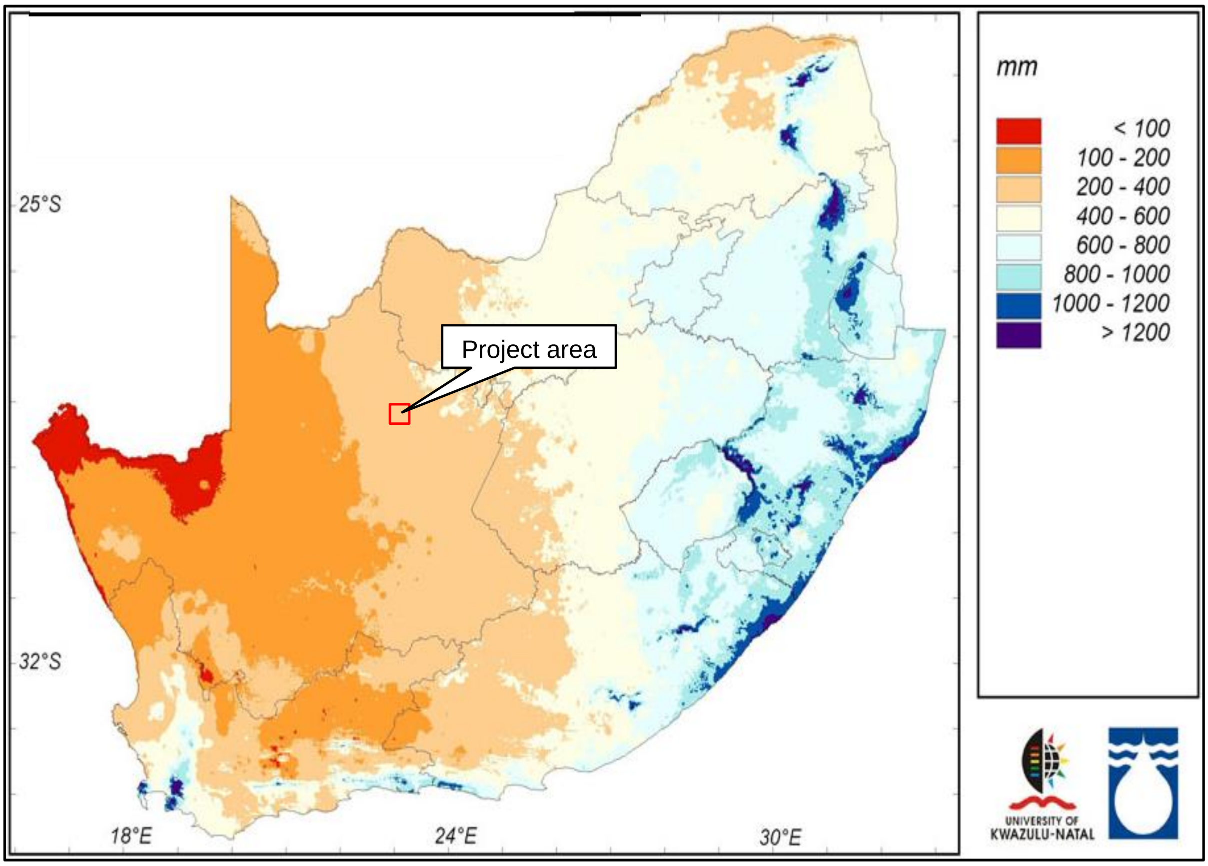


Figure 21: Mean annual precipitation for South Africa ***(Lynch, 2004)***

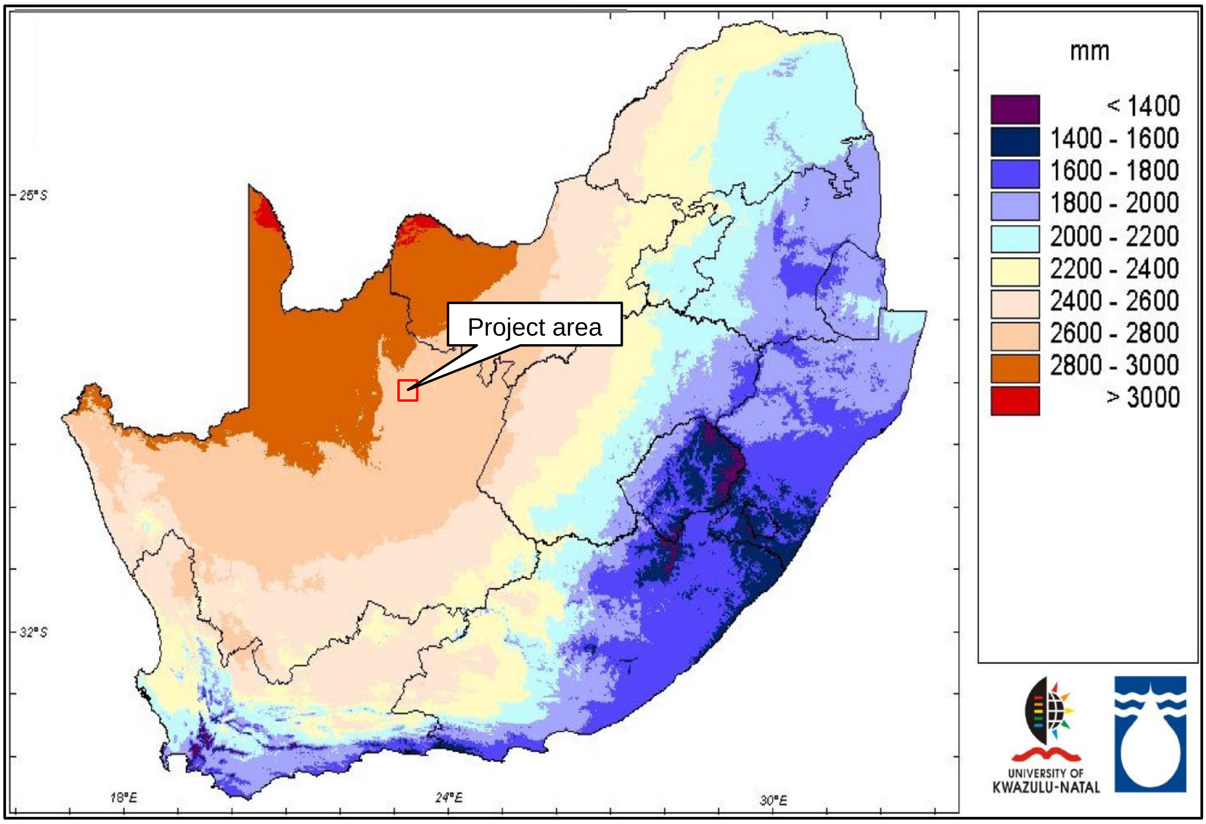


Figure 22: Mean annual evaporation for South Africa ***(Lynch, 2004)***

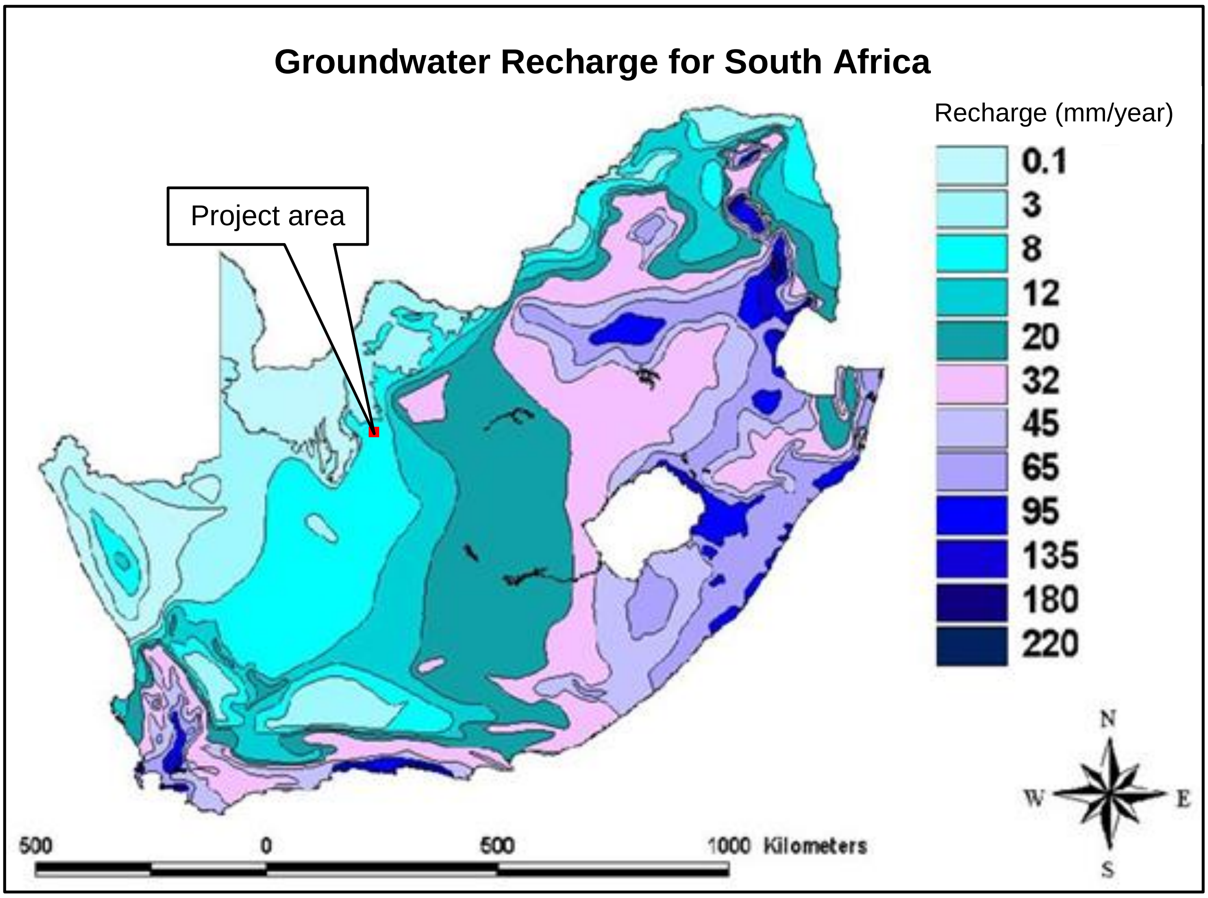


Figure 23: Groundwater recharge estimates for South Africa *(Vegter, 1995)*

1.4.3.3 DIRECTION AND RATE OF GROUNDWATER MOVEMENT IN POTENTIALLY IMPACTED AREAS

Groundwater contours are presented in **Figure 14** and were constructed with the use of a numerical groundwater flow model. These contours represent current groundwater level conditions and show the area believed to be affected by the Sishen dewatering activities, i.e. the depression cone in the Sishen Compartment. Groundwater flow gradients **(Section 1.3.2)** were used to calculate the rate of groundwater movement (the so-called 'Darcy flux') within the potentially impacted areas and the results are provided below in **Table 5**.

Table 5: Direction and rate of groundwater movement in the proposed Jenkins mining area

Groundwater flow direction	Groundwater flow gradient	Groundwater flow velocity (m/d)	Groundwater flow velocity (m/y)
North	1.6%	0.017	6.2

Notes: *Flow velocity calculations were done by assuming an average aquifer porosity of 8% and hydraulic conductivity of 0.083 m/d.*

A large number of manmade actions could impact on the groundwater regime; including the aquifer structure, flow paths and directions, storage, discharges and recharge. Possible impacts relevant to the proposed project will be discussed briefly:

Aquifer structure, flow paths and directions

During active mining and thereafter, the void created by opencast mining will impact on the natural groundwater movement. **The deepest floor elevation of the proposed Jenkins pit is estimated at approximately 1 170 mamsl, which is ± 50 meters below the current groundwater level elevation.** A local lowering of the groundwater levels is therefore expected to occur due to mine dewatering, which will lead to the formation of a cone of depression. Flow directions and velocities within the radius of the affected area will be altered and groundwater will move radially towards the center of the depression cone.

A mine void also destroys the in situ aquifer structures and could be compared to an area of very high (even infinitely high) transmissivity and also high storativity. Because groundwater will follow the route of least resistance, groundwater will preferably move through the mined-out area. The final mined area will directly determine the post closure groundwater flow paths, directions and possible decant.

The transmissivity and storativity of the backfilled opencast void will always remain higher than the pre-mining natural aquifer(s). Due to the size of the proposed pit in comparison to the mining right area being so small (less than 2% of MRA) and the fact that the pit floor will only intersect the local groundwater level during year 7 of mining, impacts on the natural flow pattern in the project area are expected to be noticeable to a limited extent and in the immediate vicinity of the operations only.

The extent of the impact however depends mostly on the transmissivity of geological structures and discontinuities that may or may not intersect the proposed pit. No such information was available at the time of completion of this report and dedicated geophysical surveys are recommended to identify and define structures that may influence groundwater level impacts caused by mine dewatering.

Aquifer discharge

A mining and processing operation may impact significantly on the discharge of an aquifer in different ways. If pit dewatering is required, the natural aquifer discharge will decrease by the volume of groundwater removed by dewatering. Aquifer discharge may also increase with the use of return water dams, slurry and other dams through leakage of water to the subsurface, especially if water is imported to the project from other sources. Other factors that may decrease the aquifer discharge are compacted surfaces, haul roads and concrete surfaces that prevent infiltration to the aquifer and decrease groundwater discharge, although increasing surface runoff. The relative surface area of these features is however usually a very small percentage of the total surface area of the operation.

After mine closure, however, recharge to the backfilled opencast pit is expected to be higher in comparison to the pre-mining aquifer. The increased recharge will subsequently lead to an increase in discharge should the void decant. **Average evapotranspiration from the Jenkins pit area was estimated to be in the order of 2 540 m^3/d, which removes the risk for potential decant since the recharge rate was estimated to be ± 60 m^3/d (Figure 23).**

Aquifer recharge

All the aspects mentioned under aquifer discharge apply to aquifer recharge. The type of mining has the most direct and profound effect on groundwater recharge. With opencast mining recharge can be as high as 30% of the MAP and is seldom less than 10%.

Water retaining infrastructure such as the planned pollution control dam/s will also usually increase recharge to the underlying aquifer, but compacted or concrete surfaces and roads will decrease the recharge.

1.5 GROUNDWATER QUALITY EVALUATION

Groundwater quality data is available for a total of 14 user boreholes located during the hydrocensus/user survey and two dedicated source monitoring boreholes. The positions of all groundwater sampling localities are indicated in **Figure 25**. The results of the chemical analyses are summarised in **Table 7**. Groundwater quality data were evaluated with the aid of diagnostic chemical diagrams and by comparing the inorganic concentrations to the South African National Standards for drinking water **(Table 6)**. Because only once-off analysis data exists, time-series graphs, statistical analyses and trend analyses are not possible.

The first step in the water quality interpretation was to classify the groundwater quality. The classification was based on the following:

- The spatial distribution of the monitoring points, and
- The proximity of the monitoring points to certain known pollution sources that are expected to impact on the groundwater and/or surface water in the downstream flow direction area.

The four main factors usually influencing groundwater quality are:

- **Annual recharge** to the groundwater system,
- **Type of bedrock** where ion exchange may impact on the hydrogeochemistry,
- **Flow dynamics** within the aquifer(s), determining the water age and
- **Source(s) of pollution** with their associated leachates or contaminant streams.

Where no specific **source of groundwater pollution** is present up gradient from the borehole, only the other three factors play a role.

One of the most appropriate ways to interpret the type of water at a sampling point is to assess the plot position of the water quality on different analytical diagrams like a Piper, Expanded Durov and Stiff diagrams. Of these three types, it is expected that the Expanded Durov diagram gives the most holistic water quality signature.

Although never clear-cut, the general characteristics of the different fields of the diagram could be summarized as follows:
Field 1:
Fresh, very clean recently recharged groundwater with HCO_3 and CO_3 dominated ions.

Field 2:
Field 2 represents fresh, clean, relatively young groundwater that has started to undergo mineralization with especially Mg ion exchange.

Field 3:
This field indicates fresh, clean, relatively young groundwater that has undergone Na ion exchange (sometimes in Na - enriched granites or felsic rocks) or because of contamination effects from a source rich in Na.

Field 4:
Fresh, recently recharged groundwater with HCO_3 and CO_3 dominated ions that has been in contact with a source of SO_4 contamination or that has moved through SO_4 enriched bedrock.

Field 5:
Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4 and NaCl mixing / contamination or old stagnant NaCl dominated water that has mixed with clean water.

Field 6:
Groundwater from field 5 that has been in contact with a source rich in Na or old stagnant NaCl dominated water that resides in Na rich host rock/material.

Field 7:
Water rarely plots in this field that indicates NO_3 or Cl enrichment or dissolution.

Field 8:
Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4, but especially Cl mixing/contamination or old stagnant NaCl dominated water that has mixed with water richer in Mg.

Field 9:
Old or stagnant water that has reached the end of the geohydrological cycle (deserts, salty pans etc.) or water that has moved a long time and / or distance through the aquifer or on surface and has undergone significant ion exchange because of the long distance or residence time in the aquifer.

The layout of the fields of the Expanded Durov diagram (EDD) is shown in **Figure 24**.

Another way of presenting the signature or water type distribution in an area is by means of Stiff diagrams. These diagrams plot the equivalent concentrations of the major cations and anions on a horizontal scale on opposite sides of a vertical axis. The plot point on each parameter is linked to the adjacent one resulting in a polygon around the cation and anion axes. The result is a small figure/diagram of which the geometry typifies the groundwater composition at the point. Groundwater with similar major ion ratios will show the same geometry. Ambient groundwater qualities in the same aquifer type and water polluted by the same source will for example display similar geometries.

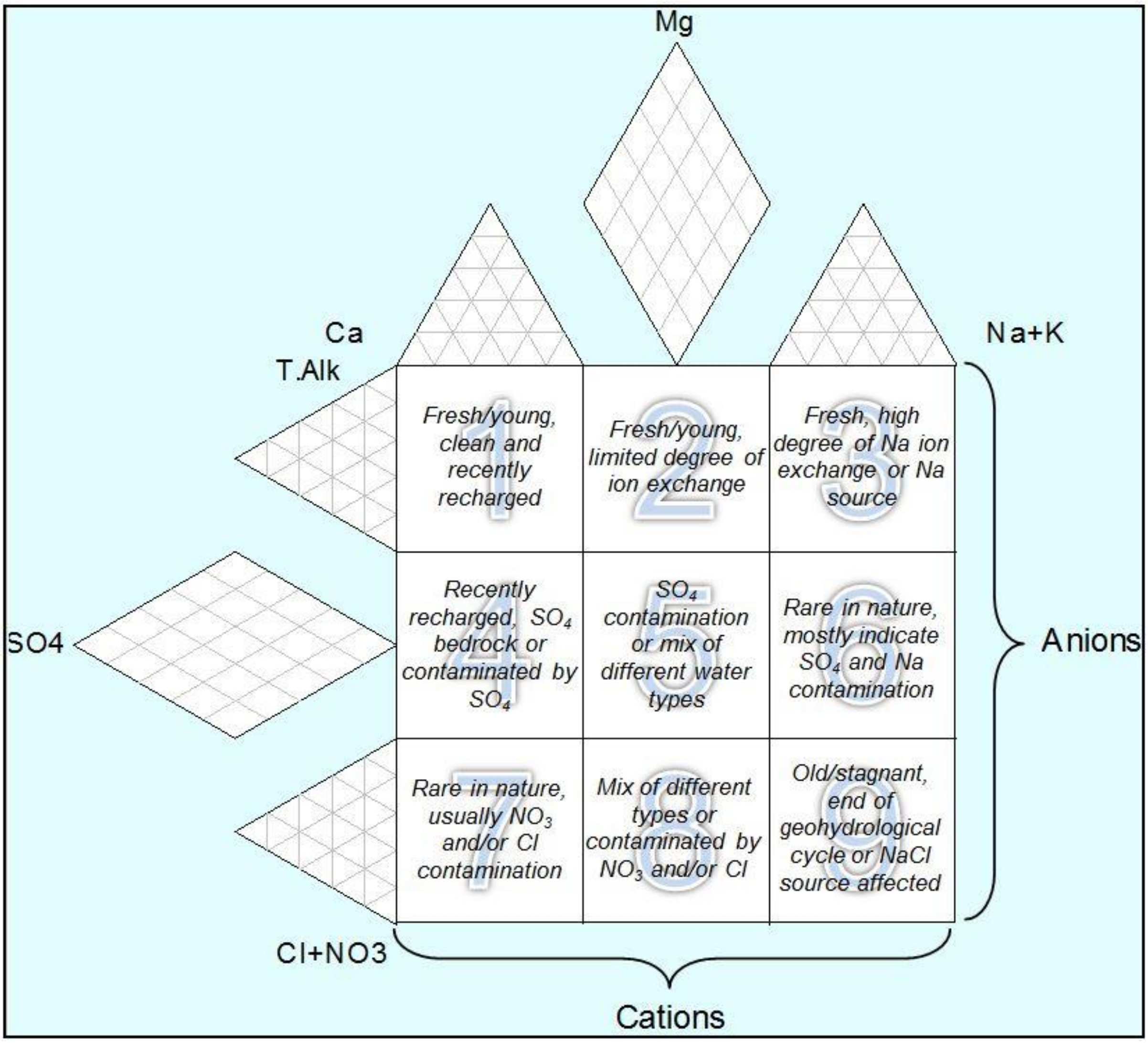


Figure 24: Layout of fields of the Expanded Durov diagram

Table 6: South African National Standards for drinking water *(SANS 241:2011)*

Determinant	Risk	Unit	Standard limits
Physical and aesthetic determinants			
Free chlorine	Chronic health	mg/L	≤ 5
Monochloramine	Chronic health	mg/L	≤ 3
Colour	Aesthetic	mg/L Pt-Co	≤ 15
Conductivity at 25 °C	Aesthetic	mS/m	≤ 170
Odour or taste	Aesthetic	–	Inoffensive
Total dissolved solids	Aesthetic	mg/L	≤ 1 200
Turbidity	Operational	NTU	≤ 1
	Aesthetic	NTU	≤ 5
pH at 25 C	Operational	pH units	≥ 5 to ≤ 9.7
Chemical determinants - macro-determinants			
Nitrate as N	Acute health – 1	mg/L	≤ 11
Nitrite as N	Acute health – 1	mg/L	≤ 0.9
Sulfate as SO_4^{2-}	Acute health – 1	mg/L	≤ 500
	Aesthetic	mg/L	≤ 250
Fluoride as F^-	Chronic health	mg/L	≤ 1.5
Ammonia as N	Aesthetic	mg/L	≤ 1.5
Chloride as Cl^-	Aesthetic	mg/L	≤ 300
Sodium as Na	Aesthetic	mg/L	≤ 200
Zinc as Zn	Aesthetic	mg/L	≤ 5
Chemical determinants - micro-determinants			
Aluminium as Al	Operational	µg/L	≤ 300
Antimony as Sb	Chronic health	µg/L	≤ 20
Arsenic as As	Chronic health	µg/L	≤ 10
Cadmium as Cd	Chronic health	µg/L	≤ 3
Total chromium as Cr	Chronic health	µg/L	≤ 50
Cobalt as Co	Chronic health	µg/L	≤ 500
Copper as Cu	Chronic health	µg/L	≤ 2 000
Cyanide (recoverable) as CN^-	Acute health – 1	µg/L	≤ 70
Iron as Fe	Chronic health	µg/L	≤ 2 000
	Aesthetic	µg/L	≤ 300
Lead as Pb	Chronic health	µg/L	≤ 10
Manganese as Mn	Chronic health	µg/L	≤ 500
	Aesthetic	µg/L	≤ 100
Mercury as Hg	Chronic health	µg/L	≤ 6
Nickel as Ni	Chronic health	µg/L	≤ 70
Selenium as Se	Chronic health	µg/L	≤ 10
Uranium as U	Chronic health	µg/L	≤ 15
Vanadium as V	Chronic health	µg/L	≤ 200

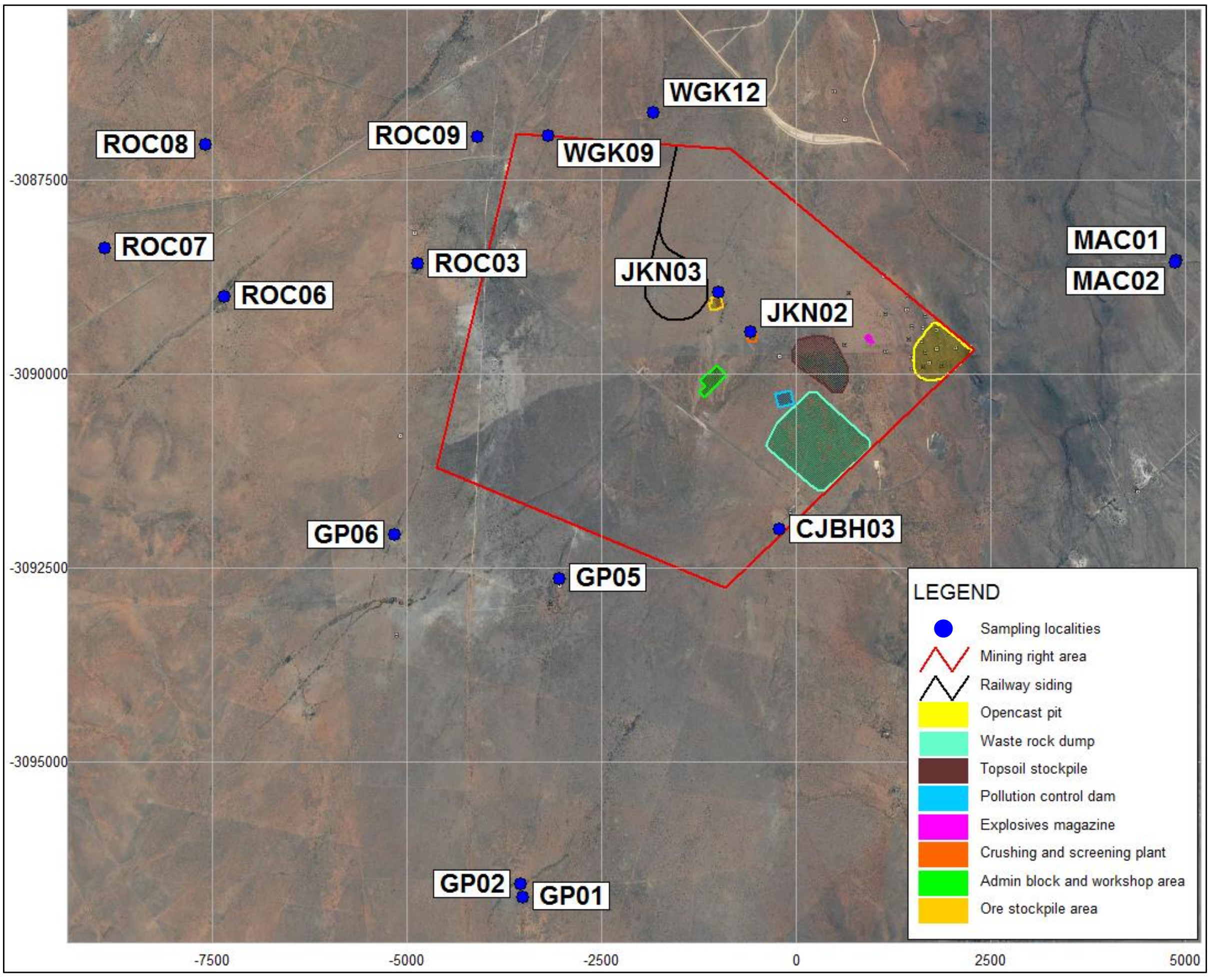


Figure 25: Distribution of groundwater sampling localities at Jenkins

Five chemical parameters (TDS, SO_4, NO_3, Cl and pH) were chosen from the full list of analytes as indicators of the specific type of contamination commonly occurring at iron ore mining operations. Although only the five parameters will be discussed, all inorganic parameters will be assessed and anomalies will be discussed.

