MANUNGU COLLIERY
Life of Mine:

Groundwater Impact Assessment

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Executive Summary

Mbuyelo Group (Pty) Ltd (*Mbuyelo*) Manungu Colliery is located 10km south of Delmas Town. The Phase-1 resource of the Manungu Colliery Project was originally estimated at 57 million tonnes, to be mined till 2033, through opencast methodologies, over an 18year period. The first coal was produced in July 2015. After additional geological drilling, the life-of-mine (LOM) plan was revised to include additional coal resources. *Tshedza* is now applying for the total 30year LOM for one opencast and two underground sections, targeting a further 68 million tonnes. A processing plant will be built to ensure the contracted qualities are always met and other markets may be explored.

The original groundwater impact study report was compiled during 2007 (Ref: FeElo/07/247, by *Geo Pollution Technologies*, compiled for *Ferret Mining*, June 2007). This groundwater study provides for 30year LOM.

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1. INTRODUCTION

1.1. Background

Tshedza Mining Resources (Pty) Ltd's Manungu Colliery is located 10km south of Delmas Town. *Tshedza*, a subsidiary of *Mbuyelo Coal (Pty) Ltd* has an approved mining right (MP30/5/1/2/2/297MR) and Environmental Management Programme (EMPR), in terms of the Minerals and Petroleum Resources Development Act (Act 28 of 2002, as amended) (MPRDA), for the mining of coal at the Manungu Colliery.

The Phase-1 resource of the Manungu Colliery Project was originally estimated at 57 million tonnes, to be mined till 2033, through opencast methodologies, over an 18year period. Mining commenced in 2014 (first coal produced in July 2015). Coal production increased since the initial mining phases. By October 2017, the average production was 161ktpm for more than two years, increasing to 250ktpm by April 2018.

After additional geological drilling, the life-of-mine (LOM) plan was revised to include additional coal resources. *Tshedza* is now applying for the total 30year LOM for one opencast and two underground sections as indicated in Figure 1.1, targeting a further 68 million tonnes going forward. A processing plant will be built to ensure the contracted qualities are always met and other markets may be explored.

The original groundwater impact study report was compiled during 2007 (Ref: FeElo/07/247, by Geo Pollution Technologies, compiled for Ferret Mining, June 2007). The introductory sections of the impact study report provided a description of the pre-mining geohydrological environment, predicted the environmental impacts on the geohydrological regime, and designed rehabilitation measures. Importantly, the report served as an initial geohydrological evaluation of the site, and included the likely impacts of the proposed mining activity on the groundwater regime and how negative impacts should be managed.