The **total dissolved solids (TDS)** content of groundwater is a good indicator of the overall quality conditions, as it provides a measurement of the total amount/weight of salts that are present in solution. An increase in TDS will therefore also indicate an increase in the total inorganic content of the groundwater. At high concentrations (>2 400 mg/l) it may have adverse health effects on the groundwater users if used for drinking water.

Groundwater TDS concentrations vary between ± 240 mg/l and 670 mg/l, which are well below the permissible SANS value of 1 200 mg/l **(Table 6)**. A positive linear correlation generally exists between groundwater salinity and aquifer residence time and because gravity dictates that groundwater moves from higher to lower hydraulic gradients, overall higher salinities are generally measured in the lower lying areas and valleys. No such correlation was however identified within the project area.

Sulphate is a prominent and widespread contaminant where sulphate type minerals are present. When liberated, crushed and washed in the mining process oxidation of these materials occurs and a reaction chain forms commonly referred to as Acid Mine Drainage (AMD):

$$2FeS_2 + 7O_2 + 2H_2O \longrightarrow 2Fe^{2+} + 4SO_4^{2-} + 4H^+$$

The reaction requires both oxygen and water to take place, which are readily available in opencast mining environments. The production of hydrogen ions will consequently lead to a decrease in the groundwater pH conditions. Acid mine drainage is however not as prominent in the iron ore mining environment in comparison to coal mining. This statement was also found to apply to the Jenkins Project area after Acid Base Accounting (ABA) tests were performed on two samples collected from the drilling of exploration boreholes. The test results are discussed in detail in **Section 3.2** of the document.

Sulphate is therefore a common indicator of pollution resulting from processing facilities and waste products. Sulphate forms salts with numerous cations, which include sodium, potassium, magnesium, calcium, lead and ammonium. When consumed at very high concentrations (>600 mg/l) it can lead to diarrhoea and the users will not be able to adapt to these high levels. It will also have a salty and bitter taste at concentrations exceeding ± 400 mg/l.

The groundwater sulphate content of the project area varies from less than 1 mg/l to approximately 100 mg/l, which are below the permissible SANS value of 500 mg/l.

Groundwater **pH** under natural conditions is affected by the geology and geochemistry of the aquifer host rocks. At very low pH levels dissolved toxic metal ions are present, which can lead to severe health problems if consumed. At low pH levels (less than ± 4.5) the water will have a sourly taste. At high pH levels (>9) there is a health hazard due to the de-protonated species and water will have a soapy taste.

Groundwater pH conditions are slightly alkaline with values ranging between 7.6 and 8.9. Such pH conditions restrict the mobilisation of metals, which are also sensitive to groundwater redox conditions.

Nitrate contamination is generally associated with the use of nitrate based explosives and will often manifest around shafts, pit areas, waste rock dumps and tailings facilities. Nitrate is affected because of remnants of explosives attached to run-of-mine rocks, including ore and waste rock – wet or dry. These nitrates are very soluble in water, resulting in the formation of nitrate enriched leachate when rainwater percolates through waste rock dumps and/or stockpiles. Health effects associated with high nitrate concentrations (>11 mg/l) are impaired concentration, lack of energy and the formation of methahemoglobin in blood cells. Feedlots may also be significant sources of nitrate contamination.

Groundwater nitrate concentrations measured in the majority of boreholes are below the permissible SANS value of 11 mg/l **(Table 7)**. Exceptions do however occur as the nitrate content measured in GP06, JKN02, ROC03, ROC06 and ROC09 exceeds the permissible SANS concentration for drinking water purposes **(Table 7)**. The once-off analyses do not allow for accurate source identification, however the nitrate contamination is likely to have originated from kraals or feedlots.

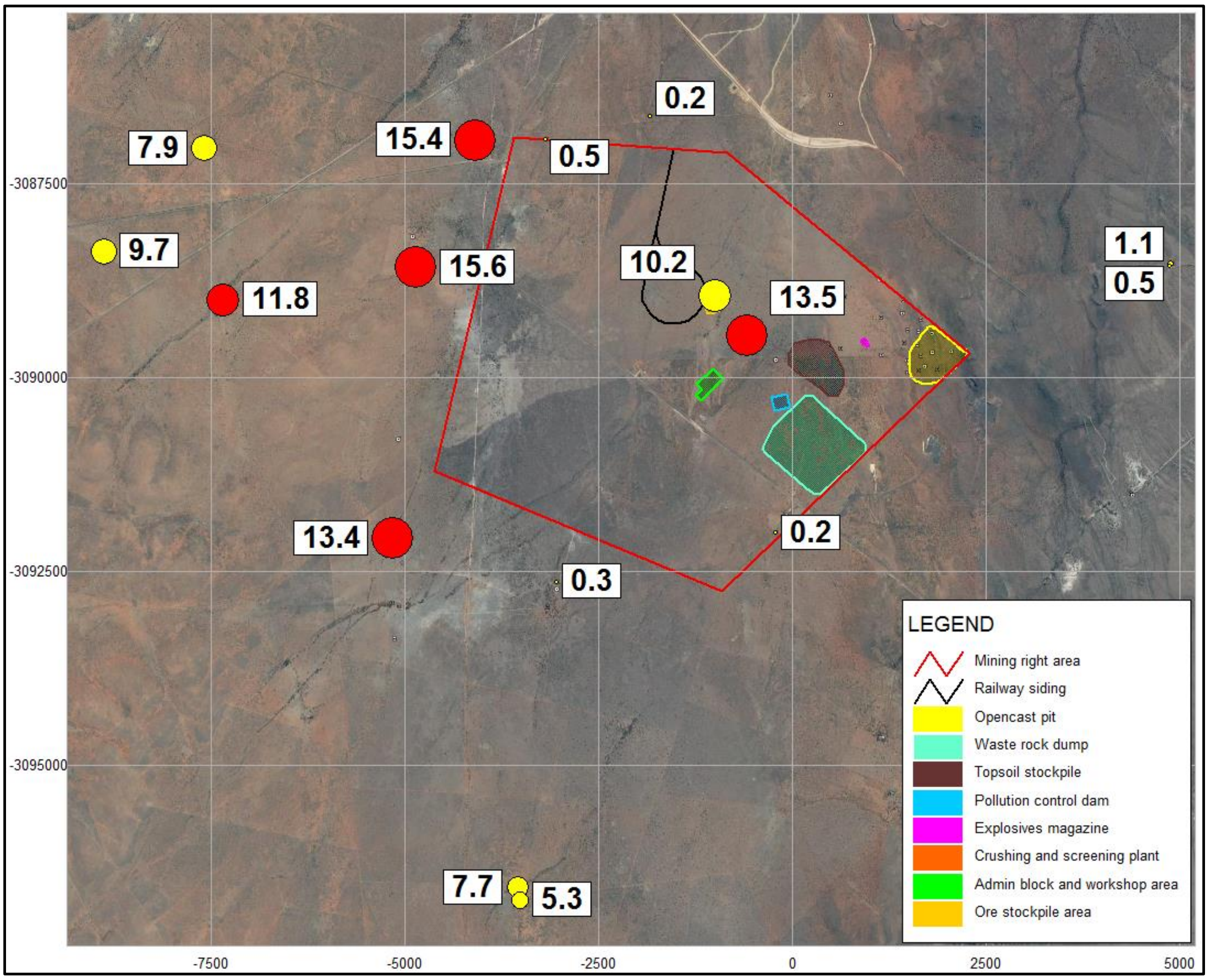


Figure 26: Thematic map of groundwater nitrate concentrations measured in regional hydrocensus boreholes

Chloride is usually present at high concentrations in connate water within the crystal structure or matrix of rocks. When blasted, crushed, smelted or processed in some other way, sodium and chloride are liberated and serve as a conservative indicator of the impact of mining and processing activities on the environment. Groundwater chloride concentrations are all well below the permissible SANS value of 300 mg/l and vary between ± 10 mg/l and approximately 50 mg/l **(Table 7)**.

Exceptionally high **fluoride** and **iron** concentrations were measured in borehole WGK12 **(Table 7)**, however the once-off monitoring data available does not provide any reasonable explanation for these anomalies.

According to the Expanded Durov diagram **(Figure 27)** and Stiff diagrams **(Figure 28)** the project area and its immediate surroundings are dominated by fresh, clean, relatively young groundwater that has started to undergo mineralization with especially magnesium ion exchange. The groundwater is dominated by **magnesium** cations, while **bicarbonate alkalinity** dominates the anion content. Interaction between the groundwater (ion exchange) and carbonate enriched aquifer host rocks (shallow calcrete aquifer and deeper dolomitic aquifer) is undoubtedly responsible for the dominant plot position in field 2 of the Expanded Durov diagram.

Exceptions do occur as borehole GP05 plots in field 6 of the Expanded Durov diagram, which represents groundwater dominated by **sodium** cations and **sulphate** anions. No suspected sources of sulphate contamination occur within the immediate vicinity of the abovementioned user borehole and no reasonable explanation can be provided for this anomaly at this point in time.

Summary:

- Groundwater is of good quality and is suitable for human consumption according to the South African National Standards for drinking water *(SANS241:2011)*.
- Exceptions do however occur as the nitrate content measured in GP06, JKN02, ROC03, ROC06 and ROC09 exceeds the permissible SANS concentration of 11 mg/l, rendering the groundwater unfit for human consumption.
- The groundwater is mainly dominated by magnesium cations, while bicarbonate alkalinity dominates the anion content.

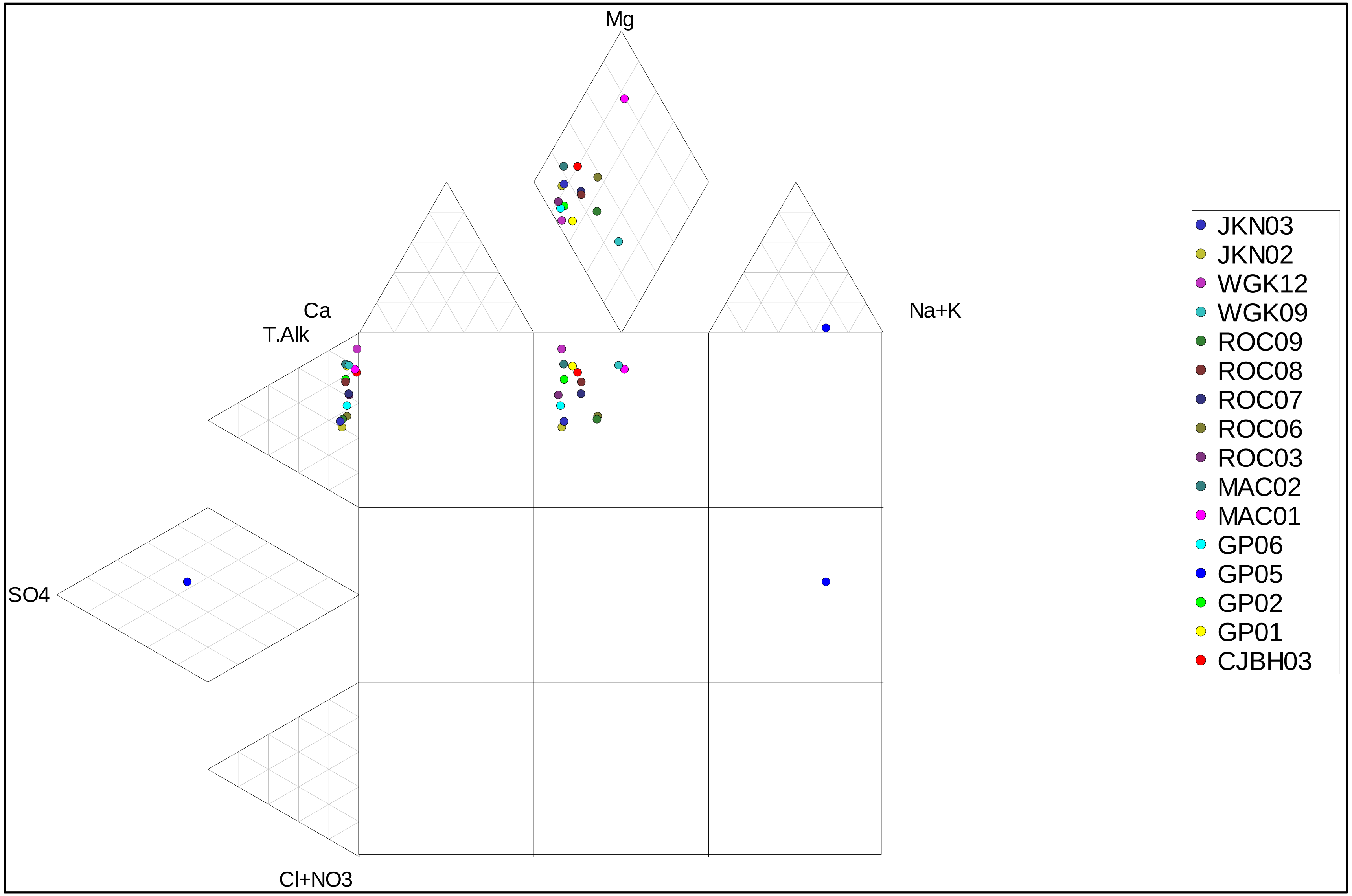


Figure 27: Expanded Durov diagram groundwater chemistries for the project area

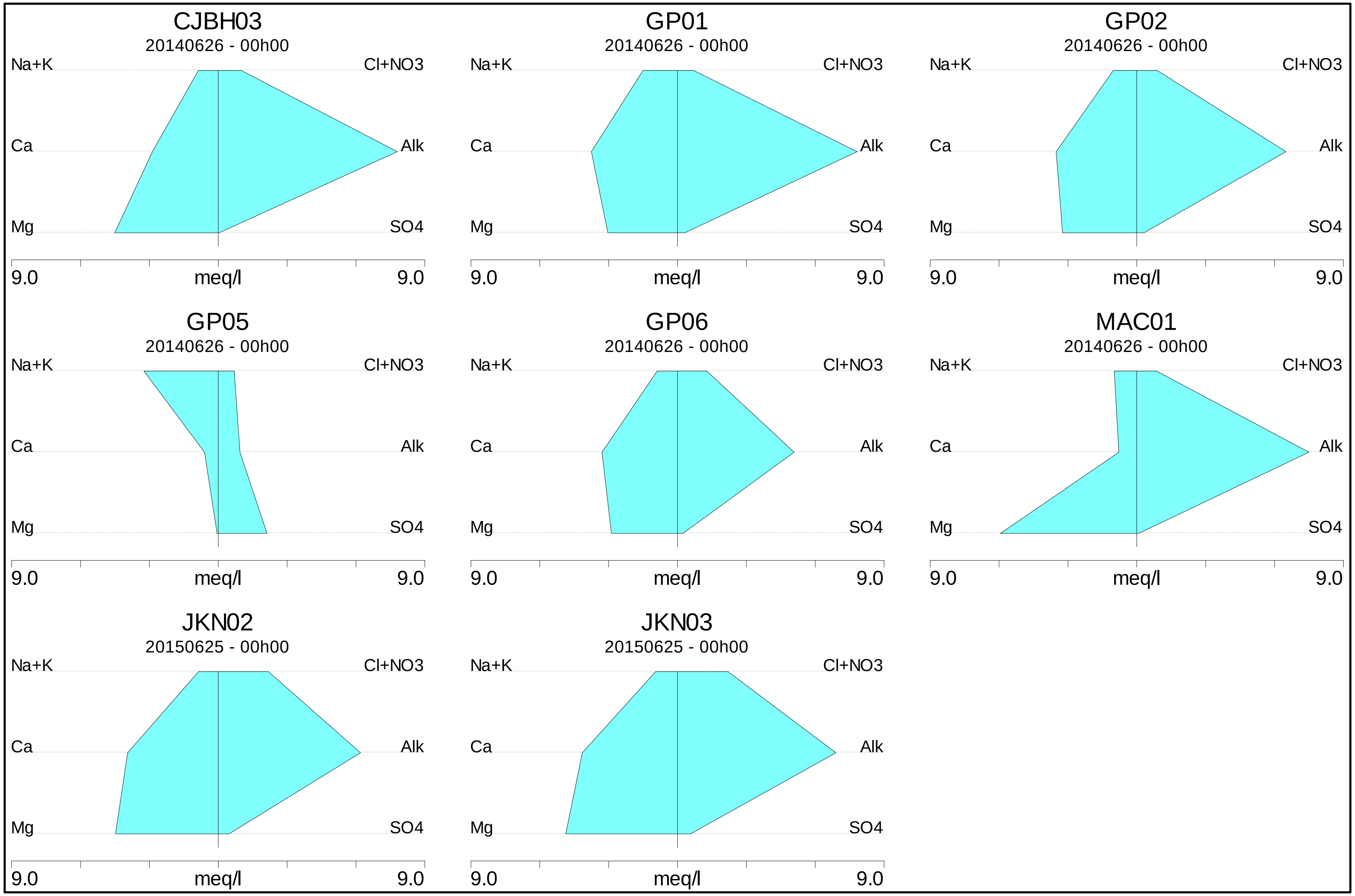


Figure 28: Stiff diagrams of groundwater chemistries for the project area

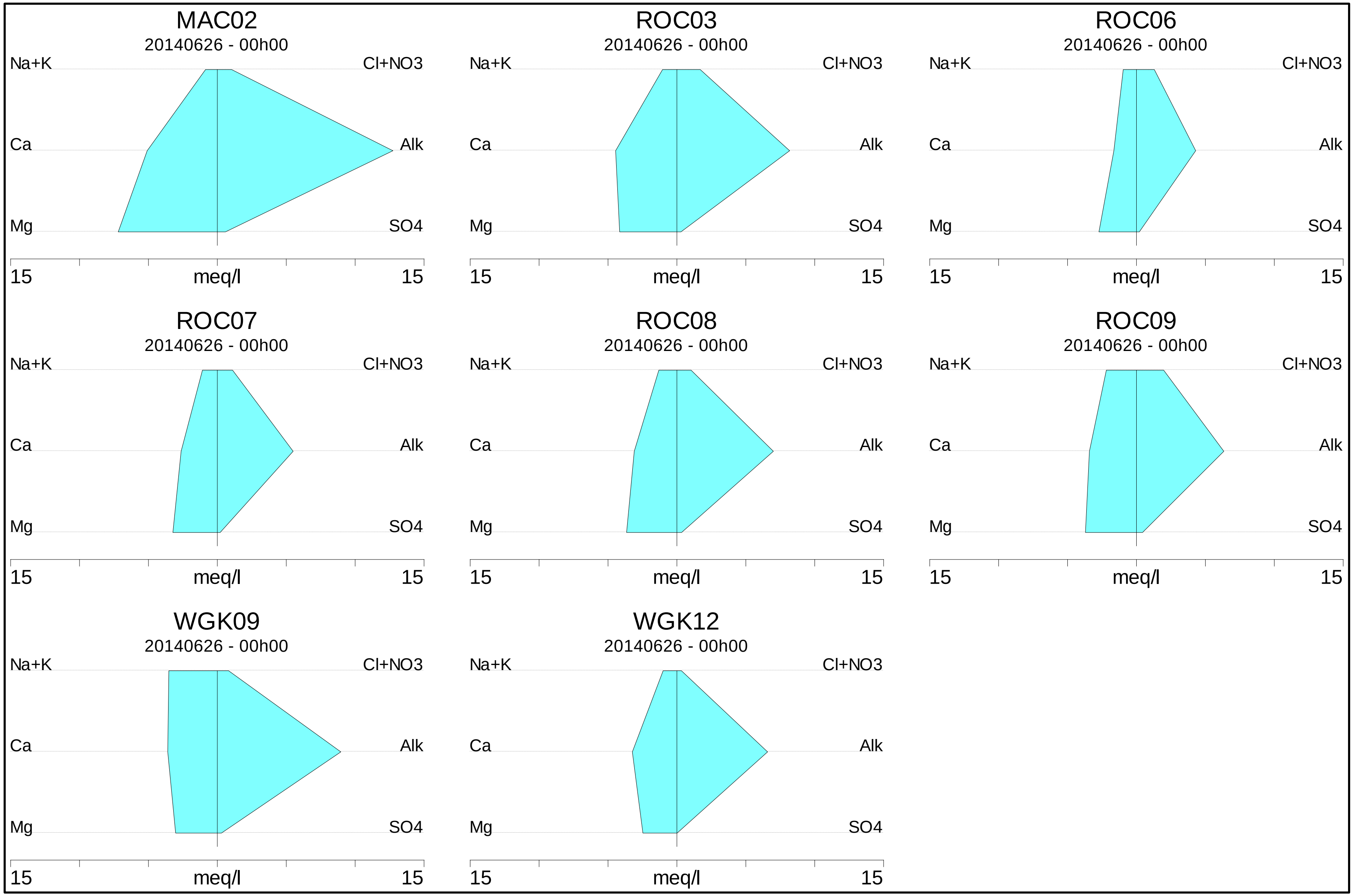


Figure 28: Stiff diagrams of groundwater chemistries for the project area (continue)

Table 7: Concentrations of indicator chemical parameters for sampling localities in the project area (mg/l)

BH	Al	Ca	Cl	F	Fe	K	Mg	Na	NO_3	pH	PO_4	SO_4	TDS
CJBH03	<0.006	57.5	35.4	0.3	<0.006	2.7	54.8	18.4	0.2	7.8	<0.025	1.9	410.0
GP01	<0.006	75.2	11.9	0.3	<0.006	1.2	36.9	33.9	5.3	8.2	<0.025	15.3	436.0
GP02	<0.006	70.4	12.4	0.2	<0.006	1.1	39.3	23.0	7.7	8.3	<0.025	15.0	393.0
GP05	<0.006	12.0	23.8	0.3	<0.006	1.4	0.6	73.6	0.3	8.9	<0.025	102.0	244.0
GP06	<0.006	65.9	11.4	0.3	<0.006	1.2	35.0	19.7	13.4	8.0	<0.025	11.5	360.0
JKN02	<0.006	79.1	43.4	0.4	<0.006	2.2	54.4	18.5	13.5	7.6	<0.025	22.4	470.0
JKN03	<0.006	83.1	52.2	0.8	<0.006	2.0	59.2	20.8	10.2	7.7	0.04	27.1	501.0
MAC01	<0.006	15.7	28.1	0.5	<0.006	3.2	72.2	20.7	1.1	8.4	<0.025	4.1	383.0
MAC02	<0.006	102.0	35.7	0.4	<0.006	2.5	87.4	18.3	0.5	7.9	<0.025	28.4	665.0
ROC03	<0.006	89.1	20.7	0.3	<0.006	3.1	50.5	22.2	15.6	7.9	<0.025	14.1	519.0
ROC06	<0.006	32.9	16.2	0.2	<0.006	2.9	33.1	20.4	11.8	8.9	<0.025	10.1	299.0
ROC07	<0.006	52.7	14.8	0.2	<0.006	3.4	39.2	22.9	9.7	8.4	<0.025	9.9	354.0
ROC08	<0.006	62.0	16.6	0.3	<0.006	3.0	44.4	28.4	7.9	8.5	<0.025	16.4	420.0
ROC09	<0.006	68.4	31.1	0.3	<0.006	2.9	45.0	48.6	15.4	8.4	<0.025	21.1	479.0
WGK09	<0.006	72.1	27.8	0.4	<0.006	3.5	36.8	78.9	0.5	8.1	<0.025	14.4	509.0
WGK12	<0.006	64.8	11.2	1.7	8.5	3.1	30.0	21.2	0.2	7.6	<0.025	1.0	337.0

Note: *- Values shaded with red exceed the SANS guideline concentrations for drinking water **(Table 6)**.*

- Source monitoring borehole JKN01 was dry at the time sampling took place.

*- Boreholes JKN04, JKN05, JKN06 and JKN07 **(Figure 40)** were primarily drilled to define important aquifer boundaries and were consequently not sampled.*

2 ENVIRONMENTAL IMPACT ASSESSMENT AND MITIGATION MEASURES FOR THE JENKINS PROJECT

This part of the geohydrological input to the EMP report describes and evaluates the potential impact of the Jenkins Project on the receiving environment. The management program proposed for the proposed new mining activities from a geohydrological perspective will also be discussed in this section. Generic aspects will be discussed together, but aspects pertaining to one project or source area specifically will be discussed as such with the specific areas.

Coza Mining (Pty) Ltd is committed to rehabilitate the Coza Jenkins Project area in a responsible manner, with a balanced approach by adequately managing negative environmental impacts to within acceptable limits. Remediation of negative impacts will, as far as possible, be based on the principle of Best Environmental Option (BEO), with the implementation of technically proven and best practice rehabilitation measures. New techniques will be evaluated when they become available and will be implemented should they prove effective within financial constraints. The criterion used for the risk evaluation is provided in **Table 8**.

It must be noted that many of the potential negative consequences can be mitigated successfully. It is however necessary to make a thorough assessment of all possible impacts in order to ensure that environmental considerations are taken into account in a balanced way, thus supporting the aim of minimizing any adverse impacts on the environment.

Groundwater contamination in the **operational phase** occurs when the rock is broken up either by blasting or excavation to expose the in situ aquifer host rock to oxygen. Apart from the exposure to the atmosphere the broken rock causes a much larger reaction surface, which greatly increases chemical reactions such as ion exchange. Connate water, if present, may also be released through the mining process and is often very saline. The results of both leaching and Acid Base Accounting tests have however shown that ore and waste rock sampled from the proposed Jenkins Project area are relatively inert and pose no significant contamination risks **(Section 3.2)**. **The most significant groundwater impact expected during the operational phase of mining is therefore considered to be the lowering of groundwater levels due to mine dewatering. Limited quality impacts are expected as a result of the usage of nitrate based explosives and hydrocarbons (i.e. petrol, diesel, etc.).**

Contrary to most other mining operations, the **post-closure impacts** of an iron ore mining operation are generally negligible as the waste material used to rehabilitate the mining areas is relatively inert. Low recharge and high evaporation rates are expected to prevent the pit from decanting, while the quality of pit water should vary from good to marginal.

The criteria used for assessing the significance of the impact are given in **Table 8**. The impact assessment method takes into account the current environment, the details of the proposed project and the findings of the geohydrological investigation. Cognisance will be given to both positive and negative impacts that may result from the development.

The significance of the impact is dependent on the consequence and the probability that the impact will occur.

Impact Significance = (Consequence x Probability)

Where:
Consequence = (Severity + Extent)/2
and
Severity = (Intensity + Frequency + Duration)/3

Each criterion is given a score from 1 to 5 based on the definitions provided in **Table 8**. Although the criteria used for the assessment of impacts attempts to quantify the significance, it is important to note that the assessment is generally a qualitative process and therefore the application of this criteria is open to interpretation. The process adopted will therefore include the application of scientific measurements and professional judgement to determine the significance of environmental impacts associated with the project. The assessment thus largely relies on experience of the environmental assessment practitioner (EAP) and the information provided by the specialists appointed to undertake studies for the EIA.

Where the consequence of an event is not known or cannot be determined, the “precautionary principle” will be adhered to and the worst-case scenario assumed. Where possible, mitigation measures to reduce the significance of negative impacts and enhance positive impacts will be recommended. The detailed actions, which are required to ensure that mitigation is successful, will be provided in the EMP, which will form part of the EIA report.

Consideration will be given to the phase of the project during which the impact occurs. The phase of the development during which the impact will occur will be noted to assist with the scheduling and implementation of management measures.

Table 8: Criteria for assessing the impact significance

Severity Criteria:

INTENSITY = MAGNITUDE OF IMPACT	RATING
Insignificant: impact is of a very low magnitude	1
Low: impact is of low magnitude	2
Medium: impact is of medium magnitude	3
High: impact is of high magnitude	4
Very high: impact is of highest order possible	5
FREQUENCY = HOW OFTEN THE IMPACT OCCURS	**RATING**
Seldom: impact occurs once or twice	1
Occasional: impact occurs every now and then	2
Regular: impact is intermittent but does not occur often	3
Often: impact is intermittent but occurs often	4
Continuous: the impact occurs all the time	5
DURATION = HOW LONG THE IMPACT LASTS	**RATING**
Very short-term: impact lasts for a very short time (less than a month)	1
Short-term: impact lasts for a short time (months but less than a year)	2
Medium-term: impact lasts for the for more than a year but less than the life of operation	3
Long-term: impact occurs over the operational life of the proposed extension	4
Residual: impact is permanent (remains after mine closure)	5
EXTENT = SPATIAL SCOPE OF IMPACT/FOOTPRINT AREA/NUMBER OF RECEPTORS	**RATING**
Limited: impact affects the mine site	1
Small: impact extends to the whole farm portion	2
Medium: impact extends to neighbouring properties	3
Large: impact affects the surrounding community	4
Very Large: The impact affects an area larger the municipal area	5

Note: *I = Intensity, F = Frequency, D = Duration, E = Extent, P = Probability.*

Probability:

PROBABILITY = LIKELIHOOD THAT THE IMPACT WILL OCCUR	RATING
Highly unlikely: the impact is highly unlikely to occur	0.2
Unlikely: the impact is unlikely to occur	0.4
Possible: the impact could possibly occur	0.6
Probable: the impact will probably occur	0.8
Definite: the impact will occur	1

Impact Significance:

Negative Impacts

≤1	Very low	Impact is negligible. No mitigation required.
>1 ≤2	Low	Impact is of a low order. Mitigation could be considered to reduce impacts. But does not affect environmental acceptability.
>2 ≤3	Moderate	Impact is real but not substantial in relation to other impacts. Mitigation should be implemented to reduce impacts.
>3 ≤4	High	Impact is substantial. Mitigation is required to lower impacts to acceptable levels.
>4 ≤5	Very High	Impact is of the highest order possible. Mitigation is required to lower impacts to acceptable levels. Potential Fatal Flaw.

Positive Impacts

≤1	Very low	Impact is negligible.
>1 ≤2	Low	Impact is of a low order.
>2 ≤3	Moderate	Impact is real but not substantial in relation to other impacts.
>3 ≤4	High	Impact is substantial.
>4 ≤5	Very High	Impact is of the highest order possible.

Cumulative Impacts

In accordance with Regulation 584 of NEMA, **cumulative impacts** are defined as: “the impact of an activity that in itself may not be significant but may become significant when added to the existing and potential impacts eventuating from similar or diverse activities or undertakings in the area”. Taking into consideration the above definition, the **cumulative impacts** for the Jenkins Project will be assessed by considering the potential impacts of the mine and the current status of the environment in which the project will be developed.

Project Phases

The environmental impacts for the project will be assessed over the **five project phases,** i.e. the **planning and design**, **construction**, **operation**, **decommissioning** and **post-closure phase**:

- The **planning and design phase** refers to the stage when the feasibility studies are being undertaken, the project description is being developed and the mine is being designed. **No groundwater related impacts are expected to occur during this project phase, therefore it was excluded from the assessment.**
- The **construction phase** will commence after the mining right and environmental authorisations have been obtained. This phase will involve the physical construction of the mine and its associated infrastructure. Construction is anticipated to commence in last quarter of 2016 until the second quarter of 2017.
- The mine **operation** is anticipated to commence in 2017, pending approval. Operational activities are anticipated to proceed for about 10 years.

- The **decommissioning phase** refers to the time in the mine life when mining operations are reduced in preparation for closure. This phase will occur once the resource has been mined optimally and economically. It is anticipated that mining activities will last for about 10 years.
- The **closure phase** refers to when the mine is shut down and no mining activities are undertaken, this phase will occur after successful decommissioning has been achieved.

Mitigation Measures

A no net loss approach will be adopted in terms of the management of impacts at the Jenkins Iron Ore Project:

- **Avoidance**: impacts are to be avoided where practicable e.g. through the implementation of alternatives.
- **Mitigation**: should it not be possible to avoid all impacts, the remaining impacts are to be mitigated to acceptable levels.
- **Offset**: should it not be possible to avoid and mitigate all impacts to acceptable levels it will be necessary to offset the remaining impacts. Suitable offsets will need to be identified.

Mitigation measures for significant impacts which cannot be avoided will be identified. The impacts will be ranked before and after the implementation of the mitigation measures. Consideration will also be given to the confidence level that can be placed on the successful implementation of the mitigation level as follows:

- **High Confidence**: mitigation measure easy and inexpensive to implement.
- **Medium Confidence**: mitigation measure expensive or difficult to implement.
- **Low Confidence**: mitigation measure expensive and difficult to implement.

2.1 GROUNDWATER CONTAMINATION ASSOCIATED WITH THE USE OF MACHINERY FOR LAND CLEARANCE

2.1.1 CONSTRUCTION PHASE

The following land clearance activities, which may have an impact on groundwater will take place during the construction phase:

- Vegetation clearance,
- Topsoil and sub-soil stripping and stockpiling.

2.1.1.1 POTENTIAL IMPACTS

The potential impact of stripping and stockpiling of topsoil and subsoil from the infrastructure and pit surface areas on the groundwater regime is considered negligible since no chemical interaction is envisaged that could have an adverse impact on groundwater quality.

Any potential spills and/or leaks from machinery used during this project phase will be contained and rehabilitated in accordance with best practice guidelines to ensure minimal impact on groundwater quality. The short duration of this activity further decreases the risk of adverse impacts occurring on groundwater quality.

Impact	Mitigation	I	F	D	E	P	Impact Significance
Land clearance	Before mitigation	2	1	4	1	0.4	Very low
	After mitigation	2	1	4	1	0.4	Very low

2.2 GROUNDWATER QUALITY AND QUANTITY IMPACTS ASSOCIATED WITH THE CONSTRUCTION AND OPERATION OF SURFACE INFRASTRUCTURE

2.2.1 CONSTRUCTION PHASE

The following surface infrastructure will be constructed during the construction phase:

- Primary processing plant,
- Main power supply,
- Rail balloon and rail loading,
- Main administrative offices,
- Truck service and wash-bay,
- Explosives magazine,
- Change house,
- Store and workshop,

2.2.1.1 POTENTIAL IMPACTS

The construction of infrastructure will cause a very small reduction in recharge to the underlying aquifer system due to the compaction of the surface of the roads and foundation layers.

Clean run-off from areas such as roofs and parking areas eventually contributes to catchment yields. Run-off from haul-roads will be diverted and contained in the dirty water system. No adverse impact is foreseen on groundwater quality since material used for construction is inert.

Any potential spills and/or leaks from machinery used during this project phase will be contained and rehabilitated in accordance with best practice guidelines to ensure minimal impact on groundwater quality. The short duration of this activity further decreases the risk of adverse impacts occurring on groundwater quality.

Impact	Mitigation	I	F	D	E	P	Impact Significance
Construction of surface infrastructure	Before mitigation	2	1	4	1	0.4	Very low
	After mitigation	2	1	4	1	0.4	Very low

2.2.2 OPERATIONAL PHASE

The following activities will take place during the operational phase:

- Operation of surface infrastructure (i.e. plant, workshops, change house, etc.),
- Operation of access and service roads.

2.2.2.1 POTENTIAL IMPACTS

Very little impact is expected since no water seepage or abstraction is involved that could affect water levels. For dry facilities (i.e. plant dirty footprint area, workshops, etc.) impact on the groundwater only occurs through leachate formation from surface. Impacts thus only occur as a result of rainfall recharge or when water is introduced in some form where leachate can form that seeps to the groundwater regime.

Impact	Mitigation	I	F	D	E	P	Impact Significance
Operation of surface infrastructure	Before mitigation	2	5	4	1	0.8	Low
	After mitigation	2	1	4	1	0.4	Very low

2.2.2.2 MANAGEMENT OBJECTIVES AND PRINCIPLES

Haul roads and other compacted surfaces will be kept free of potentially hazardous material by cleaning spillages, thereby reducing infiltration of contaminated water.

The size of compacted areas must be minimized to as small as practically possible. The surface area of the fuel depot will be covered and bunded with concrete to prevent fuel from seeping into the underlying aquifer system in the event of an accidental spillage and/or leakage.

Very little impact on groundwater quantity and quality is expected overall during the operational phase activities mostly because of the small surface area involved during this project life phase. Clean run-off from areas such as roofs and parking areas eventually contributes to catchment yield.

2.2.2.3 MANAGEMENT ACTIVITIES OR MITIGATION MEASURES

No significant groundwater impacts are expected. Run-off from haul-roads will be diverted and contained in the dirty water system.

2.3 GROUNDWATER QUALITY AND QUANTITY IMPACTS ASSOCIATED WITH THE CONSTRUCTION AND OPERATION OF SURFACE AND WASTE WATER MANAGEMENT MEASURES

2.3.1 CONSTRUCTION PHASE

The following activities will take place during the construction phase:

- Construction of water management and reticulation infrastructure (i.e. pollution control dam/s, water supply dam, cut-off berms, canals, reservoirs, etc.),
- Construction of waste management infrastructure (i.e. sewage treatment facility),
- Pipelines for the bulk transportation of water, sewage or storm water.

2.3.1.1 POTENTIAL IMPACTS

The construction of surface and waste water management measures will cause a very small reduction in recharge to the underlying aquifer system due to the compaction of the surface of the foundation layers. No adverse impact is foreseen on groundwater quality since material used for construction is inert.

Any potential spills and/or leaks from machinery used during this project phase will be contained and rehabilitated in accordance with best practice guidelines to ensure minimal impact on groundwater quality. The short duration of this activity further decreases the risk of adverse impacts occurring on groundwater quality.

Impact	Mitigation	I	F	D	E	P	Impact Significance
Construction of surface/waste water management measures	Before mitigation	2	1	4	1	0.4	Very low
	After mitigation	2	1	4	1	0.4	Very low

2.3.1.2 MANAGEMENT OBJECTIVES AND PRINCIPLES

- An appropriate liner is recommended for all water retaining infrastructure,
- Prevent contact between clean and dirty areas,
- Recycle and reuse contaminated water as far as possible,
- All contaminated water will be contained for re-use and/or evaporation,
- To minimize the extent of disturbance of the aquifer,
- To limit degeneration of groundwater quality.

2.3.1.3 MANAGEMENT ACTIVITIES OR MITIGATION MEASURES

- No construction of any water management measures will be undertaken with potentially hazardous material,
- All dams will be constructed to comply with the relevant DWS requirements in an effort to minimize the seepage of poor quality leachate,
- Clean surface water will not come into contact with dirty water (as outlined in the GN704).

2.3.2 OPERATIONAL PHASE

The following activities will take place during the operational phase:

- Operation of water and waste management measures and pollution control facilities,
- Containment and re-use of contaminated water within isolated dirty water management areas.

2.3.2.1 POTENTIAL IMPACTS

The operation of water and waste management measures and pollution control facilities must inadvertently have some form of impact on groundwater, although the primary purpose of the facilities is to minimize or contain water contamination. Facilities (e.g. pollution control dam) will be constructed to comply with the relevant DWS requirements.

For wet management facilities (i.e. pollution control dam) seepage has a direct impact and is only governed by the hydraulic properties of the liner of the facility and the rest of the unsaturated zone.

The added seepage from the wet facilities (especially where no lining material occurs) causes artificial recharge to the aquifer and often result in mounding of the groundwater level below the facility. The mounding causes a local increase in the groundwater gradient, which leads to an increased flow rate of contaminated seepage.

For dry facilities (i.e. waste disposal sites, stockpile areas, waste rock dumps, etc.) impact on the groundwater only occurs through leachate formation from surface. Impacts thus only occur as a result of rainfall recharge or when water is introduced in some form where leachate can form that seeps to the groundwater regime.

The artificial recharge and mounding concept does not come into play with dry sources and therefore the intensity and rate of contaminant transport are far less significant compared to wet sources.

Impact	Mitigation	I	F	D	E	P	Impact Significance
Operation of surface/waste water management measures	Before mitigation	4	5	4	4	1	Very High
	After mitigation	2	1	3	1	0.2	Very Low

2.3.2.2 MANAGEMENT OBJECTIVES AND PRINCIPLES

- An appropriate liner is recommended for all water retaining facilities in an effort to minimise poor quality seepage to the groundwater regime,
- Prevent contact between clean and dirty areas,
- Recycle and reuse contaminated water as far as possible,
- To minimize the extent of disturbance of the aquifer,
- To minimize the impact on groundwater quality.

2.3.2.3 MANAGEMENT ACTIVITIES OR MITIGATION MEASURES

- Clean surface water will not come into contact with dirty water or material (as outlined in the GN704),
- Wet facilities will be lined to prevent the seepage of poor quality leachate,
- Continuous monitoring of groundwater quality.

2.4 GROUNDWATER QUALITY AND QUANTITY IMPACTS ASSOCIATED WITH THE DEVELOPMENT AND OPERATION OF THE WASTE ROCK DUMP

2.4.1 OPERATIONAL PHASE

The following activities will take place during the operational phase:

- The development and operation of the waste rock dump as waste material is produced by the extraction of the ore.

2.4.1.1 POTENTIAL IMPACTS

In the iron ore mining scenario nitrate contamination is more often than not associated with rock material (waste rock dump/s) that contains remnants of nitrate based explosives, which are highly soluble in water. Seepage emanating from such areas is therefore expected to contain high concentrations of nitrate and pose a significant groundwater contamination risk. Sporadic contamination of the groundwater regime therefore occurs whenever water seeps through the contaminated material during periods of rainfall.

The dump is not regarded as a wet facility and mounding of the underlying groundwater levels as a result of artificial aquifer recharge is not expected to occur.

Impact	Mitigation	I	F	D	E	P	Impact Significance
Development and operation of the waste rock dump	Before mitigation	1	2	4	3	1	Moderate
	After mitigation	1	1	3	1	0.4	Very Low

2.4.1.2 MANAGEMENT OBJECTIVES AND PRINCIPLES

- An appropriate liner is recommended in an effort to minimise poor quality seepage to the groundwater regime,
- Prevent contact between clean and dirty areas,
- To minimize the extent of disturbance of the aquifer,
- To minimize the impact on groundwater quality.

2.4.1.3 MANAGEMENT ACTIVITIES OR MITIGATION MEASURES

- Clean surface water will not come into contact with dirty water or nitrate contaminated ROM material (as outlined in the GN704),
- The surface area should be lined to prevent the ingress of poor quality seepage,
- Continuous monitoring of groundwater quality.

2.5 GROUNDWATER QUALITY AND QUANTITY IMPACTS ASSOCIATED WITH THE DEVELOPMENT AND PROGRESSION OF THE OPENCAST PIT

2.5.1 OPERATIONAL PHASE

The following activities will take place during the operational phase:

- Progressive development of opencast mining cuts, including blasting and extraction of iron ore.

2.5.1.1 POTENTIAL IMPACTS

Groundwater levels are expected to decrease within the immediate vicinity of the opencast pit as a result of mine dewatering. The degree of aquifer dewatering depends on the extent and depth of the opencast pit below the local groundwater level as well as the hydraulic properties of the aquifer host rock.

Dewatering of the aquifer system will only begin once the pit floor elevation decreases below the local groundwater elevation, which is expected to occur from year seven and onwards. The area affected by mine dewatering depends on the transmissivity and storativity of the aquifer host rock and geological structures. Depletion of the groundwater resource will impact negatively on:

- The groundwater **resource itself** and interrelations with other natural resources (e.g. pans and wetlands), and
- The users that depend on groundwater as **sole source** of domestic water as well as for livestock and gardening.

The aquifer structure will be destroyed wherever it is intersected by the opencast pit.

Pit dewatering will occur whenever necessary to ensure dry and safe mining conditions. Groundwater contamination of surrounding users is therefore not expected to take place while the mine is still operational. Only after groundwater levels have recovered from the impacts of mine dewatering is contamination expected to migrate in the down gradient groundwater flow direction/s.

Affected storm water runoff will be contained in the purpose-built containment facilities.

Impact	Mitigation	I	F	D	E	P	Impact Significance
Development and progression of the opencast pit	Before mitigation	3	4	5	1	1	Moderate
	After mitigation	3	4	5	1	1	Moderate

Note: *Assessment provided above is related to groundwater level impacts.*

Impact	Mitigation	I	F	D	E	P	Impact Significance
Development and progression of the opencast pit	Before mitigation	2	1	1	1	0.4	Very low
	After mitigation	2	1	1	1	0.4	Very low

Note: *Assessment provided above is related to groundwater quality impacts.*

2.5.1.2 MANAGEMENT OBJECTIVES AND PRINCIPLES

No management action is available to prevent dewatering and the destruction of the aquifer structure.

2.5.1.3 MANAGEMENT ACTIVITIES OR MITIGATION MEASURES

The dewatering of the local aquifer system and destruction of its structure/s cannot be prevented. A quarterly monitoring program will be implemented to monitor the extent of the dewatering. If the monitoring program indicates that nearby groundwater users are affected negatively by the dewatering, the users should be compensated for the loss.

2.6 GROUNDWATER QUALITY AND QUANTITY IMPACTS ASSOCIATED WITH THE TRANSPORTATION OF ORE

2.6.1 OPERATIONAL PHASE

The following activities will take place during the operational phase:

- Hauling of iron ore from the opencast pit via road to the ROM stockpile.

2.6.1.1 POTENTIAL IMPACTS

A reduction in recharge will result due to the compaction of the surface of the roads relating to the hauling of ore. Since all contaminated surface water runoff from haul road areas will be collected in the dirty water management system, infiltration of contaminated water will be minimized.

Impact	Mitigation	I	F	D	E	P	Impact Significance
Transportation of ore	Before mitigation	2	1	4	1	0.4	Very low
	After mitigation	2	1	4	1	0.4	Very low

2.6.1.2 MANAGEMENT OBJECTIVES AND PRINCIPLES

To ensure that contaminated surface water runoff from haul roads do not come into contact with clean surface water runoff (GN704), or infiltrate into the groundwater system.

2.6.1.3 MANAGEMENT ACTIVITIES OR MITIGATION MEASURES

All contaminated surface water runoff from haul road areas will be collected in the dirty water management system, which means that the infiltration of contaminated water will be minimized.

2.7 GROUNDWATER QUALITY AND QUANTITY IMPACTS ASSOCIATED WITH THE STOCKPILING OF IRON ORE AT THE RUN-OF-MINE/PRODUCT STOCKPILE

2.7.1 OPERATIONAL PHASE

The following activities will take place during the operational phase:

- Stockpiling of iron ore at a dedicated site.

2.7.1.1 POTENTIAL IMPACTS

The iron ore itself is inert and pose no significant contamination risk, however remnants from nitrate based explosive may lead to poor quality seepage being generated during times of rainfall.

Impact	Mitigation	I	F	D	E	P	Impact Significance
Stockpiling of iron ore at ROM stockpile	Before mitigation	1	2	4	3	1	Moderate
	After mitigation	1	1	3	1	0.4	Very Low

2.7.1.1 MANAGEMENT OBJECTIVES AND PRINCIPLES

- To prevent contact of clean runoff water with the ore,
- To minimize further degeneration of groundwater quality,
- To contain all dirty water in the pollution control dam,
- To minimize the impact of the proposed ROM stockpile on groundwater quality.

2.7.1.2 MANAGEMENT ACTIVITIES OR MITIGATION MEASURES

- The surface area will be covered with an appropriate liner,
- Clean runoff water will be diverted away from the stockpile area,
- Quarterly monitoring of boreholes will be implemented to monitor the groundwater quality. If the monitoring program indicates that nearby groundwater users are affected negatively by the handling of iron ore, the users should be compensated for their loss.

2.8 REHABILITATION

2.8.1 DECOMMISSIONING PHASE

The following activities will take place during the decommissioning phase:

- Removal of all mining and related infrastructure,
- Shaping and landscaping of the opencast pit and waste rock dump,
- Removal of potentially hazardous material from disturbed land use areas,
- Demolition and rehabilitation of redundant surface infrastructure, such as pollution control facilities and buildings, depending on the long-term groundwater management strategy and agreed end land use,
- Removal of exotic and invasive plants and the re-establishment of such species within the rehabilitated areas will be prevented,
- Final rehabilitation, including the placement of topsoil and establishment of vegetation on rehabilitated areas,
- Aim to establishment a sustainable and agreed end land use through final rehabilitation.

2.8.1.1 POTENTIAL IMPACTS

The rehabilitation of the disturbed surface areas will have a positive effect on the groundwater system.

Impact	I	F	D	E	P	Impact Significance
Rehabilitation of disturbed surface areas	4	5	5	3	1	High

2.8.1.2 MANAGEMENT OBJECTIVES AND PRINCIPLES

To establish a sustainable and agreed end land use through final rehabilitation.

2.8.1.3 MANAGEMENT ACTIVITIES OR MITIGATION MEASURES

Same as discussed in **Section 2.8.1.**

3 RESIDUAL IMPACTS AFTER CLOSURE

Two types of impacts can remain on groundwater long after mining has been completed, namely groundwater **quality** and **water level impacts**. The former (quality) impact is very common in the coal and base metal mining industry where chemical reactions and processes like oxidation, ion exchange and consequent acid mine drainage (AMD) influence the water quality where water comes into contact with the host rocks in the presence of oxygen and water. Acid Base Accounting (ABA) and leaching tests were performed on two samples collected from the drilling of exploration boreholes in the Jenkins Project area and the results are discussed in detail in **Section 3.2** of the document.

Contrary to most other mining operations, the residual impacts of an iron ore mining operation are generally small and are mostly related to contaminants such as nitrate and hydrocarbons that were brought onto site and used during the operational phase of mining.

Negligible negative groundwater level impacts are expected to occur after closure as water levels will begin to recover as soon as active mining has ceased.

3.1 GROUNDWATER LEVEL REBOUND, RECHARGE RATE AND DECANT

During decommissioning, and for a certain time after closure, the geohydrological environment will dynamically attain a new equilibrium after the dewatering effects of the opencast workings. Decant predictions in an opencast mining environment are affected by the following:

- The mean annual precipitation (MAP),
- Recharge to the mine void, expressed as a percentage of the MAP. Recharge on the other hand is affected by:
  - The size of the surface area disturbed by mining activities,
  - The transmissivity of the backfill material,
  - Surface water runoff,
- The overall porosity of the rehabilitated pit area,
- The groundwater contribution to water inflow, which is determined by the hydraulic properties of the surrounding undisturbed aquifer/s.

The groundwater gradient within a rehabilitated opencast pit is generally very close to being zero as a result of the high transmissivity of the backfill material. Decanting of an opencast pit is therefore most likely to occur wherever the pit intersects the lowest surface elevation. This concept is further explained and schematically illustrated in **Figure 29** by means of a conceptual cross section through a typical opencast pit.

The time it will take the proposed Jenkins pit to fill with water after mine closure was calculated with the use of volume/recharge calculations and the results are provided in **Table 9**, while the most probable decant position is indicated in **Figure 30.**

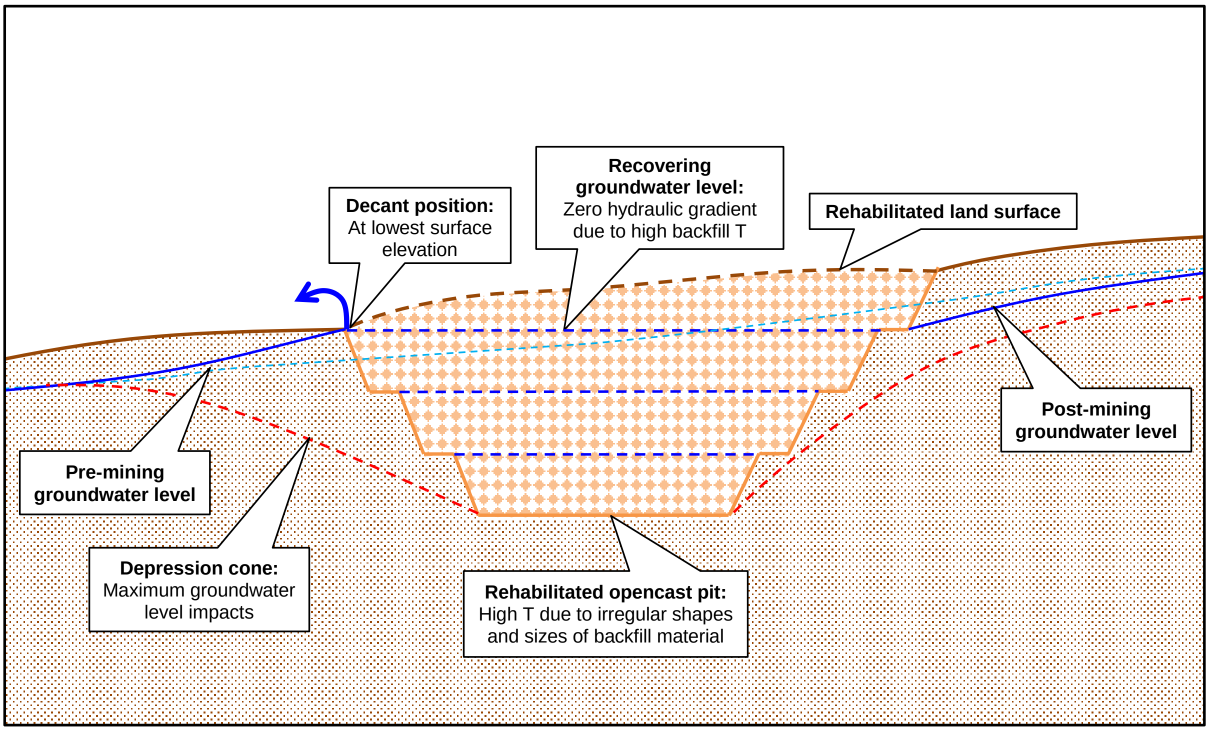


Figure 29: Conceptual model for the decanting of an opencast mine void

Table 9: Time-to-fill calculations for proposed Jenkins pit

General information		
Surface area	m^2	356 320
Decant elevation	mamsl	1 284
Total void volume	m^3	14729630
Mean annual precipitation	m/a	400
Backfilled void volume		
20% Porosity	m^3	2 945 926
25% Porosity	m^3	3 682 408
30% Porosity	m^3	4 418 889
Decant/Recharge rate		
14% Recharge	m^3/y	19 954
16% Recharge	m^3/y	22 804
18% Recharge	m^3/y	25 655
Time to fill		
Worst case scenario (20% Ø and 18% RCH)	Years	115
Most probable scenario (25% Ø and 16% RCH)	**Years**	**161**
Best case scenario (30% Ø and 14% RCH)	Years	221

Notes: *Ø - Porosity,*
RCH - Recharge.

If the proposed pit was to decant it is expected to occur at an elevation of ± 1 284 mamsl and the decant position is indicated in **Figure 30**. The most probable time it will take the backfilled void to fill with water to the decant elevation was calculated to be in the order of 160 years after active mining has ceased **(Table 9)**. Low rainfall combined with the relatively small surface area expected to be disturbed by the opencast pit contribute to the long time it will take the water level within the backfilled pit to reach the decant elevation.

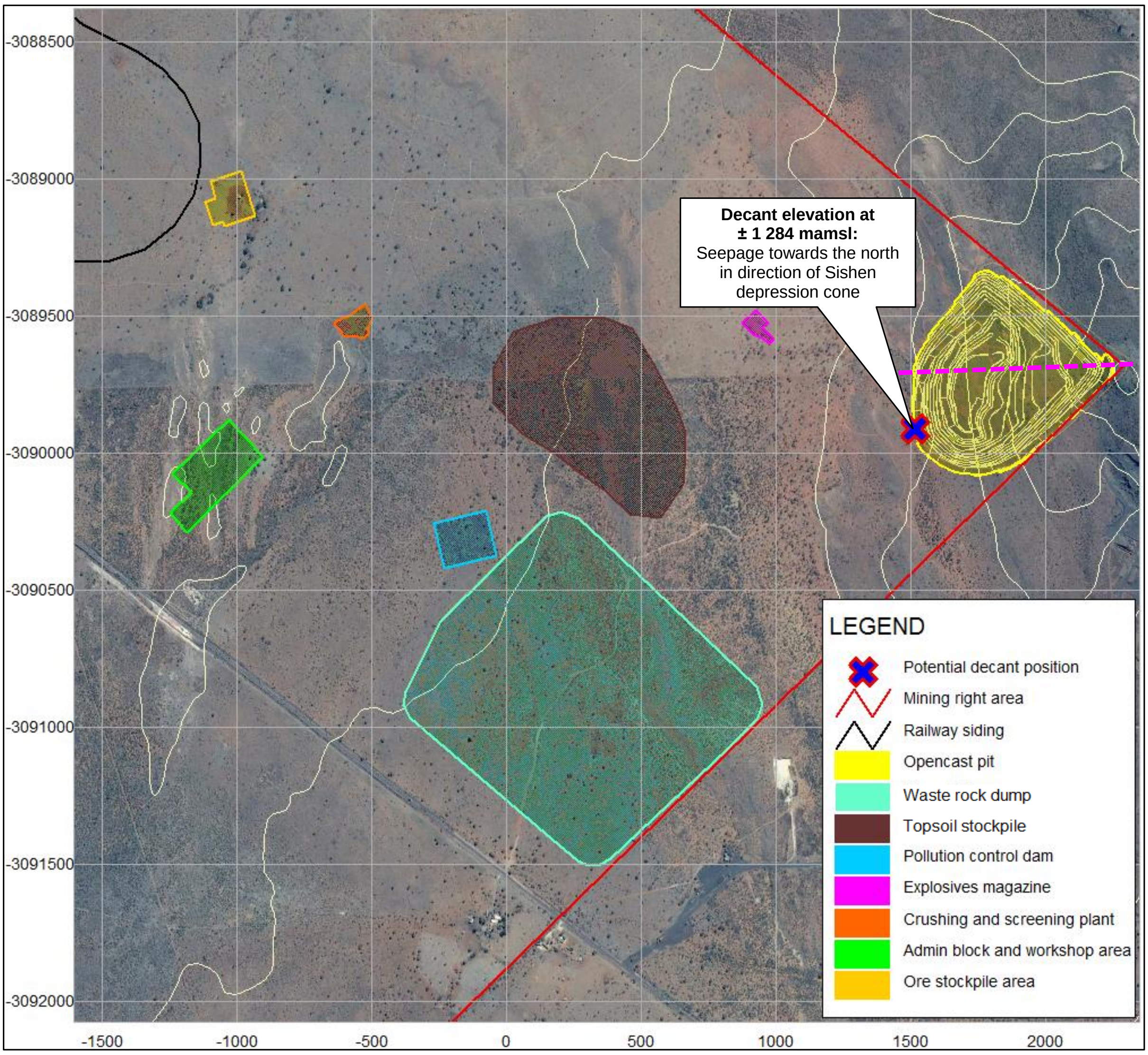


Figure 30: Most probable decant position for the Jenkins pit

Decanting of a mine void generally occurs as a result of an excess volume of water that cannot be "absorbed" by the aquifer system. The excess water is generated by the increased recharge from surface due to the destruction of the aquifer structure.

An evaporation rate of approximately 962 100 m^3/y **(Figure 22)** was calculated to occur from the surface of the backfilled pit, which far exceeds the expected recharge volume of ± 22 800 m^3/y **(Table 9)**. **The water level within the backfilled opencast pit is therefore not expected to reach the surface and decanting should not occur**.

3.2 GROUNDWATER QUALITY

The two most common processes by which groundwater is contaminated include **interstitial release** and **ion exchange release**. Argillaceous sediments such as shale and mudstone are known to contain pore water with high saline content. Significant amounts of contaminants may therefore be released as these sediment structures disintegrate because of weathering or when exposed and crushed through the mining process. The most commonly released ions during this weathering process are sodium and chloride.

Pyrite in coal-bearing material and base metal sulphides are very prone to oxidation when brought into contact with water under oxidation conditions. The chemical reactions are collectively referred to as acid mine drainage (AMD). The root of the problem lies in chemical and bacteriological oxidation of pyrite occurring in the coal, other carbonaceous material and base metals. The following are the most commonly occurring reaction train:

$2FeS_2 + 7O_2 + 2H_2 – 2FeSO_4 + H_2SO_4$ .... (1)
$4FeSO_4 + 2H_2SO_4 + O2 – 2Fe_2\ (SO_4)_3 + 2H_2O$ .... (2)
$3Fe_2\ (SO_4)_3 + 12H2O – 2HFe_3(SO_4)_2\ (OH)_6 + 5H_2SO_4$................... (3)

The pH and bicarbonate value of the water is expected to decrease. Metals go into solution and sulphate (SO_4) and Total Dissolved Solids (TDS) values increase. As the water leaves the mining area, it usually mixes with better quality water and the pH and bicarbonate values will be buffered back to more acceptable levels. Metals then also precipitate and the SO_4 and TDS concentrations decrease.

Results of various studies conducted for the surrounding iron ore mines have shown that none of these reactions or contaminants applies to the iron ore mining environment. The in situ ore and host rock are chemically inert and ion exchange and accompanying groundwater contamination do not occur (*Sishen South Iron Ore Project, 2005*).

Even so, Acid Base Accounting (ABA) and leaching tests were performed by an accredited laboratory *(Waterlab)* on two samples collected from the drilling of exploration boreholes in the Jenkins Project area. The Modified Sobek method was used for the ABA tests, while for the leaching tests the samples were leached with distilled water as a realistic scenario expected for the project area.

Acid Base Accounting is done to determine the net acid generating and neutralising potentials of material. The main principles of acid-base accounting are:

- Samples are exposed to complete oxidation of all sulphide-bearing minerals.
- This generates acid, which is counteracted by the natural base potential in the material.
- The initial pH before oxidation and the oxidised pH are recorded for each sample.

Little or no drop in pH occurs whenever the base potential exceeds the acid potential. The opposite holds true when the acid potential exceeds the base potential – such a sample is therefore expected to generate acidic conditions when exposed to oxygen and water.

The following criteria were used on the ABA test data to assess the potential for each of the samples to generate ARD:

- The difference between the acid-neutralising potential and acid-generating potential is known as the net-neutralising potential (NNP = NP – AP). Therefore, whenever the NNP is a negative value the acid potential exceeds the base potential, suggesting that water leaching through this material will tend to turn acidic **(Table 10),** and
- The ratio of NP:AP is termed the Net Potential Ratio (NPR). ARD screening criteria based on NPR and sulphur % are listed in **Table 11**.

Table 10: Classification of samples according to nett neutralising potential *(Usher et al., 2003)*

NNP < 0	Potentially acid forming
NNP > 0	Non-acid forming

Any sample with NNP < 20 is potentially acid-generating, while any sample with NNP > -20 might not generate acid.

Table 11: Classification of samples according to the neutralising potential ratio (NPR)

TYPE I	Potentially acid forming	Total S(%) > 0.25% and NP:AP ratio 1:1 or less
TYPE II	Intermediate	Total S(%) > 0.25% and NP:AP ratio 1:3 or less
TYPE III	Non-acid forming	Total S(%) < 0.25% and NP:AP ratio 1:3 or greater

The results of the ABA tests are provided in **Table 12**. Both samples collected from the Jenkins Project area are classified as Type III according to the **sulphur content and NPR classification (Table 11)**. Similar to the surrounding iron ore mines the conclusion is therefore drawn that both the ore and waste rock material are non-acid forming.

In both samples the neutralising potential (NP) exceeds the acid potential (AP), which result in positive nett neutralising potential values. According to the **nett neutralising potential classification (Table 10)** both samples are therefore considered to be non-acid forming.

Table 12: Results of ABA tests

Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification	
	Jenkins Ore Composite	Jenkins Hanging Wall Composite
Sample Number	17046	17047
Paste pH	6.2	6.5
Total Sulphur (%) (LECO)	0.02	0.11
Acid Potential (AP) (kg/t)	0.625	3.44
Neutralization Potential (NP)	2.71	18.15
Nett Neutralization Potential (NNP)	2.08	14.71
Neutralising Potential Ratio (NPR) (NP : AP)	4.33	5.28
Rock Type	III	III

In basic terms a **leaching test** involves the percolation of a liquid through a finely crushed rock sample after which the leachate retrieved from the sample (extract) is analysed to determine what chemical changes have occurred. Different liquids are used for different purposes and numerous documented leach procedures exist. For the Jenkins samples the so-called distilled Water Leach was used. The distilled water leach is considered a realistic scenario that can be expected to realise in the project area. The rainfall in the region is not acidic and the quality of the rain water is very similar to that of distilled water.

The distilled water leach procedure can be summarised as follows:

- 50g of the sample is weighed into a container and 1000 ml of distilled water is added.
- The sample is shaken for 20 hours.
- The sample is filtered and sent for analysis.

The extract was analysed for:

- Physical parameters (pH, Alkalinity, Electrical Conductivity) and
- Macro element anions (Chloride, Sulphate, Nitrate and Fluoride), after which
- It was sent for an ICP-OES metals scan.

The results of the leaching tests are provided in **Tables 13** and **14** and are compared against the South African National Standards for drinking water **(Table 6)**. Parameters highlighted with red are those that exceed the SANS guideline concentrations. All physical parameters and concentrations of macro element anions are below the permissible SANS values for drinking water purposes. Metal concentrations are largely below the detection limits, however the aluminium content of leachate from both samples exceeds the SANS permissible concentration of 0.3 mg/l.

The results of the leaching tests therefore conclude that both the ore and waste rock from the project area are mostly inert and any leachate generated by planned ROM stockpiles and/or waste rock dumps should be of an acceptable quality. The only metal found to be present in the leachate at significant concentrations was aluminium.

Table 13: Results of leaching tests – physical parameters and macro element anions

Analyses	**Jenkins Ore Composite**		**Jenkins Waste Rock Composite**	
TCLP / Acid Rain / Distilled Water / H_2O_2	**Distilled Water**		**Distilled Water**	
Dry Mass Used (g)	**250**		**250**	
Volume Used (mℓ)	**1000**		**1000**	
pH Value at 25˚C	6.6		7.0	
Electrical Conductivity in mS/m at 25°C	3.7		5.7	
Inorganic Anions	**mg/ℓ**	**mg/kg**	**mg/ℓ**	**mg/kg**
Total Alkalinity as $CaCO_3$	<5	<20	20	80
Chloride as Cl	6	24	5	20
Sulphate as SO_4	<5	<20	6	24
Nitrate as N	<0.2	<0.8	<0.2	<0.8
Fluoride as F	<0.2	<0.8	0.2	0.8
ICP-OES Scan	See **Table 14**		See **Table 14**	

Table 14: Results of leaching tests – metals (mg/l)

Sample Id	**Ag**	**Al**	**As**	**Au**	**B**	**Ba**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Det Limit	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Jenkins Ore Composite	<0.010	0.661	<0.010	<0.010	0.385	0.418
Jenkins Waste Rock Composite	<0.010	0.883	<0.010	<0.010	0.441	0.710
Sample Id	**Be**	**Bi**	**Ca**	**Cd**	**Ce**	**Co**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Det Limit	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Jenkins Waste Rock Composites	<0.010	<0.010	2.10	<0.010	<0.010	<0.010
Jenkins Ore Composites	<0.010	<0.010	3.88	<0.010	<0.010	<0.010
Sample Id	**Cr**	**Cs**	**Cu**	**Dy**	**Er**	**Eu**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Det Limit	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Jenkins Waste Rock Composites	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Jenkins Ore Composites	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Sample Id	**Fe**	**Ga**	**Gd**	**Ge**	**Hf**	**Ho**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Det Limit	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Jenkins Waste Rock Composites	1.06	0.163	<0.010	<0.010	<0.010	<0.010
Jenkins Ore Composites	0.410	0.276	<0.010	<0.010	<0.010	<0.010

Sample Id	**In**	**Ir**	**K**	**La**	**Li**	**Lu**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Det Limit	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**
Jenkins Waste Rock Composites	<0.010	<0.010	1.3	<0.010	0.056	<0.010
Jenkins Ore Composites	<0.010	<0.010	2.0	<0.010	0.026	<0.010
Sample Id	**Mg**	**Mn**	**Mo**	**Na**	**Nb**	**Nd**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Det Limit	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**
Jenkins Waste Rock Composites	0.796	0.363	<0.010	6.30	<0.010	<0.010
Jenkins Ore Composites	1.25	0.785	<0.010	6.32	<0.010	<0.010
Sample Id	**Ni**	**Os**	**P**	**Pb**	**Pd**	**Pt**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Det Limit	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**
Jenkins Waste Rock Composites	0.026	<0.010	<0.010	<0.010	<0.010	<0.010
Jenkins Ore Composites	0.017	<0.010	<0.010	<0.010	<0.010	<0.010
Sample Id	**Rb**	**Rh**	**Ru**	**Sb**	**Sc**	**Se**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Det Limit	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**
Jenkins Waste Rock Composites	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Jenkins Ore Composites	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Sample Id	**Si**	**Sm**	**Sn**	**Sr**	**Ta**	**Tb**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Det Limit	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**
Jenkins Waste Rock Composites	0.9	<0.010	<0.010	0.040	<0.010	<0.010
Jenkins Ore Composites	2.0	<0.010	<0.010	0.074	<0.010	<0.010
Sample Id	**Te**	**Th**	**Ti**	**Tl**	**Tm**	**U**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Det Limit	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**
Jenkins Waste Rock Composites	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010
Jenkins Ore Composites	<0.010	<0.010	0.025	<0.010	<0.010	<0.010
Sample Id	**V**	**W**	**Y**	**Yb**	**Zn**	**Zr**
	mg/l	**mg/l**	**mg/l**	**mg/l**	**mg/l**	**mg/l**
Det Limit	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**	**<0.010**
Jenkins Waste Rock Composites	<0.010	<0.010	<0.010	<0.010	0.217	<0.010
Jenkins Ore Composites	<0.010	<0.010	<0.010	<0.010	0.274	<0.010

The only water quality impacts that might occur result from the physical mining operation itself and from seepage or accidental spills of hazardous substances imported into the mining area for a variety of uses like fuel, lubricants, cleaning agents and solvents.

The types and sources of contamination that usually occur in the iron ore environment, and also expected at Jenkins, are:

- Organic/hydrocarbon contamination sources like **fuels**, **lubricants** and **organic cleaning agents**/solvents used in mining equipment and workshops.
- **Nitrate** contamination inside the pit areas where nitrate-based explosives are used in large quantities.
- Contamination by **suspended solids**, especially haematite dust and mud particles created by the physical impact of the mining operation.

Hydrocarbon/Organic contamination

Because macro-scale loading and moving equipment will be used in the proposed mining operation, vast quantities of diesel fuel and other hydrocarbons will be used per year. Fuel depots present the risk of leakage and spillage incidents and the highest standards in design, monitoring and management at these sites should be used from construction to decommissioning. The same applies to storage, handling and disposal of all other hazardous substances like organic cleaning agents and solvents that will be used widely at workshops and service stations.

Nitrate contamination

Haematite ore is extremely hard and therefore high impact explosives are required for breaking and blasting of the in situ material. The explosives are usually nitrate based. Nitrate levels therefore tend to increase close to the blasting areas in the pit. It was found at comparative mining operations that the nitrate concentrations return to acceptable levels within one or two years after regular blasting has ended in the specific area.

Nitrate concentrations could be expected to become elevated in all areas where ROM material is stockpiled and waste material is discarded.

Suspended solids

Rainfall and run-off in the pit, waste rock dump/s and ROM stockpiles have high suspended solids content directly after rainfall events. Movement of heavy mining equipment through the water further creates mud and aggravates this contamination. The suspended material usually has a high iron content because of the hematite particles it consists of. Contamination by iron or any other heavy metals is, however, not a significant risk because of the generally neutral groundwater pH conditions that dominate the dolomitic aquifer environment. Iron and other metals do not stay in solution but form insoluble metal oxides and hydroxides and precipitate. Conventional settling of the suspended solids improves the water quality significantly.

Please note that groundwater quality within the rehabilitated pit will gradually improve due to recharge (dilution) with fresh rainwater. Minor groundwater quality impacts are therefore expected, but the surrounding groundwater users should not be affected.

3.3 NUMERICAL GROUNDWATER MODEL

3.3.1 FLOW MODEL

Numerical flow and mass transport groundwater models were constructed to simulate current aquifer conditions and impacts and to provide a tool for the evaluation of different management options for the future. A risk analysis could also be performed where effects of different flow and concentration parameters as well as the impacts of nearby existing operations and management options could be evaluated.

The modeling package Processing Modlfow 8 was used for the simulations. A multiple layered numerical groundwater flow model was constructed to include the entire Jenkins mining right area. The model was extended towards the north to also include the Sishen Iron Ore Mine and covers an area of ± 660 km^2 (33 by 20 km). Mine dewatering at Sishen Mine causes significant dewatering that extends in a north-south elongated compartment right down to the Jenkins area. These dewatering effects dominate the groundwater flow in the entire region (Sishen Mine, Khumani Mine and the Jenkins area) and had to be incorporated in the Jenkins model simulation. Aquifer parameters assigned to the model are provided below in **Table 15**.

Table 15: Numerical flow model grid layout and hydraulic parameters

Jenkins numerical flow model	
Grid size	Easting = 20 000 m Northing = 33 000 m
Rows and Columns	Rows = 662, Columns = 400
Cell size	50 m by 50 m
Transmissivity: Shallow aquifer	3.2 m^2/day
Transmissivity: Deeper aquifer	0.9 m^2/day
Storage coefficient: Deeper aquifer	0.008 to 0.01
Effective porosity: Shallow aquifer	10%
Effective porosity: Deeper aquifer	6%
Recharge	1 to 4% of MAP

All information regarding the geological makeup (especially geological structures) of the project area was considered in the construction of the numerical flow model. Geological structures such as dykes and faults, because the aquifer is of a secondary fractured nature, usually have higher transmissivities in comparison to the host rock and serve as preferred flow paths or conduits for groundwater movement.

After the model was run and the steady state solution was used to calibrate simulated water levels with the available measured water level information, a groundwater mass transport model was constructed. Calibration of the flow model was aided largely by existing flow and water level information gathered from nearly 200 boreholes located in the modelled area.

The model calibration results are indicated in **Figure 31** and a correlation of ± 97% was achieved with the calibration of the flow model. The Jenkins model simulation was subdivided into a total of six different stress periods:

Stress period	Simulation time	Comment
1 – 4	4 Years	Simulate intersection of water table from year 7 through to 10 (EOM).
5 – 6	50 Years	Simulate post-closure groundwater impacts

A stress period in the model is a period where groundwater flow and mass transport conditions are constant. All time dependent parameters in the model, like drains, rivers, aquifer recharge, contaminant sources, sinks and contaminant concentrations remain constant during the course of a stress period.

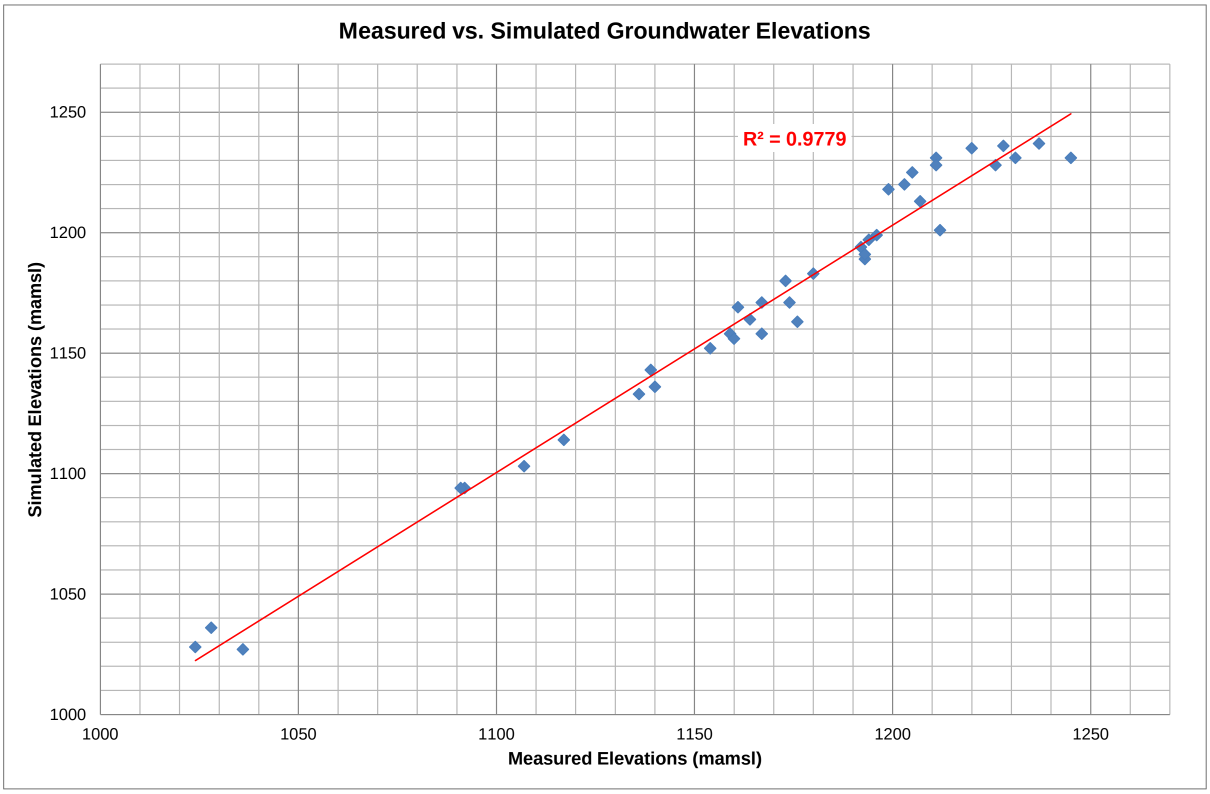


Figure 31: Numerical flow models calibration results

In order to better indicate the impact of opencast mining on the surrounding groundwater levels, groundwater elevations were exported from the flow model and used to construct the simulated cone of depression, which is provided in **Figures 33** to **36**. No groundwater level impacts were simulated for the first six years of mining, as the pit floor elevation only decreases below the local groundwater level elevation of ± 1 227 mamsl during year 7 of mining.

The extent of the groundwater level impacts is determined by the hydraulic properties of the aquifer host rock. The influence of aquifer transmissivity on the radius/extent of the cone of depression (water level impact) is explained by means of the following equation:

$$R(t) = 1.5(Tt/S)^{1/2}$$

Where R = *Radius (m),*
T = *Aquifer transmissivity* (m^2/d)*,*
t = *Time (days),*
S = *Storativity.*

From the equation it is made clear that an increase in transmissivity will lead to an increase in the radius of influence (extent of depression cone), while the opposite holds true for aquifer storativity. Should the mine workings intersect transmissive geological structures, the groundwater level impacts may be extended. Such structures may also greatly increase groundwater discharge into the active mine workings and we therefore strongly recommend a revision of the Jenkins model simulations should any significant geological structures be encountered during the early stages of mining.

Mine dewatering causes the local groundwater levels to decrease below the mining elevation. An increase in mining depth will consequently lead to an increase in groundwater level drawdown. The generally low transmissivity of the deeper fractured rock aquifer will however restrict the formation of a drawdown cone (water level impacts). The depth of the proposed pit relative to the depth of the local groundwater level was calculated and is indicated in **Figure 32**. The abovementioned figure concludes that approximately 25% of the pit floor is expected to be below the local groundwater level.

The model simulated drawdown cones are provided in **Figures 33** to **36**, while the simulated groundwater inflows are summarised below in **Table 16**.

No groundwater discharge was simulated for the first six years of mining, as the pit floor elevation only decreases below the local groundwater level during the seventh year of mining. Due to the highly heterogeneous nature of the aquifer host rock a degree of uncertainty will always remain. Geological structures such as dykes and faults may intersect the proposed pit, which should then have a significant influence on the flow of groundwater to the mine void. For this reason a sensitivity analysis was conducted during which the minimum and maximum expected inflows were simulated for the proposed Jenkins pit **(Table 16)**.

Table 16: Model simulated groundwater influx into proposed pit

Year	Lowest pit floor elevation	Minimum flow (m^3/d)	Maximum flow (m^3/d)
1	1280	N/A	N/A
2	1280	N/A	N/A
3	1275	N/A	N/A
4	1270	N/A	N/A
5	1260	N/A	N/A
6	1235	N/A	N/A
7	1195	160	270
8	1195	140	240
9	1195	130	230
10	1170	250	500

Note: *The highest groundwater elevation in the proposed pit area is at approximately 1227 mamsl, meaning that the water table is only expected to be intersected during/after year 7 of mining.*

Groundwater level impacts as simulated with the numerical flow model are summarised in **Table 17**.

Table 17: Model simulated groundwater level impacts

Year	Simulated groundwater level drawdown (m)	Simulated area affected (km^2)
7	20	0.4
8	20	0.7
9	20	1.0
10	50	1.3

A groundwater level drawdown of approximately 20 meters was simulated for the seventh year of active mining and is indicated in **Figure 33**. Maximum groundwater level impacts are expected to occur during the tenth and final year of mining and a groundwater level drawdown of ± 50 meters was simulated **(Figure 36)**. The cone of depression was simulated not to exceed the pit boundary by more than approximately 420 meters. **Except for user borehole CJBH01, which will in any case be demolished by the planned opencast workings, no other user boreholes are expected to be affected by the aquifer dewatering.**

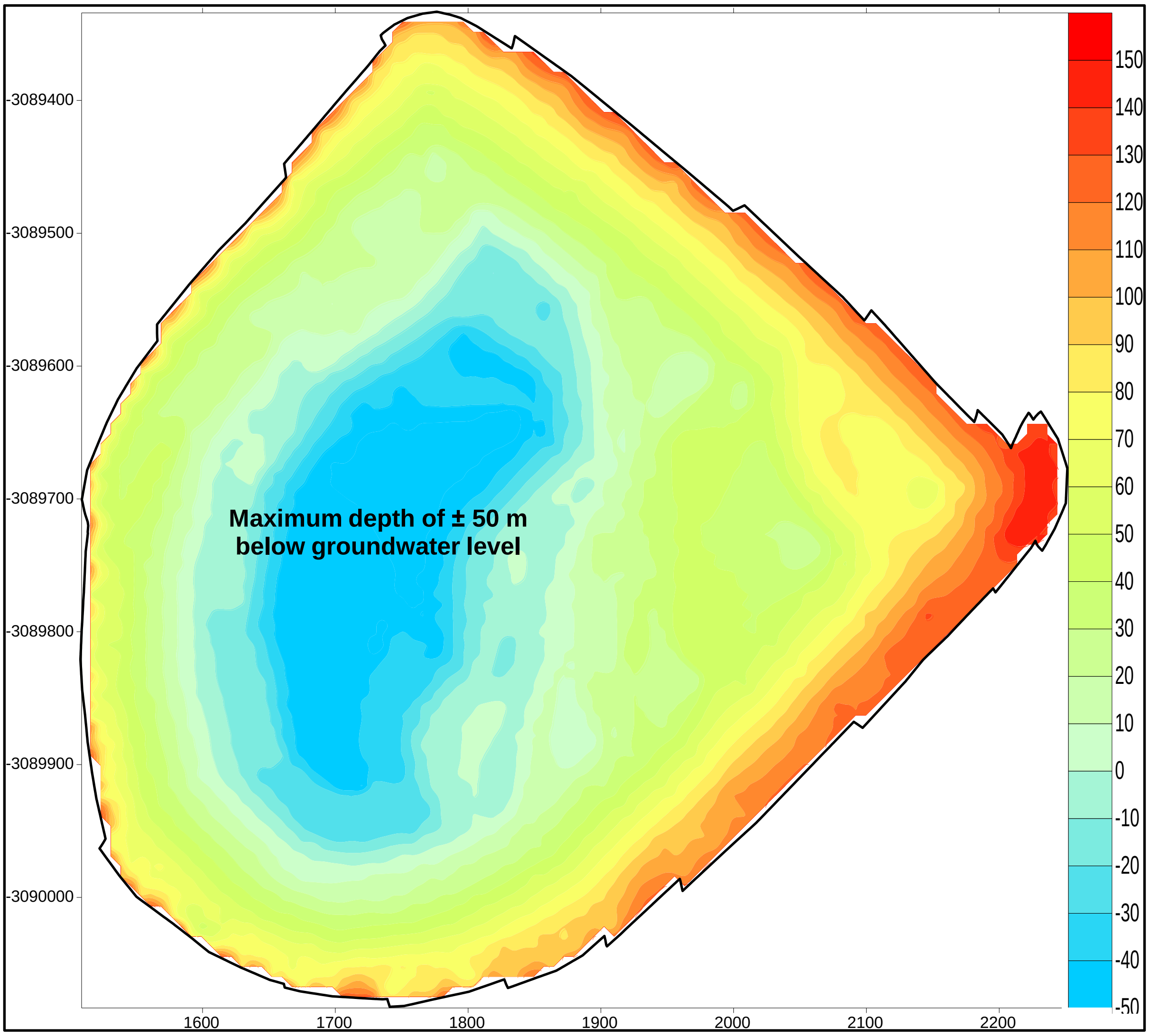


Figure 32: Depth of proposed pit floor relative to groundwater level (m)

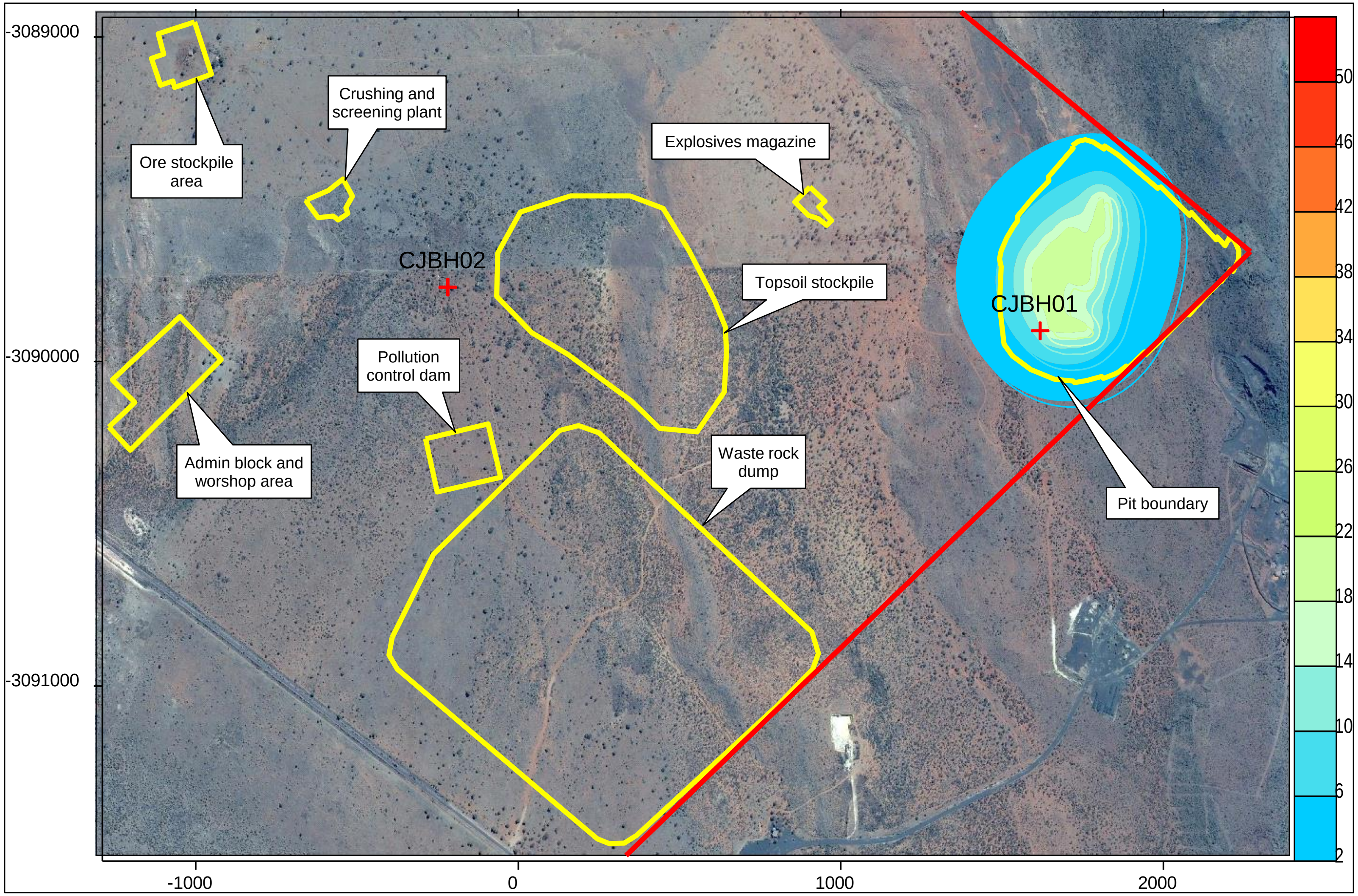


Figure 33: Simulated cone of depression at the end of year 7

Notes: *- Maximum simulated groundwater level drawdown of approximately 20 meters at the end of year 7 of mining.*
- Radius of influence/cone of depression not expected to extend more than ± 200 meters away from pit area.

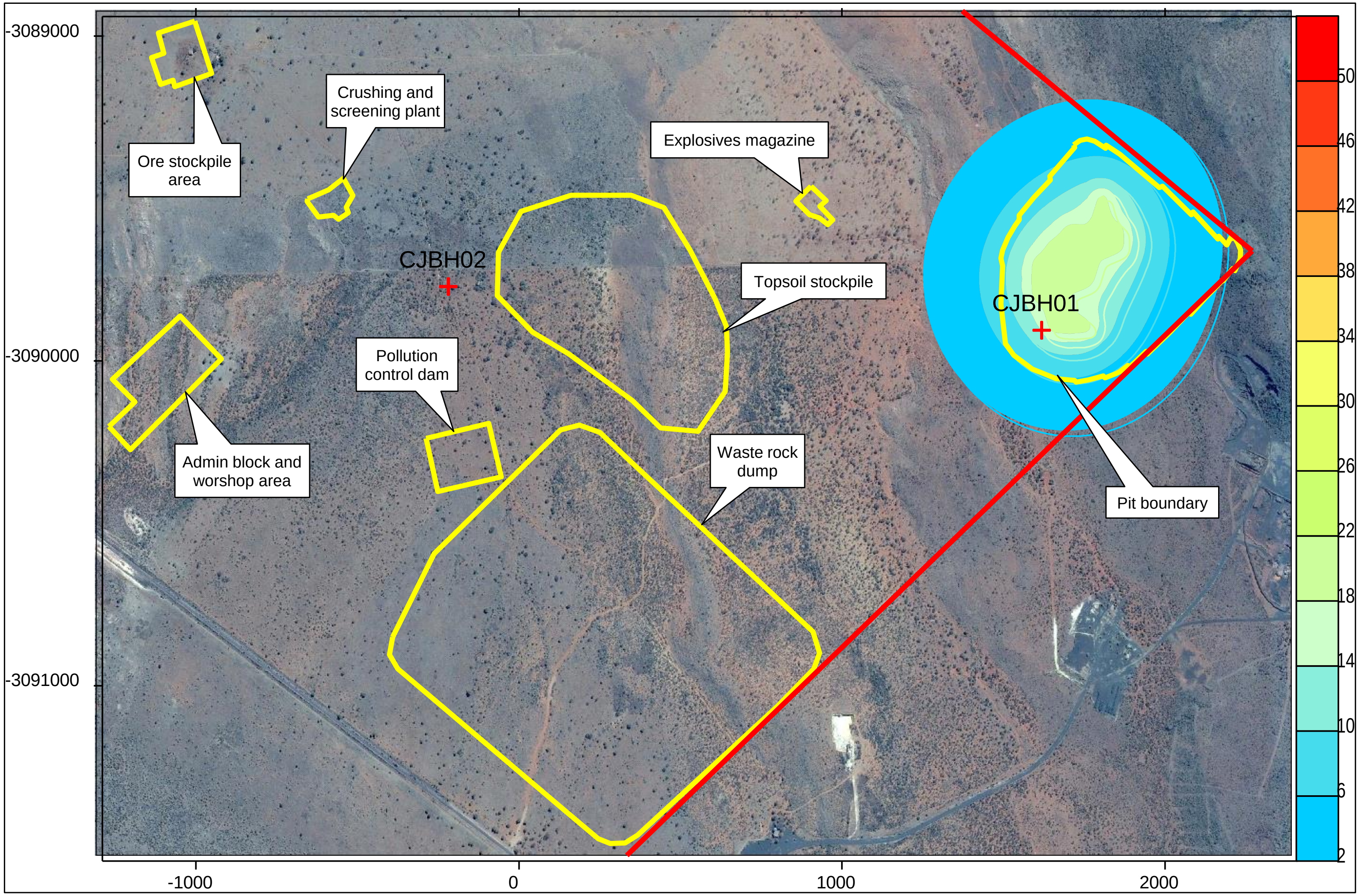


Figure 34: Simulated cone of depression at the end of year 8

Notes: *- Maximum simulated groundwater level drawdown of approximately 20 meters at the end of year 8 of mining.*
- Radius of influence/cone of depression not expected to extend more than ± 240 meters away from pit area.

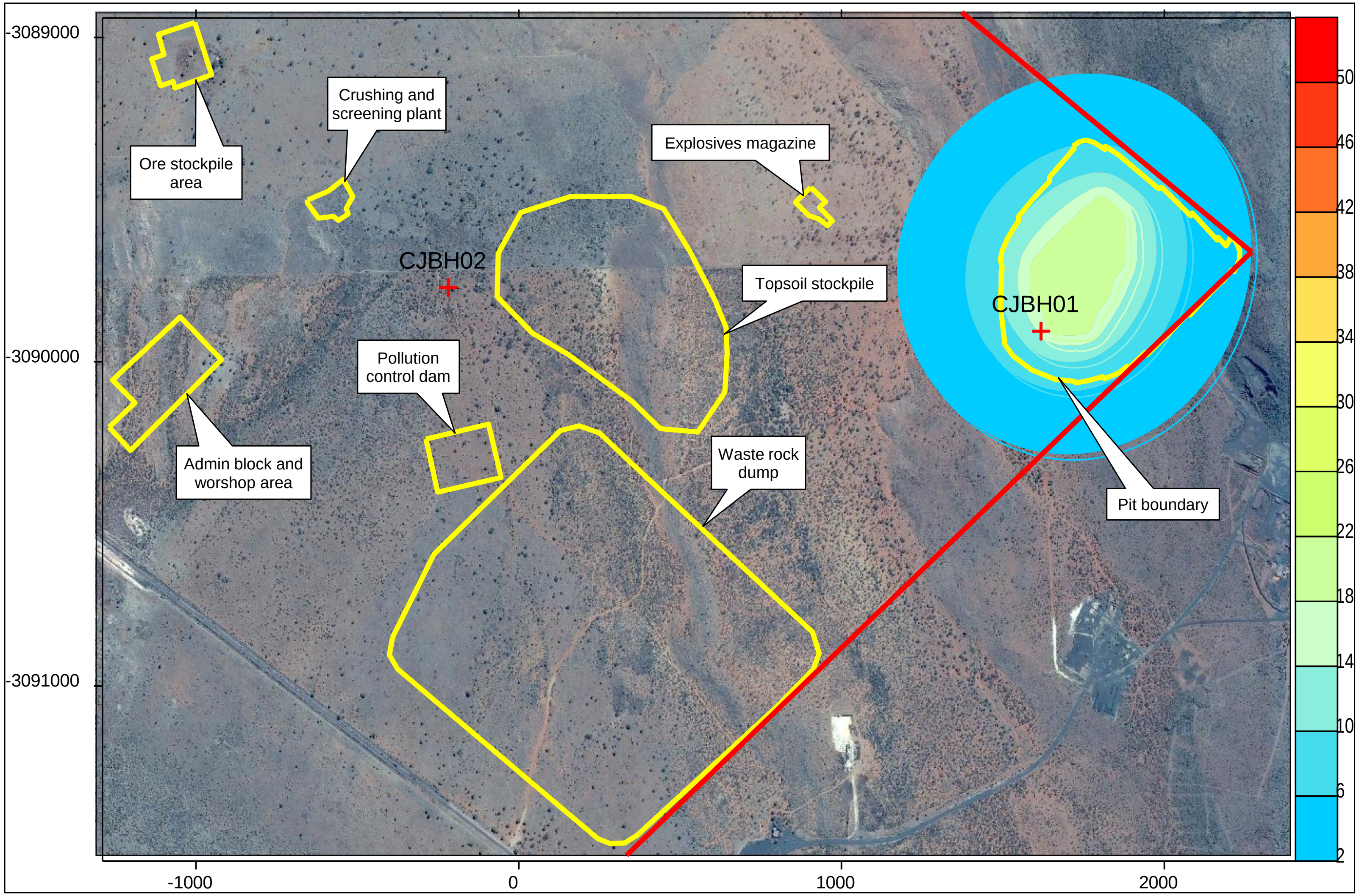


Figure 35: Simulated cone of depression at the end of year 9

Notes: *- Maximum simulated groundwater level drawdown of approximately 20 meters at the end of year 9 of mining.*
- Radius of influence/cone of depression not expected to extend more than ± 340 meters away from pit area.

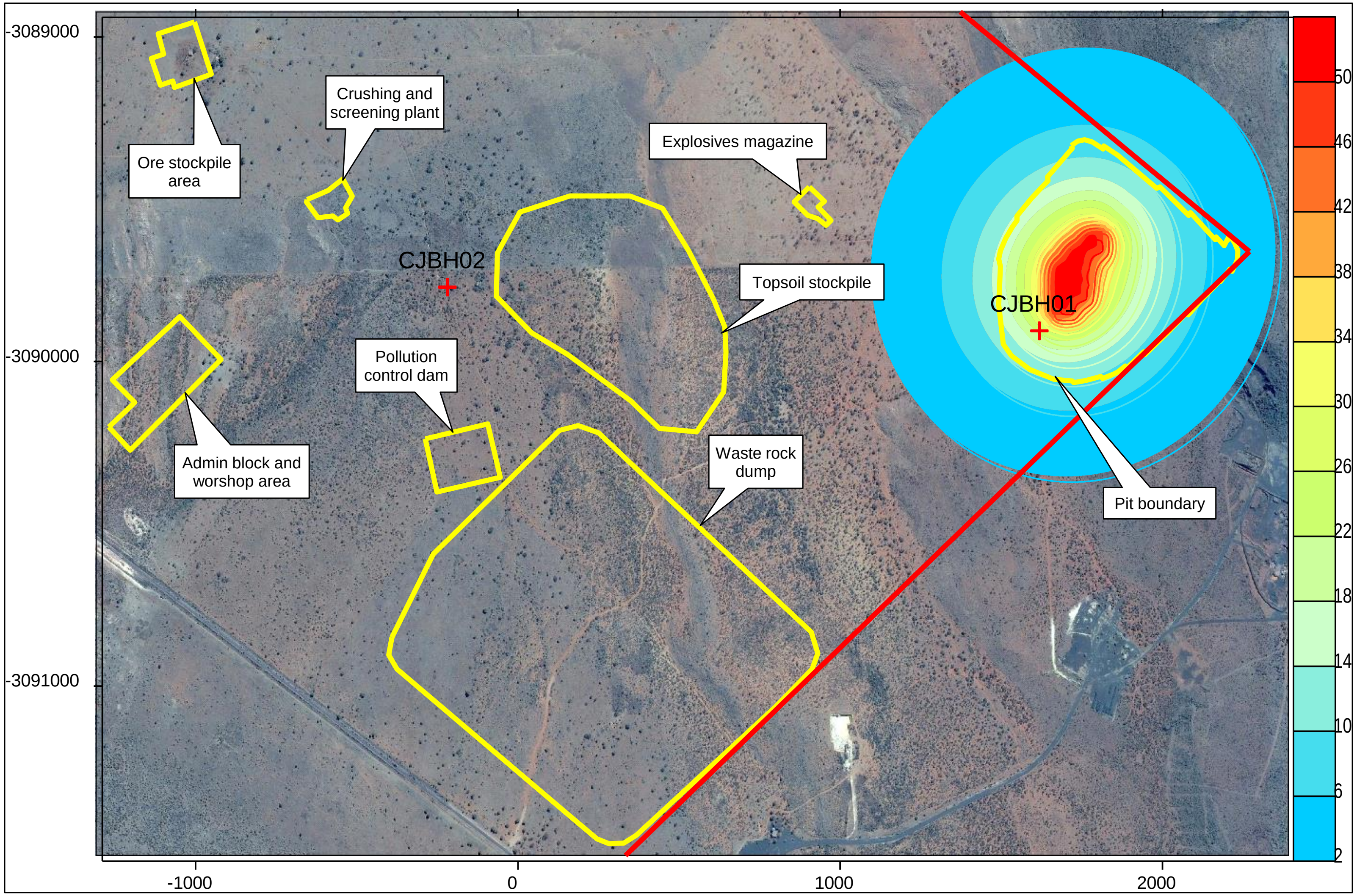


Figure 36: Simulated cone of depression at the end of year 10

Notes: *- Maximum simulated groundwater level drawdown of approximately 50 meters at the end of year 10 of mining.*
- Radius of influence/cone of depression not expected to extend more than ± 420 meters away from pit area.

It should however be kept in mind that a secondary fractured rock aquifer (such as the one underlying the Jenkins Project area) is a highly complex system and is by no means homogeneous. Coupled with numerous model restrictions, over or under estimations of the predicted groundwater impacts should be expected. The model results should therefore only be regarded as being qualitative rather than quantitative for use in planning of management and mitigation measures. The model results/predictions also need to be verified and updated regularly by means of a comprehensive groundwater monitoring program as outlined in Section 4 of this report.

3.3.2 MASS TRANSPORT MODEL – SIMULATED POLLUTION PLUMES AND MOVEMENT

In the case of a perched water table or an unconfined/semi-confined aquifer, the hydraulic gradient is equal to the slope of the water table, measured at different points in the aquifer. The hydraulic gradients in the Jenkins Project area were calculated from the difference in elevation of groundwater levels in each area. The averaged hydraulic conductivities of the saturated zone, as calculated from the low rate pumping tests, were used as approximations of the saturated hydraulic conductivity of the Jenkins Project area.

The average groundwater flow velocities in the project area were calculated using the following equation *(after Fetter, 1994)*:

$$v = \frac{KI}{\phi}$$

Where: *v = flow velocity (m/day)*

K = hydraulic conductivity (m/day) = 0.083

I = average hydraulic gradient = 0.016 northwards

ϕ = probable average porosity = 0.08

The hydraulic conductivity and average porosity were chosen so as to provide a liberal estimation of seepage velocity. The actual seepage through the aquifer matrix should be lower than the products calculated, but highly transmissive fracture zones or areas of steeper gradient might cause higher transport rates.

The hydraulic conductivity and the average hydraulic gradient are known parameters. By making use of these values, the average steady state flow velocity in the Jenkins Project area was calculated to be in the order of ± 0.017 m/d, or 6.2 m/y towards the north (please refer to **Figure 14** for groundwater elevations and flow directions).

These estimates do not however take into account all known or suspected zones in the aquifer like preferential flow paths formed by igneous contact zones like the intrusive dykes that have higher than average flow velocities. In fractured aquifer media, the transport velocity is usually significantly higher than the average velocities calculated with this formula and may increase several meters or even tens of meters per year under steady state conditions.

Under stressed conditions, such as at groundwater abstraction areas, the seepage velocities could increase another order of magnitude.

During active opencast mining and until a new groundwater equilibrium has been reached, the mine void acts as a groundwater sink and groundwater will move radially inwards towards the void. This means that during this period poor quality leachate generated by the mining activities is likely to move towards the mine void and should not drain towards the immediate surroundings. Numerous potential sources of groundwater contamination were simulated in the mass transport model and are discussed shortly in **Table 18**.

Table 18: Potential source areas and expected impacts

Source area	Potential impact
- Jenkins Pit	- Post closure decant of poor quality water. - Down gradient movement of pollution plume in shallow weathered zone aquifer.
- Waste Rock Dump	- Surface water run-off originating from dumps and stockpiles, toe-seeps and seepage through the base of the facilities may potentially be of poor quality and could cause adverse groundwater quality impacts should it enter the aquifer regime. Nitrate is more often than not the dominant pollutant.
- Primary processing plant	- Impact on the groundwater only occurs through leachate formation from surface. Impacts thus only occur as a result of rainfall recharge or when water is introduced in some form where leachate can form that seeps to the groundwater regime.
- Service station - Wash bay - Workshops - Fuel depot	- Spillages and leakages from hydrocarbon storage facilities may lead to the contamination of the underlying aquifer regime by harmful hydrocarbons.
- Pollution control dams - Storm water dam	- Spillages and leakages of poor quality water from pollution control dams and any water retaining facilities/dams may lead to adverse groundwater quality impacts and the down gradient movement of a pollution plume.

It should be noted that all potential source areas listed in **Table 18**, excluding the pit and waste rock dump, will be underlain by some form of a confining layer, be it a concrete floor or a clay or synthetic liner. They are therefore regarded as being “low risk” source areas. Even so, these source areas were included in the mass transport model – simulating plume movement should a defective liner cause contamination to escape the source area.

In order to better indicate the impact of the potential sources **(Table 18)** on the surrounding groundwater quality conditions, contamination contours were exported from the mass transport model and used to construct the simulated contamination plumes, which are provided in **Figures 37** to **39**. The contamination was simulated by applying contaminated recharge to the entire surface areas of the potential sources as listed in **Table 18**.

Source concentrations cannot be estimated or predicted with a high degree of confidence. Source areas were therefore assigned a theoretical concentration of 100% and the figures provided should be regarded as qualitative rather than quantitative.

No significant groundwater quality impacts were simulated at the time of mine closure **(Figure 37)**, which is mainly the result of:

- Low groundwater recharge percentage,
- Dilution with fresh groundwater and contaminant dispersion, and
- Short simulation time (10 years of active mining).

Groundwater contamination was simulated with the mass transport model to migrate in a north/north-westerly direction away from the potential source areas. Contaminant migration was simulated to not exceed a maximum distance of approximately 300 meters in the down gradient groundwater flow direction at a time of 50 years post closure, which translates to a seepage velocity of approximately 6 meters per year **(Figure 39)**.

Except for user borehole CJBH01, which will in any case be demolished by the planned opencast workings, no other user boreholes are expected to be affected by contamination that may originate from the mining and related activities.

The long-term impacts on groundwater quality have been estimated through numerical modeling, but should be confirmed through groundwater monitoring during the operational and decommissioning phases and updating and refinement of the models.

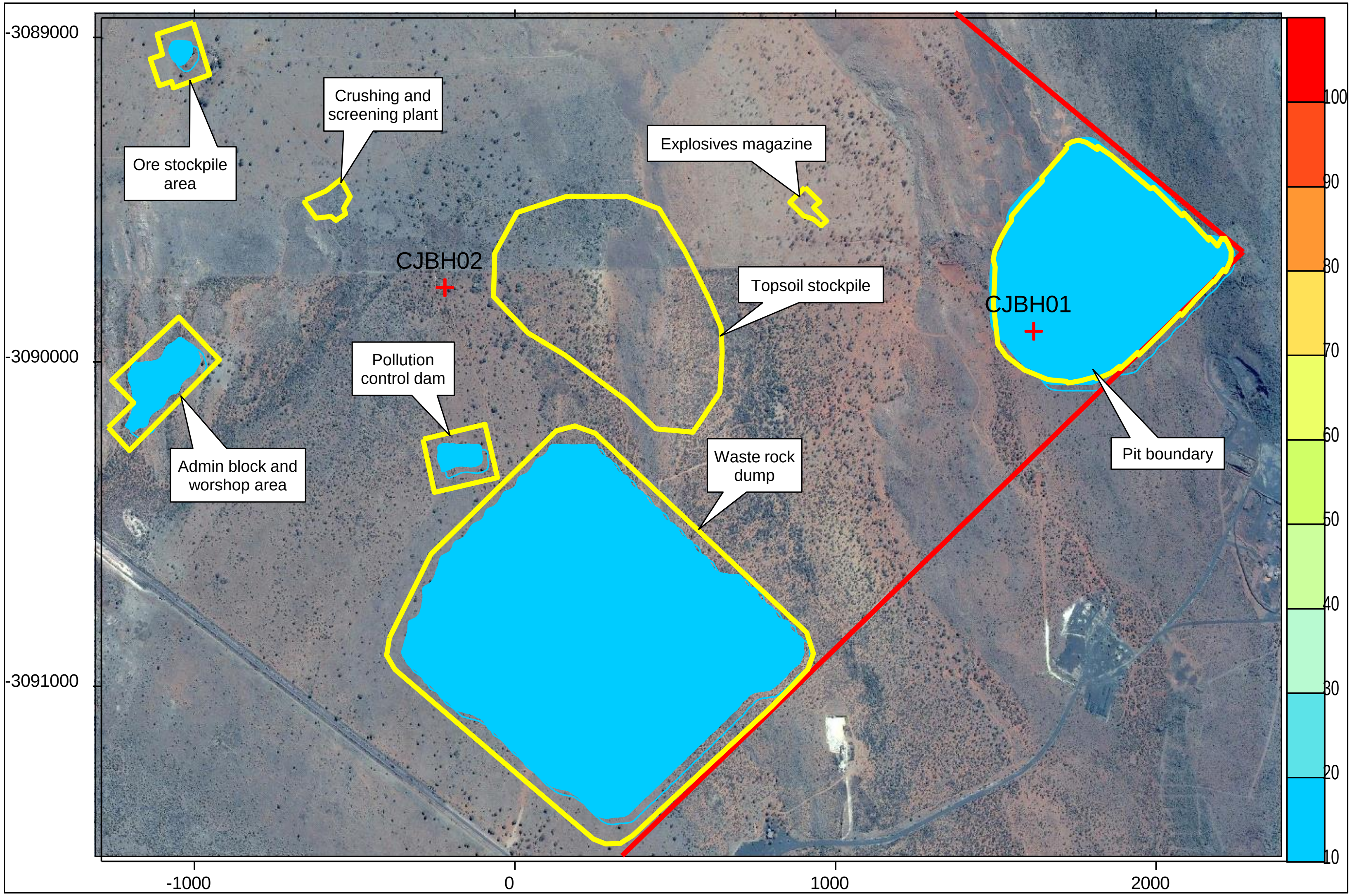


Figure 37: Model simulated pollution plumes at mine closure (%)

Notes: *- Contamination restricted to source areas at time of mine closure.*

Figure 38: Model simulated pollution plumes at 25 years post closure (%)

Notes: *- Plume has migrated a maximum distance of ± 180 m in the down gradient groundwater flow direction at 25 years post closure.*

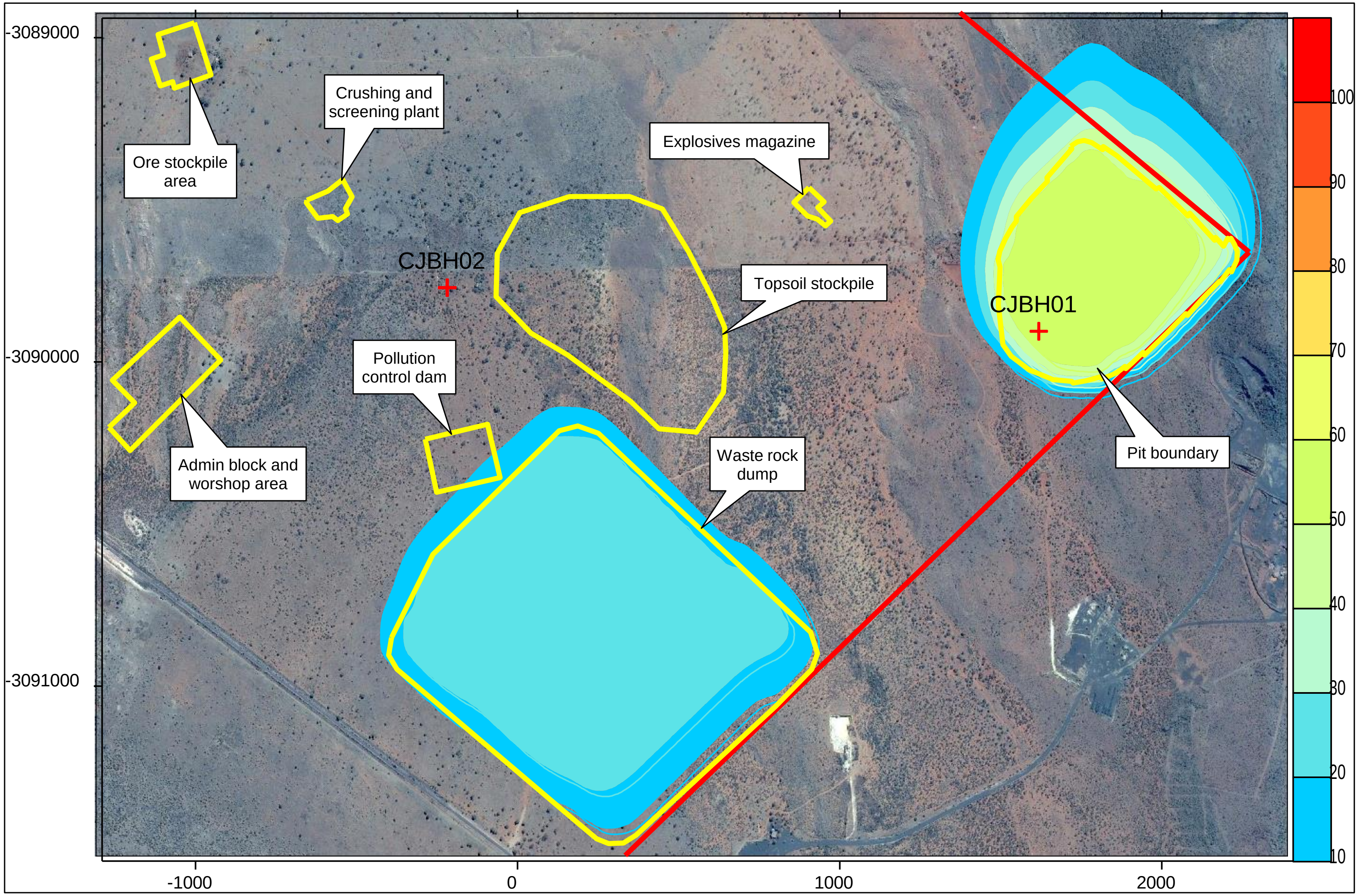


Figure 39: Model simulated pollution plumes at 50 years post closure (%)

Notes: *- Plume has migrated a maximum distance of ± 300 m in the down gradient groundwater flow direction at 50 years post closure.*

4 GROUNDWATER MONITORING PROTOCOL

4.1 MONITORING PLAN/PROTOCOL – WHERE, WHAT, HOW

Water samples will be taken around the Jenkins Project area as well as in the dams constructed for the purposes of dirty water management and water supply on a quarterly basis. A total of seven monitoring boreholes were drilled on targets identified during a geophysical investigation of the project area and their positions are indicated below in **Figure 40**. Relevant information regarding the drilled monitoring boreholes is also provided in **Table 19**, while borehole logs are provided in **Appendix C**.

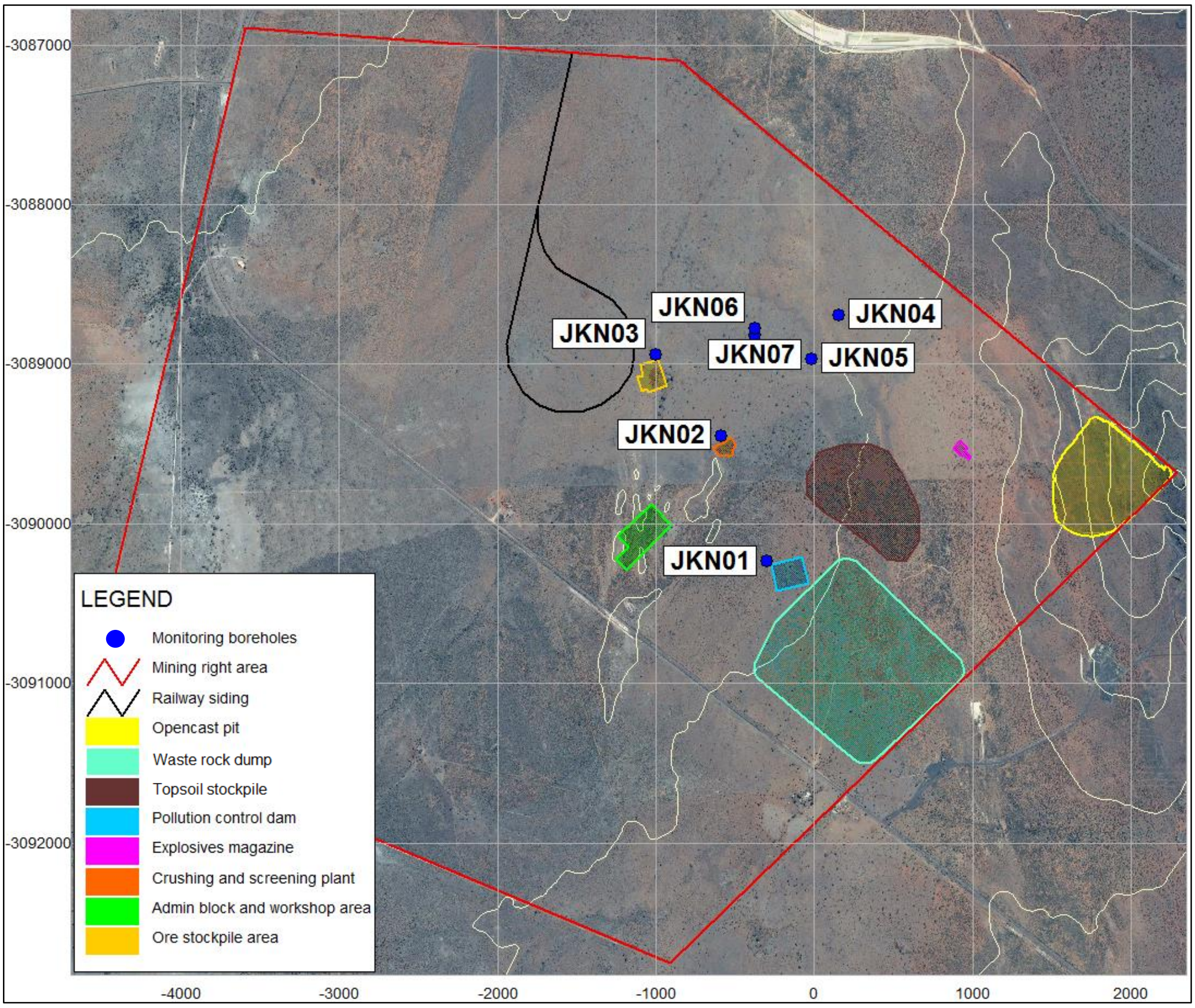


Figure 40: Positions of monitoring boreholes

Water levels of these boreholes will also be determined on a quarterly basis when the sampling is done. Samples will be analyzed for chemical and physical constituents normally associated with iron ore mining. These constituents are listed in **Table 20**.

Table 19: Summary of monitoring boreholes

BH	Coordinates		Elevation (mamsl)	Depth (m)	Water strike (m)	Blow yield (l/h)	Water level (m)
	South	East					
JKN01	-27.92594	22.99694	1246	50	N/A	N/A	49.1
JKN02	-27.91886	22.99403	1241	50	44	4000	17.7
JKN03	-27.91430	22.98981	1236	30	22	4000	16.6
JKN04	-27.91204	23.00160	1244	75	N/A	N/A	Dry
JKN05	-27.91454	22.99980	1243	50	37	1500	21.6
JKN06	-27.91280	22.99617	1239	50	38	1000	18.9
JKN07	-27.91316	22.99618	1239	50	44	6000	18.34

***Note:** Coordinates – WGS84.*

It should be noted that this monitoring schedule will be re-assessed by a qualified geohydrologist at a later stage in terms of stability of water levels and quality. Should the sampling program be changed, it should be done in consultation with the Department of Water and Sanitation (DWS).

Table 20: Groundwater constituents for routine analysis

Monitoring	Variable
Quarterly*	EC, pH, TDS, total hardness, total alkalinity, calcium, magnesium, sodium, potassium, chloride, sulphate, fluoride, nitrate, iron, manganese, aluminium and turbidity.

***Note**:*

** Once trends are established, some of these constituents may be sampled less frequent, while others found to be problematic may be added as determined on consultation with the relevant role players, such as the DWS: Regional Office.*

The following maintenance activities will be adhered to:

- Monitoring boreholes will be capped and locked at all times,
- Borehole depths will be measured quarterly and the boreholes will be blown out with compressed air, if required and
- Vegetation around the boreholes will be removed on a regular basis and the borehole casings painted, when necessary, to prevent excessive rust and degradation.

Reporting on groundwater quality conditions will be included in the annual report.

The quarterly report should be an update of the database with time-series graphs and statistical analysis (average, maximum, minimum, 5 -, 50 – and 95 percentile values as well as linear performance). Data will also be presented in a map format to present a clear picture of the water quality situation.

Laboratory results will be analyzed against the target water quality guidelines for domestic use, the aquatic environment, livestock watering and irrigation (according to the South African National Standards for drinking water; *SANS 241:2015*). The strictest value between the target water quality objectives or objectives through a reserve determination will be used.

In terms of flow, all water uses and discharges will be measured on an ongoing basis. The flows include:

Make-up water:

- Volumes of groundwater seepage into the opencast workings,
- Volumes of contaminated water used for dust suppression,
- An annual detailed evaluation report on the surface and groundwater quality will be prepared that will analyze the water quality situation in detail to investigate trends and non-compliance.

Data Management:

- Monitoring results will be entered into an electronic database as soon as results are available, and at no less than one quarterly interval, allowing:
- Data presentation in tabular format,
- Time-series graphs with comparison abilities,
- Statistical analysis (minimum, maximum, average, percentile values) in tabular format,
- Graphical presentation of statistics,
- Linear trend determination,
- Performance analysis in tabular format,
- Presentation of data, statistics and performance on diagrams and maps, and
- Comparison and compliance to the South African National Standards for drinking water *(SANS 241:2011)*.

As far as possible, the same monitoring points should be used from the construction phase through the operational and decommissioning phases to after mine closure to develop a long data record and enable trend analysis and recognition of progressive impacts with time.

4.2 SURFACE REHABILITATION INSOFAR IT AFFECTS GROUNDWATER

It was indicated that it is the purpose of the surface rehabilitation to re-establish surface drainage to the pre-mining conditions as far as practical.

The rehabilitation will aim to:

- Restore normal infiltration rates to areas where recharge was reduced due to surface compaction such as the access roads and other infrastructure areas,
- Restore normal infiltration rates in areas where recharge was increased (i.e. pollution control dam/s), and
- Decrease seepage from the waste rock dump.

The dams constructed for the purposes of dirty water management and water supply will also be rehabilitated and the disturbed areas sloped to be free draining and vegetated with the purpose of maximizing clean runoff.

4.3 LEGITIMATE REQUIREMENTS OF GROUNDWATER USERS

The proposed new project is in short expected to have the following impacts on the legitimate requirements of the surface or surrounding groundwater users in terms of quantity or quality:

- No user boreholes (except for CJBH01 located within the proposed pit boundary) are located within the area expected to be affected by the planned pit dewatering. It is expected that this user borehole will in any case be destroyed when mining commences.
- Pollution plumes were simulated to have migrated no further than approximately 300 m at a time of 50 years post closure, falling well short of all groundwater users identified during the hydrocensus/user survey.

All of the above predictions and estimates will however be verified during monitoring through the operational, closure and post-closure phases according to the proposed monitoring program.

Management actions will be evaluated to deal with any potential decant predicted by this investigation at the proposed opencast pit. **The mine remains committed to a zero effluent operating principle and contaminated water will be prevented from entering the receiving surface water environment through actions like reuse or treatment.**

Should it be indicated through monitoring and investigation by a suitably qualified person that any legitimate groundwater users are impacted upon in terms of quantity or quality of borehole water, alternative water sources will be made available to such users by the mine.

Coza Mining (Pty) Ltd will comply with the target objectives set for the surface- and groundwater resources in terms of a reserve determination under the National Water Act 36 of 1998 (NWA).

4.4 REPORTING AND SUBMISSION OF INFORMATION

A report with regards to the following issues will be compiled and submitted to the relevant authorities on a yearly basis:

- Water quality results,
- Water levels of identified boreholes, and
- A copy of the complaints register.

5 REFERENCES

Bredenkamp et al. 1995. Manual on Quantitative Estimation of Groundwater Recharge and Aquifer Storativity, Water Research Commission.

Clean Stream Groundwater Services, 2005. Sishen Iron Ore Project: Report on Geohydrological Investigation as Part of the EMPR.

Dennis et al. 2012. Climate Change Vulnerability Index for South African Aquifers, Water SA.

Lynch, S.D., 2004: Development of a Raster Database of Annual, Monthly and Daily Rainfall for Southern Africa. WRC Report No. 1156/1/04.

Parsons, R. (1995). A South African Aquifer System Management Classification. WRC Report KV 77/95, Water Research Commission, Pretoria.

PGS Heritage, 2013. Coza Iron Ore Project.

The South African Bureau of Standards (SABS), ISO 5667-1 to 5667-15, First Edition, 1999.

Usher, B.H., Cruywagen, L.M., De Necker, E. & Hodgson, F.D.I. 2003. Acid-Base Accounting Techniques and Evaluation (ABATE): Recommended Methods for Conducting and Interpreting Analytical Geochemical Assessments at Opencast Collieries in South Africa. Water Research Commission Report No 1055/2/03. Pretoria.

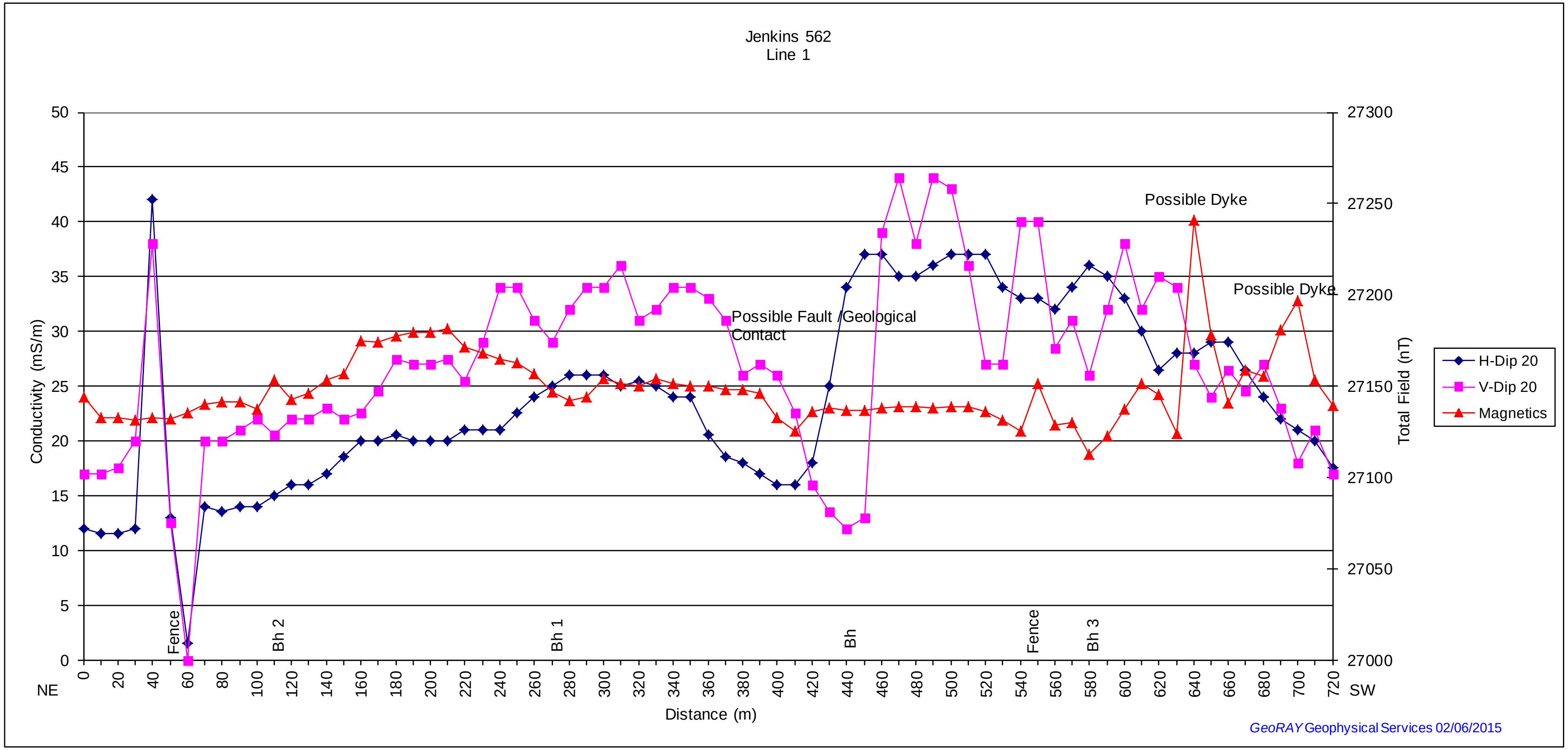
Vegter, 1995. An explanation of a set of National Groundwater Maps. Water Research Commission. Report No TT 74/95.

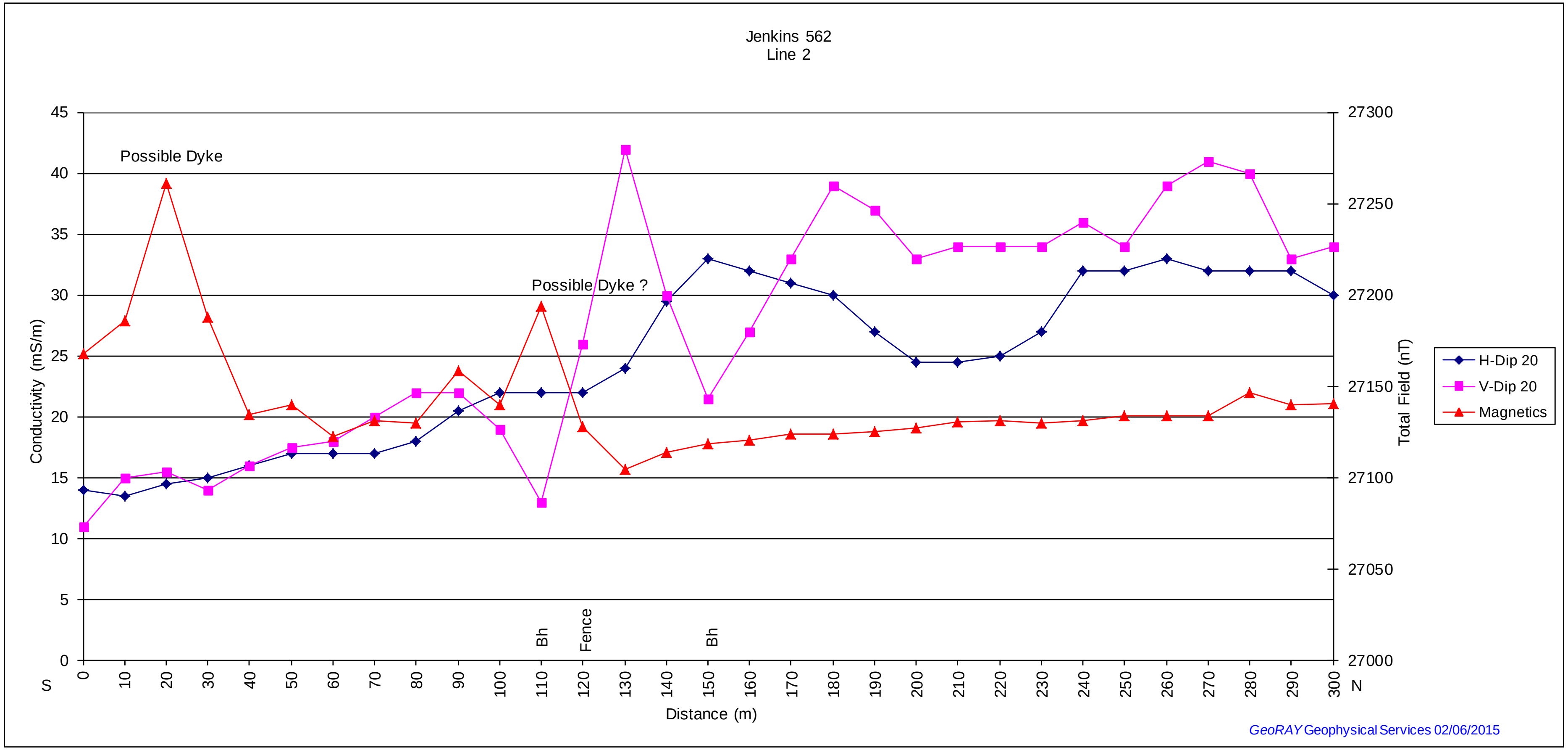
Van Tonder G, Bardenhagen I, Riemann K, van Bosch J, Dzanga P, Xu, Y,. 2001. Manual on pumping test analysis in fractured-rock aquifers, Part A3, IGS.

Van Tonder, G.J. and Kirchner, J. (1990). Estimation of Natural Groundwater Recharge in the Karoo Aquifers of South Africa. J. Hydrol., Vol. 121, pp 395-419.

6 APPENDIX A: HYDROCENSUS REPORT

7 GEOPHYSICAL LINE SURVEY GRAPHS

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Possible Dyke
Possible Dyke ?
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Distance (m)
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27050
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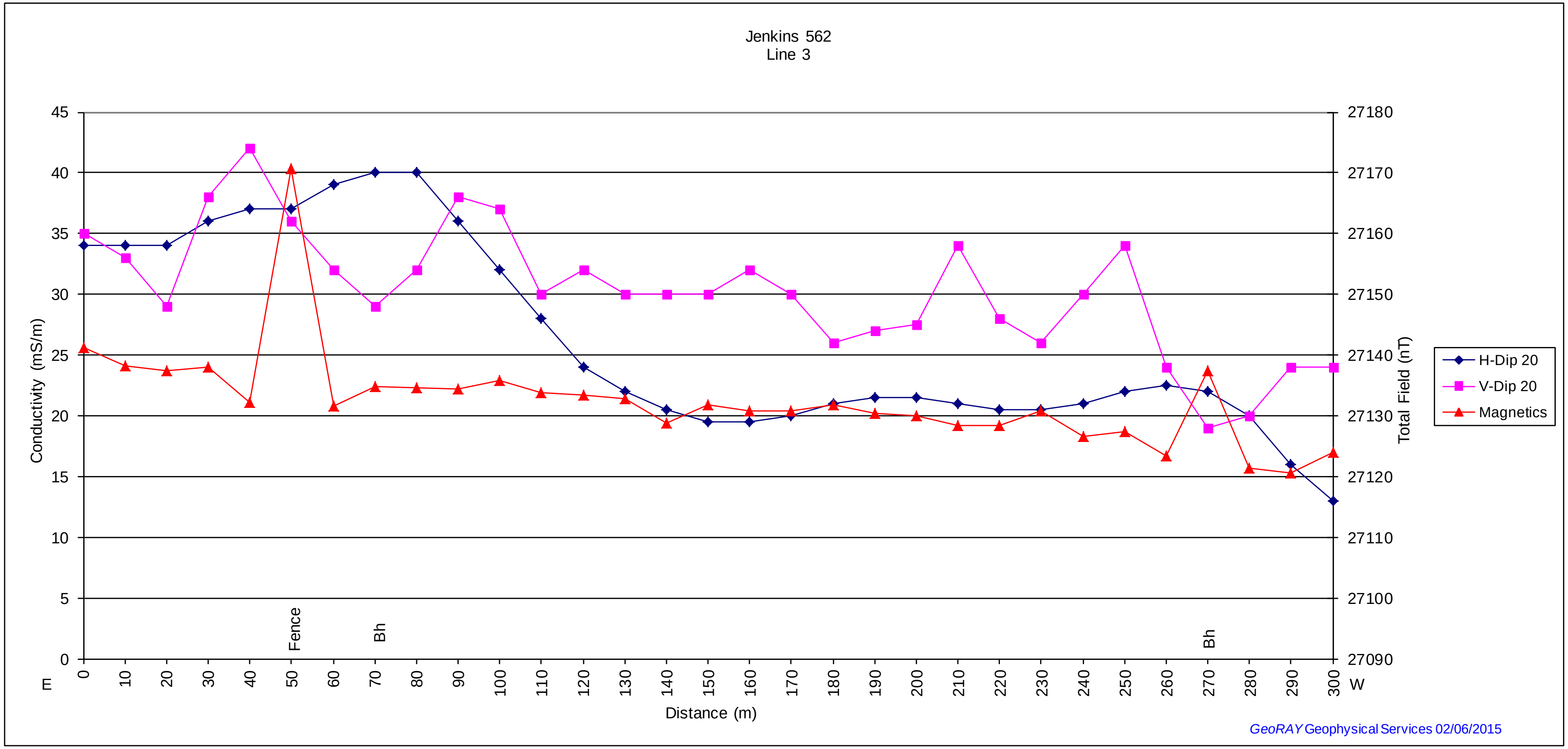
V-Dip 20
Magnetics
GeoRAY Geophysical Services 02/06/2015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27120
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27180
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H-Dip 20
V-Dip 20
Magnetics
GeoRAY Geophysical Services 02/06/2015


Jenkins 562
Line 4
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26850
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V-Dip 20
Magnetics
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Distance (m)
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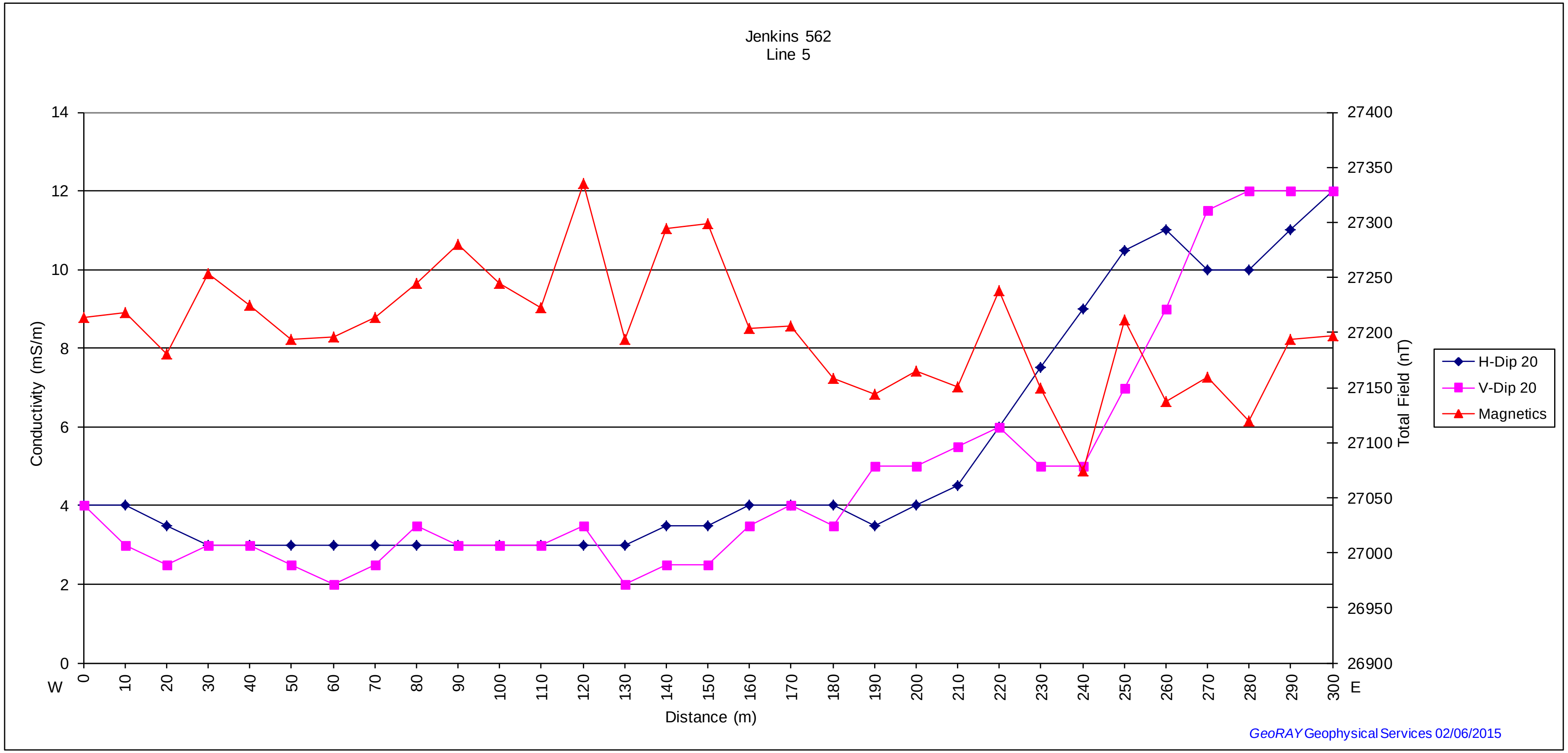
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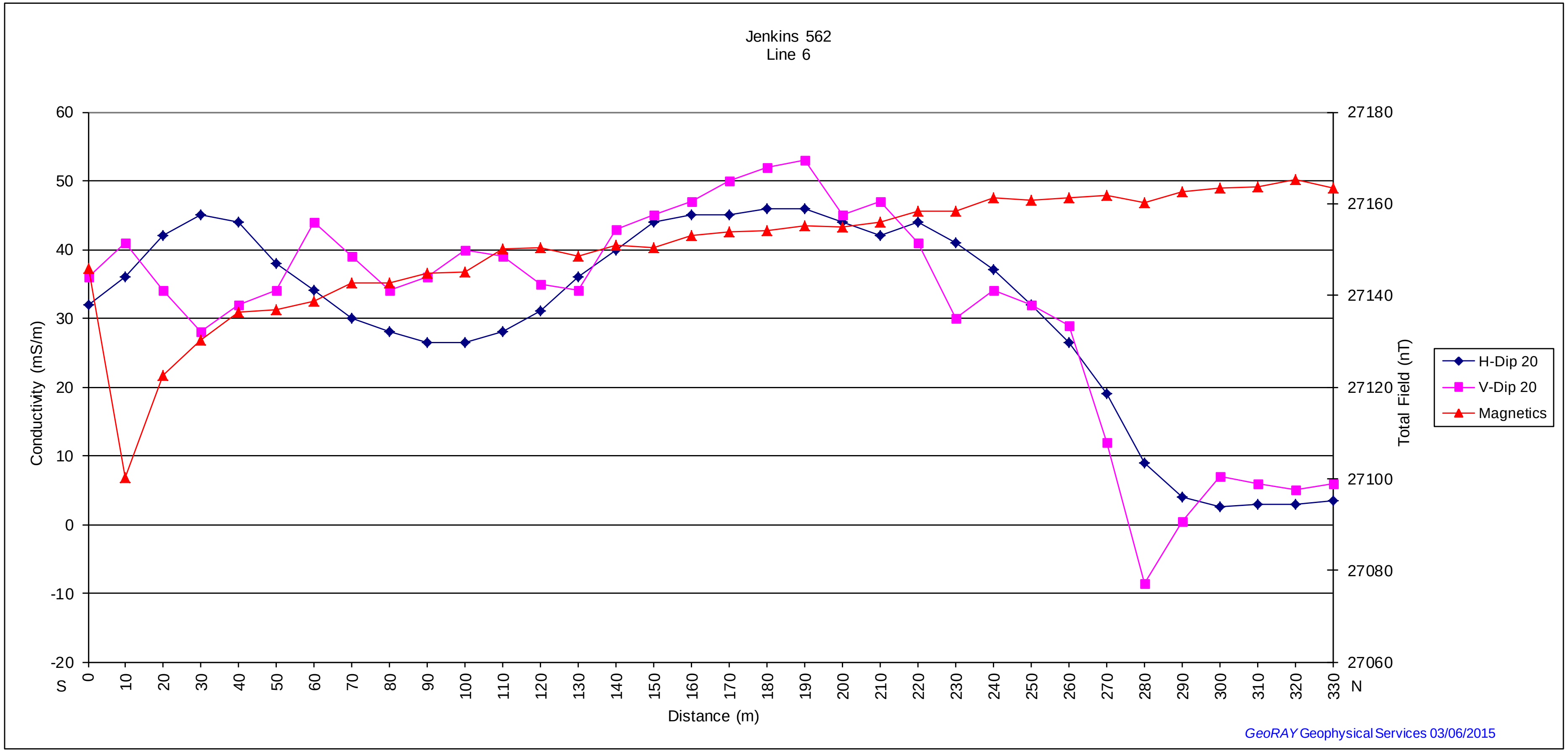
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27060
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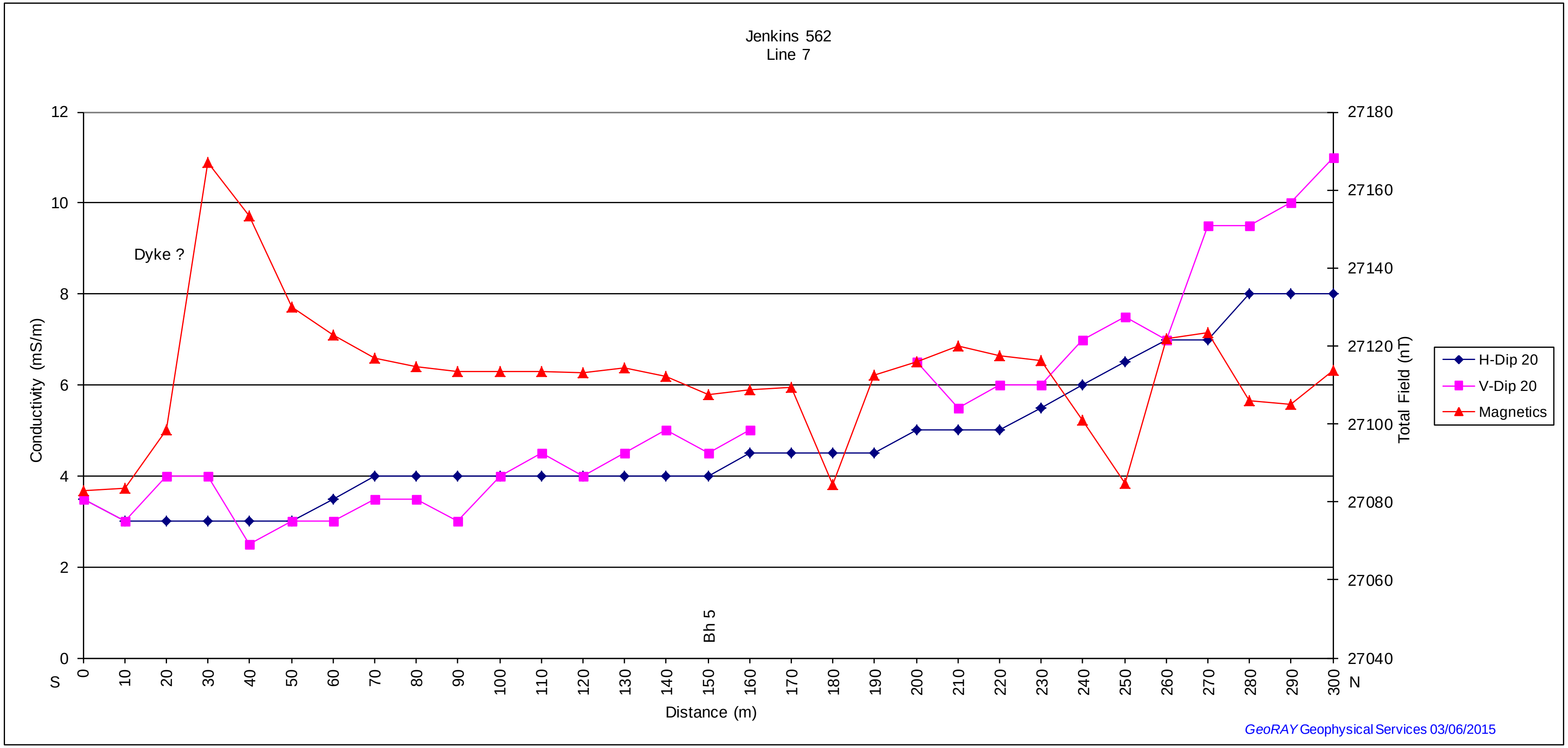
V-Dip 20
Magnetics
GeoRAY Geophysical Services 03/06/2015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Magnetics
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Jenkins 562
Line 8
Conductivity (mS/m)
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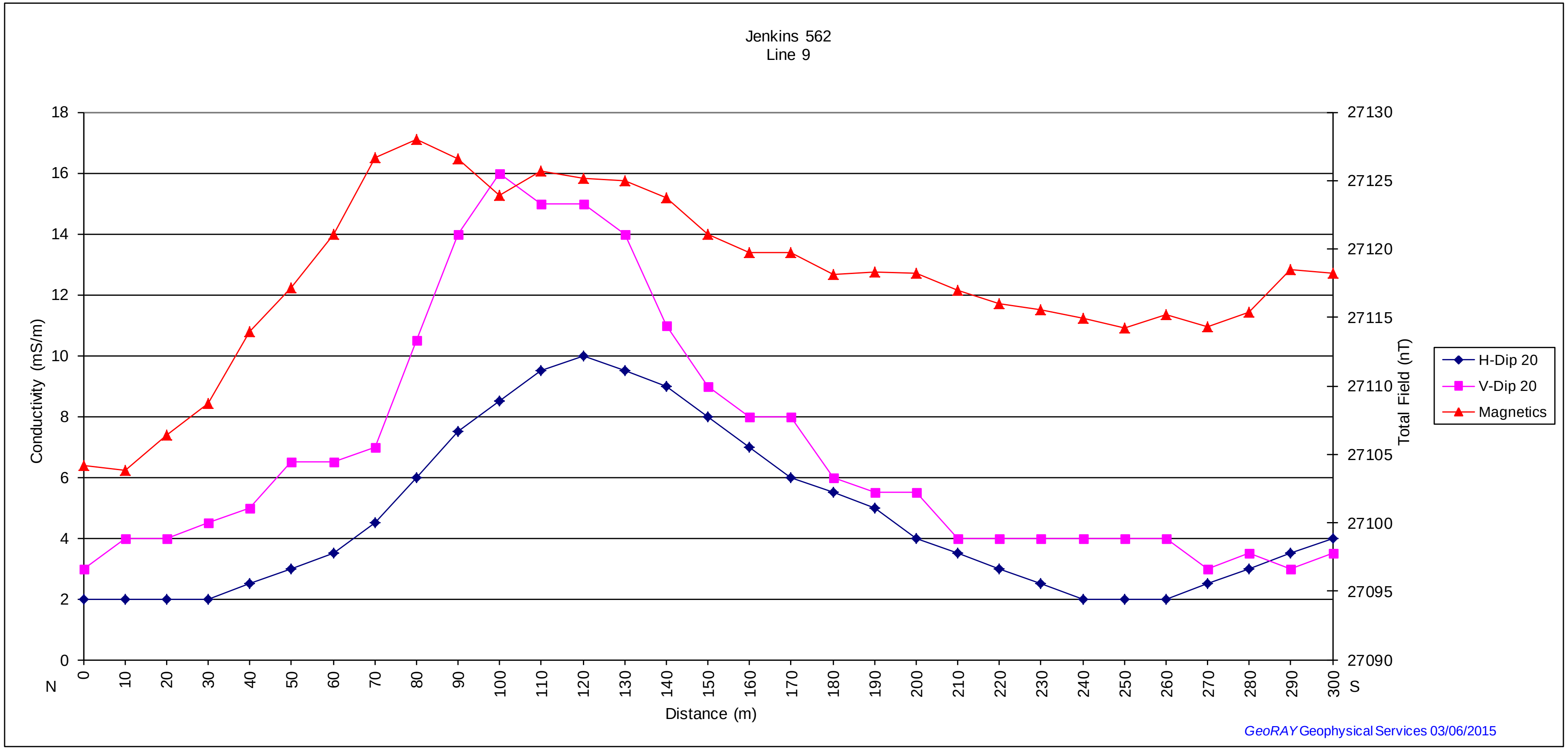
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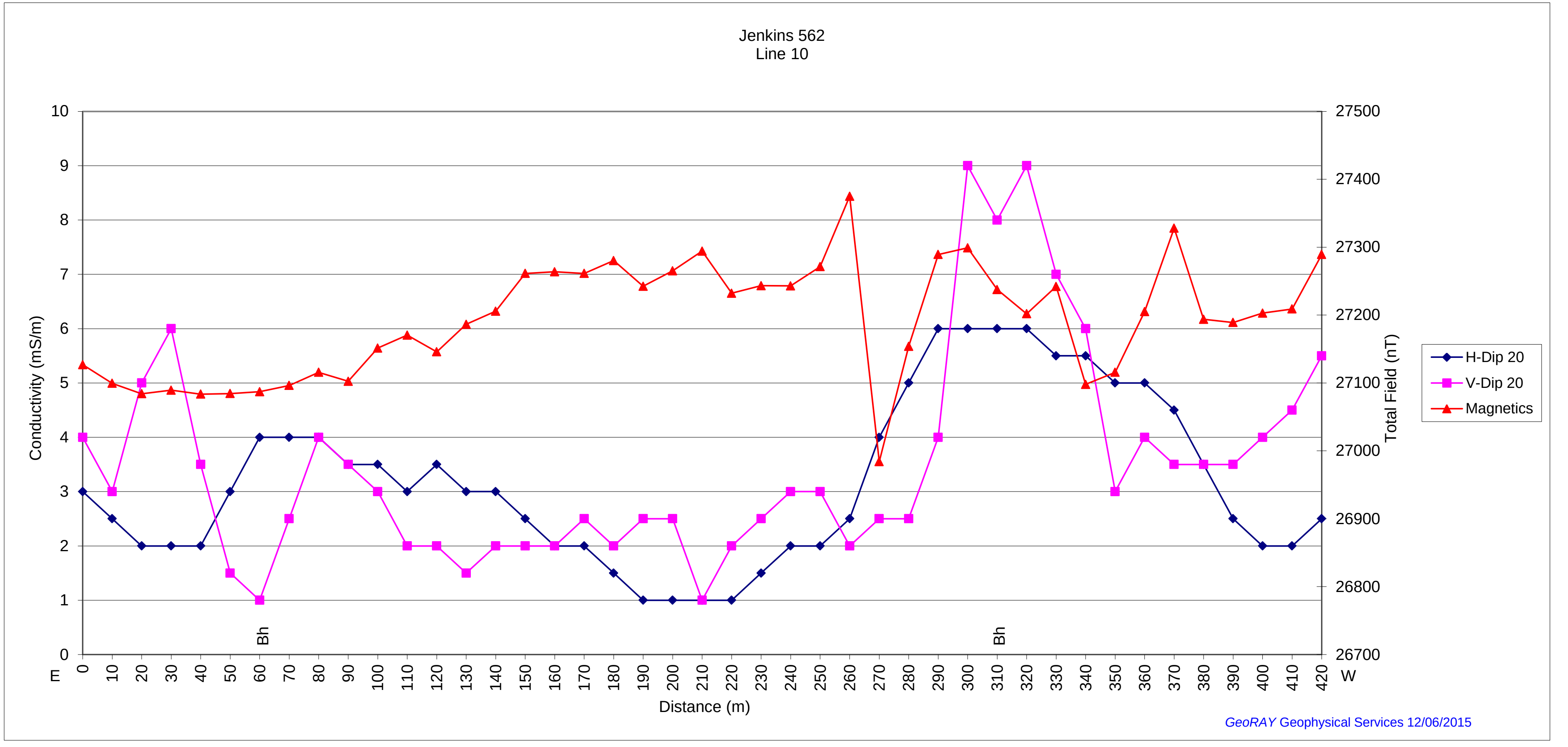
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Distance (m)
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V-Dip 20
Magnetics
GeoRAY Geophysical Services 12/06/2015


Jenkins 562
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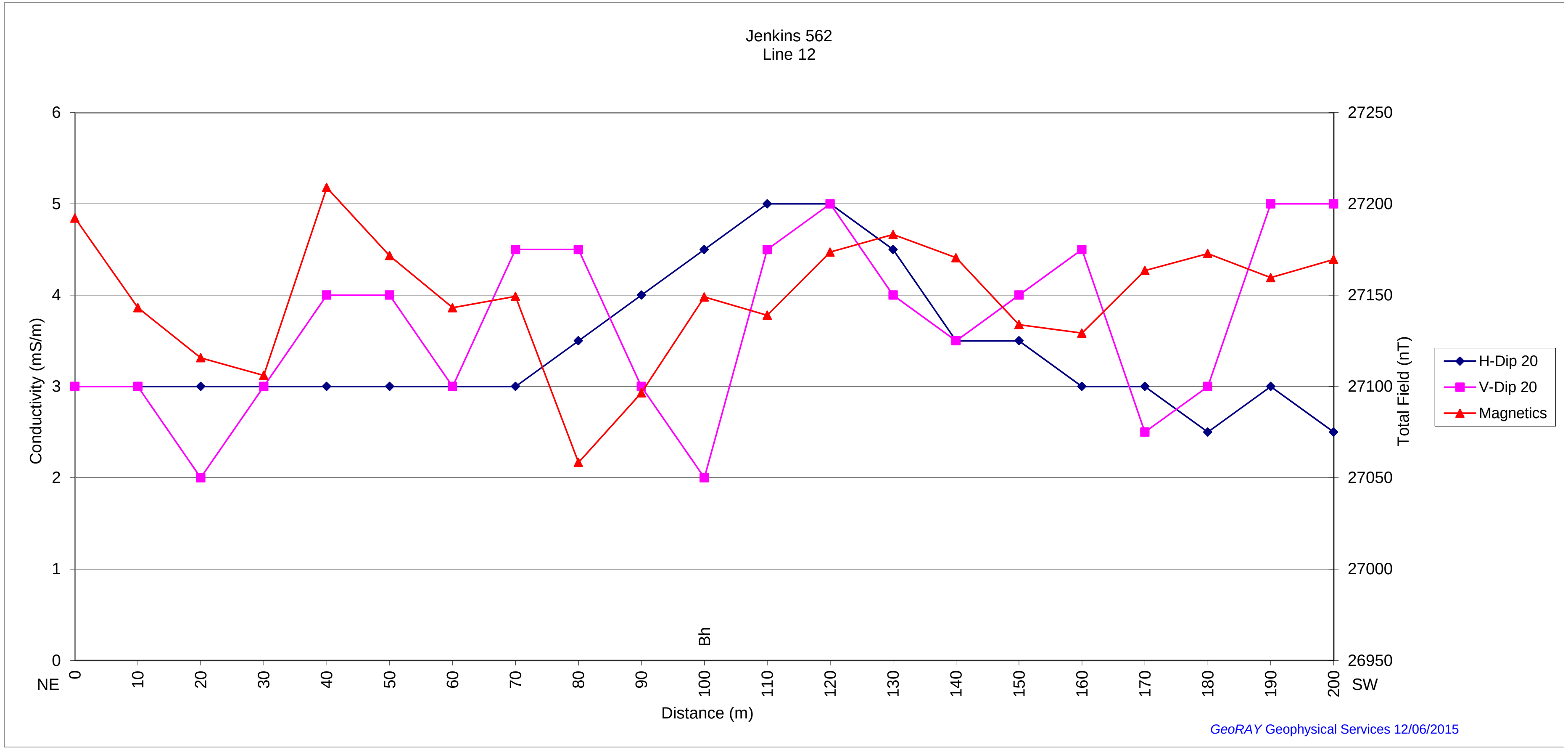
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V-Dip 20
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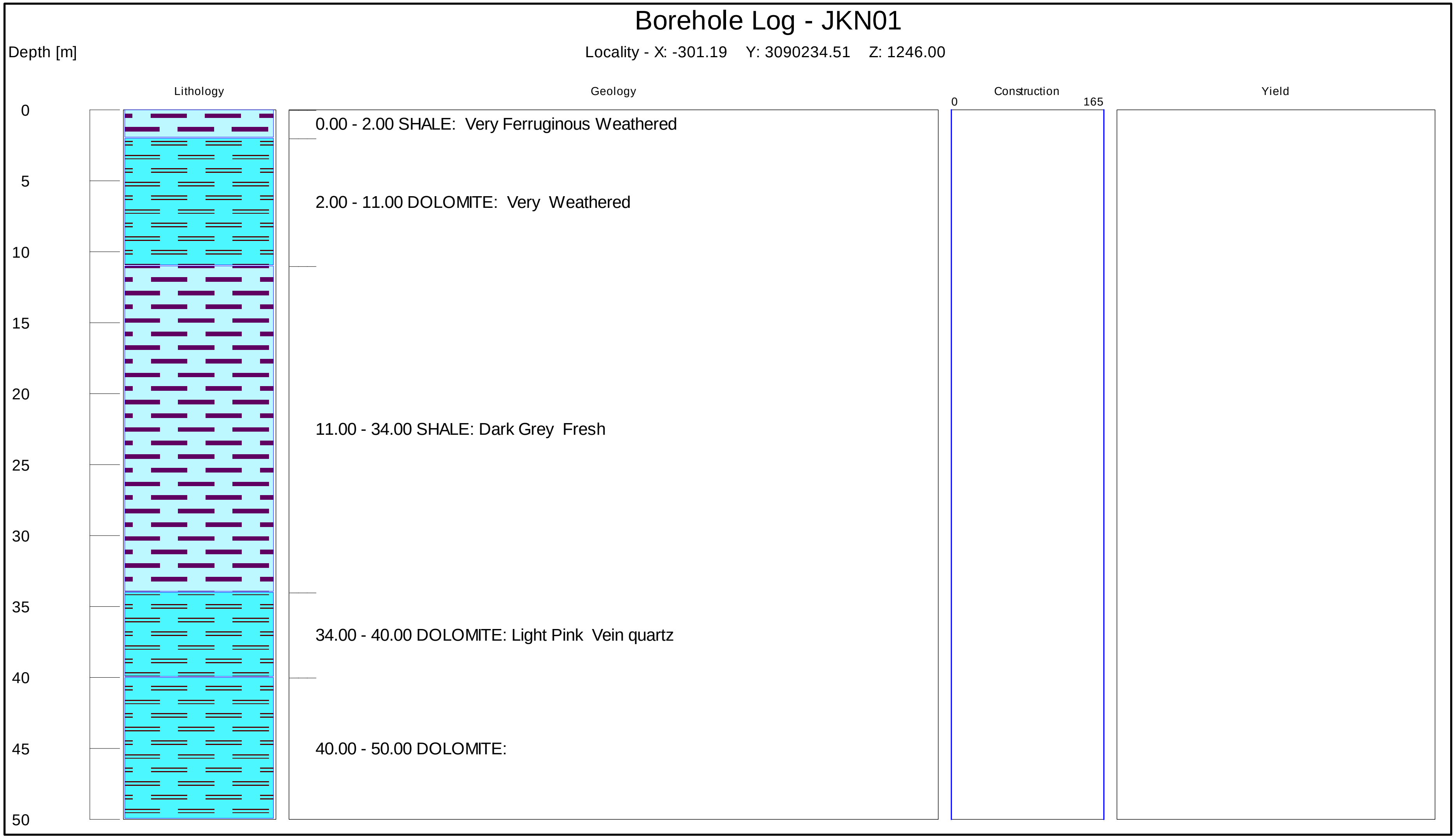
Distance (m)
GeoRAY Geophysical Services 12/06/2015

8 MONITORING BOREHOLE LOGS



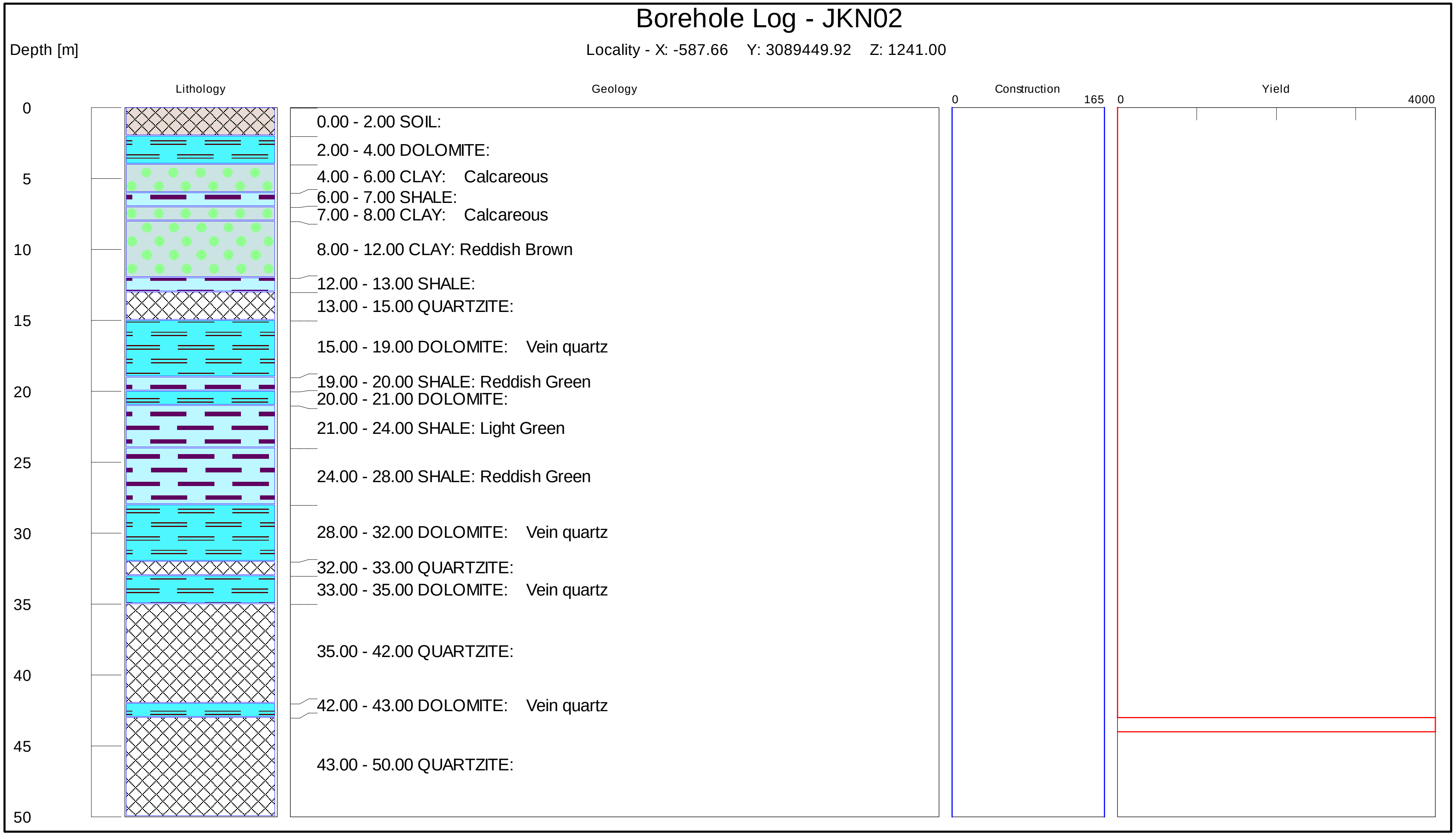
0.00 - 2.00 SHALE: Very Ferruginous Weathered

2.00 - 11.00 DOLOMITE: Very Weathered

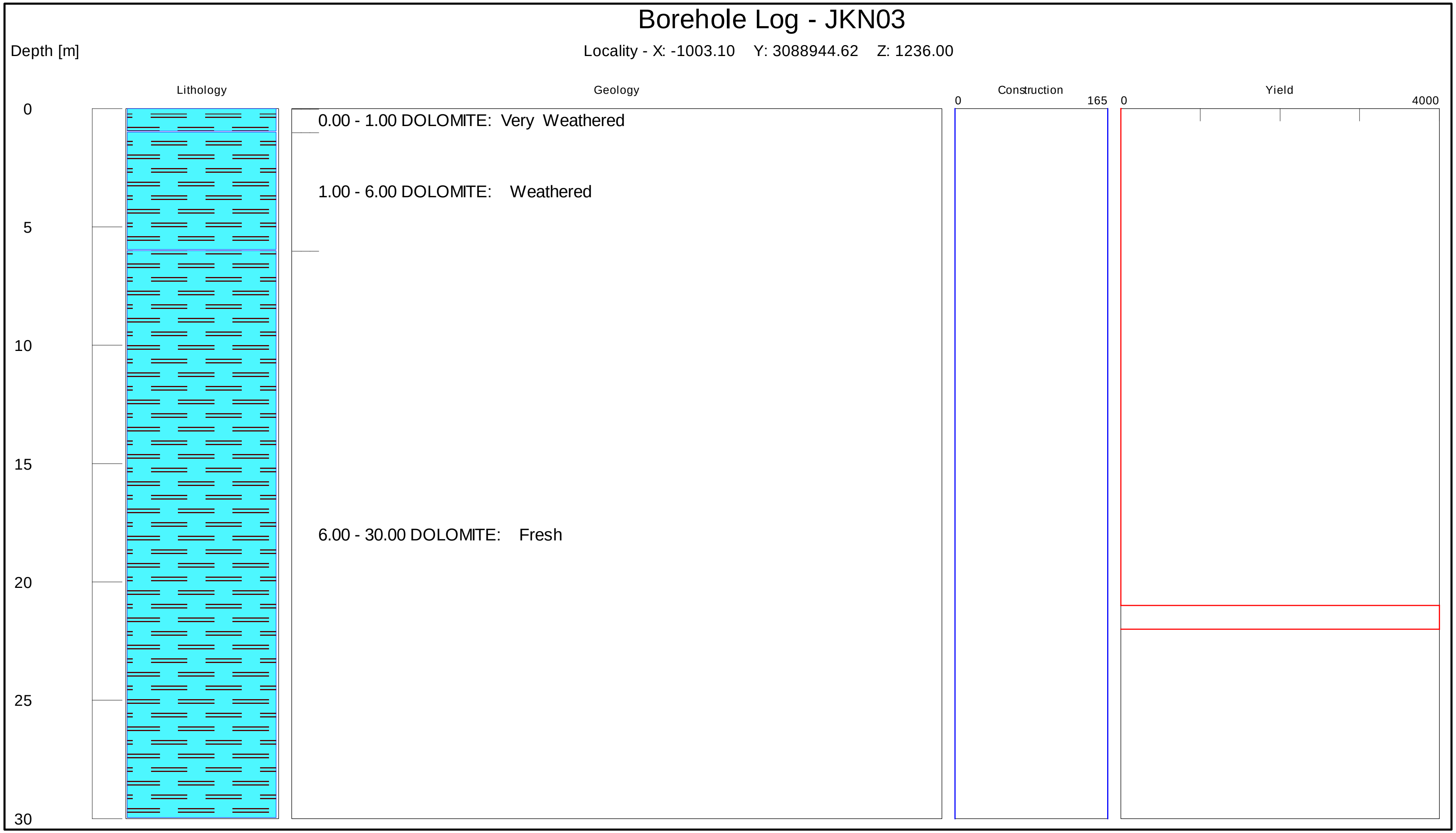
11.00 - 34.00 SHALE: Dark Grey Fresh

34.00 - 40.00 DOLOMITE: Light Pink Vein quartz

40.00 - 50.00 DOLOMITE:

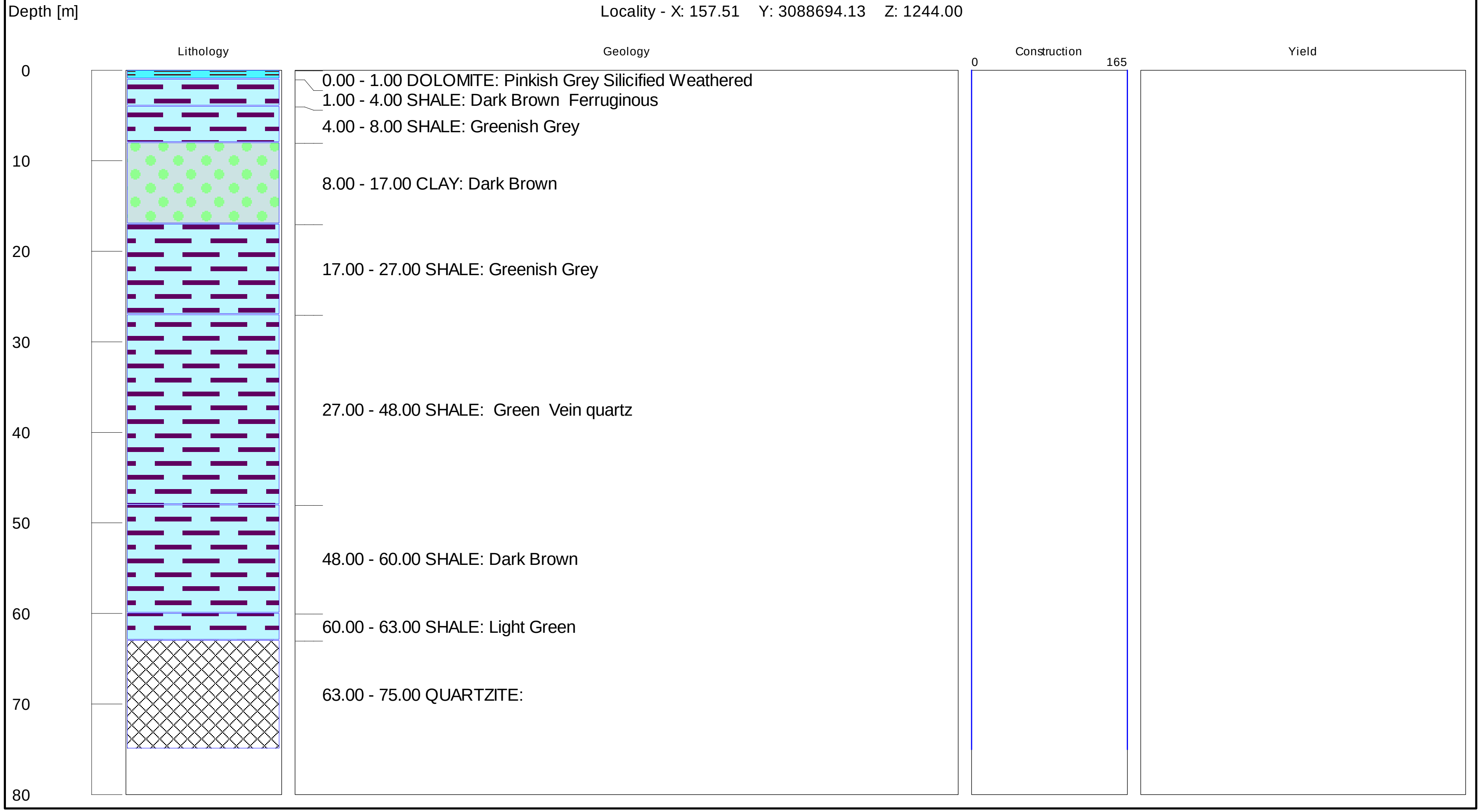


0.00 - 2.00 SOIL:
2.00 - 4.00 DOLOMITE:
4.00 - 6.00 CLAY: Calcareous
6.00 - 7.00 SHALE:
7.00 - 8.00 CLAY: Calcareous
8.00 - 12.00 CLAY: Reddish Brown
12.00 - 13.00 SHALE:
13.00 - 15.00 QUARTZITE:
15.00 - 19.00 DOLOMITE: Vein quartz
19.00 - 20.00 SHALE: Reddish Green
20.00 - 21.00 DOLOMITE:
21.00 - 24.00 SHALE: Light Green
24.00 - 28.00 SHALE: Reddish Green
28.00 - 32.00 DOLOMITE: Vein quartz
32.00 - 33.00 QUARTZITE:
33.00 - 35.00 DOLOMITE: Vein quartz
35.00 - 42.00 QUARTZITE:
42.00 - 43.00 DOLOMITE: Vein quartz
43.00 - 50.00 QUARTZITE:


Borehole Log - JKN03
Locality - X: -1003.10 Y: 3088944.62 Z: 1236.00
Depth [m]
Lithology
Geology
Construction
0
165
Yield
0
4000
0
5
10
15
20
25
30
0.00 - 1.00 DOLOMITE: Very Weathered
1.00 - 6.00 DOLOMITE: Weathered
6.00 - 30.00 DOLOMITE: Fresh

Borehole Log - JKN04

Locality - X: 157.51 Y: 3088694.13 Z: 1244.00



Borehole Log - JKN05

Locality - X: -19.69 Y: 3088971.18 Z: 1243.00

0.00 - 4.00 DOLOMITE: Pinkish Grey Silicified

4.00 - 13.00 CLAY: Grey

13.00 - 17.00 DOLOMITE: Weathered

17.00 - 21.00 QUARTZITE:

21.00 - 22.00 DOLOMITE: Vein quartz

22.00 - 28.00 QUARTZITE:

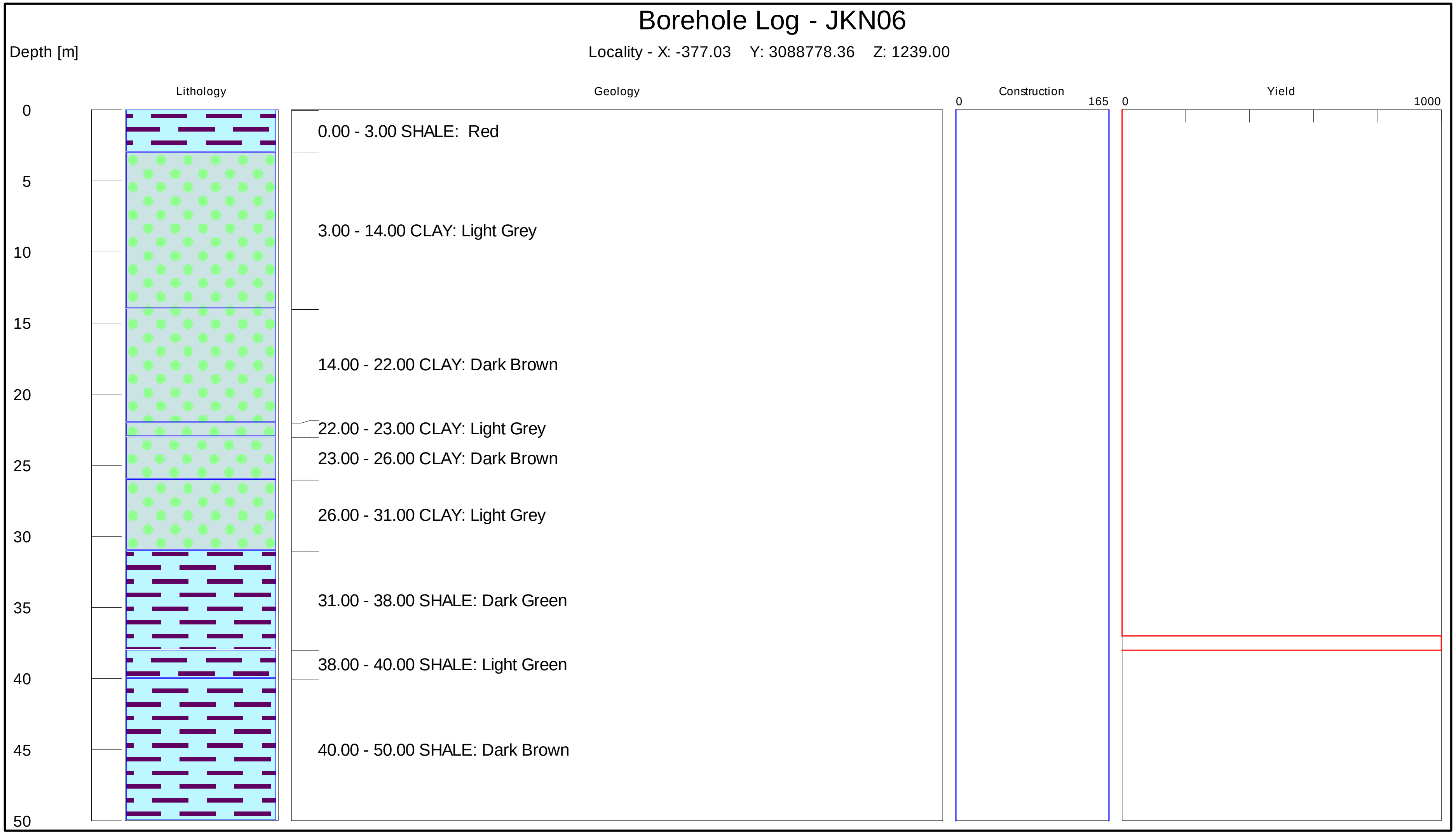
28.00 - 30.00 DOLOMITE: Dark Green

30.00 - 32.00 CLAY: Light White

32.00 - 35.00 CLAY: Black

35.00 - 43.00 DOLOMITE: Dark Green

43.00 - 50.00 SHALE: Reddish Green Vein quartz



Borehole Log - JKN06

Locality - X: -377.03 Y: 3088778.36 Z: 1239.00

0.00 - 3.00 SHALE: Red

3.00 - 14.00 CLAY: Light Grey

14.00 - 22.00 CLAY: Dark Brown

22.00 - 23.00 CLAY: Light Grey

23.00 - 26.00 CLAY: Dark Brown

26.00 - 31.00 CLAY: Light Grey

31.00 - 38.00 SHALE: Dark Green

38.00 - 40.00 SHALE: Light Green

40.00 - 50.00 SHALE: Dark Brown

Borehole Log - JKN07

Locality - X: -376.04 Y: 3088818.25 Z: 1239.00