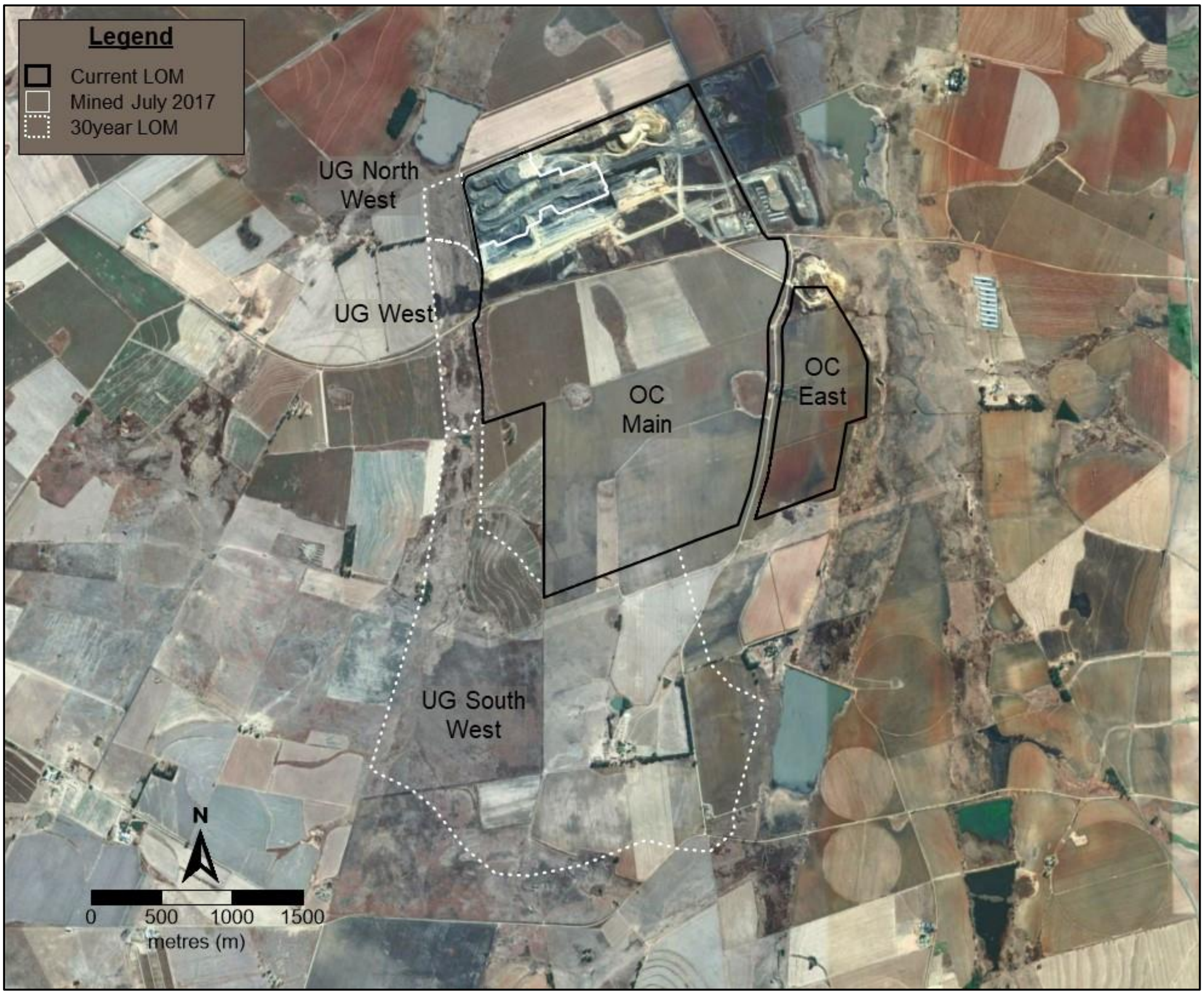


Figure 1.1 Manungu Colliery depicted against Google Earth aerial photo backdrop

Groundwater Square was approached to provide a proposal to update/upgrade the existing Manungu groundwater study, after recommendations in this regard from several consultants (environmental auditing on closure costs, water balance and water use licence consultants).

Groundwater Square recommended a completely new groundwater impact assessment, with the primary objective of studying the impact of the Manungu Phase-1 opencast on the local groundwater system, in terms of groundwater quality and groundwater levels (i.e. also studying groundwater flow and aquifer yield). After the decision in 2017 to revise the LOM plan, the groundwater study was again updated. *Groundwater Square* received the following appointments relating to the groundwater impact assessment of the Manungu Colliery:

- *Tshedza* (December 2016) – to update/upgrade the existing Manungu groundwater study; specifically, for the Phase-1 mining area;
  - One condition of the Phase-1 Water Use License (WUL), is the compilation of a numerical groundwater model. Supporting studies that have already been completed around the Phase-1 mining area, were interpreted for the local aquifer characteristics and current groundwater situation; to be updated for the total 30year life of mine plan once these field studies have been completed and evaluated.
  - Based on the results of the numerical groundwater model, the operational phase impacts were determined in terms of influence on surrounding groundwater levels and operational phase groundwater inflow into the Manungu Phase-1 pit. The numerical groundwater model was also utilised to assess the post-mining impact on the surrounding aquifers in terms of decant locations, volumes and groundwater quality.
- *Geo Soil & Water (Pty) Ltd* (May 2017) – to evaluate the deposition of discard into the Manungu pit if a coal processing plant is to be constructed;
- *Environmental Impact Management Services (Pty) Ltd* (*EIMS*) (July 2017) – to study the entire mining area; after decisions were taken by *Mbuyelo* Management to study the total 30year life-of-mine (LOM) (i.e. beyond the initial Phase-1, 18year mine plan);
- *EIMS* (July 2018)[*] similar to the 2017 appointment but providing for the amendment to the existing Mine Works Programme (MWP) and EMPR, through a MPRDA Section 102 Application, and a full Environmental Impact Assessment (EIA) for the newly proposed planned LOM.

[*] This Section 102 application is supported by an application for environmental authorisation (EA) and waste management license (WML) as applicable. A new integrated water use license application (IWULA) for the relevant water use triggers associated with the proposed current and future planned mine will also be undertaken as well as any other public participation and regulatory approval requirements is complied with.

1.2. Life-of-Mine (LOM) Plan

Manungu Colliery's 30year LOM plan is indicated in Figure 1.2, targeting 68 million tonnes, at a production rate of ±275ktpm going forward. The Seam-2 coal will be the primary target due to its economic thickness and quality (Denner, 2018). The top portion of the Seam-2 is typically of a poor coal quality with interbedded shales.

Figure 1.3 depicts the layout of the Coal Processing Wash Plant, which will be constructed to ensure that the contracted qualities are met. The Wash Plant will be located in the current coal handling area between the mining offices and the pollution control dam. Because the Wash Plant will include a filter press, there will not be any slurry to dispose. However, discard will be generated, which will have to be backfilled into the pit.

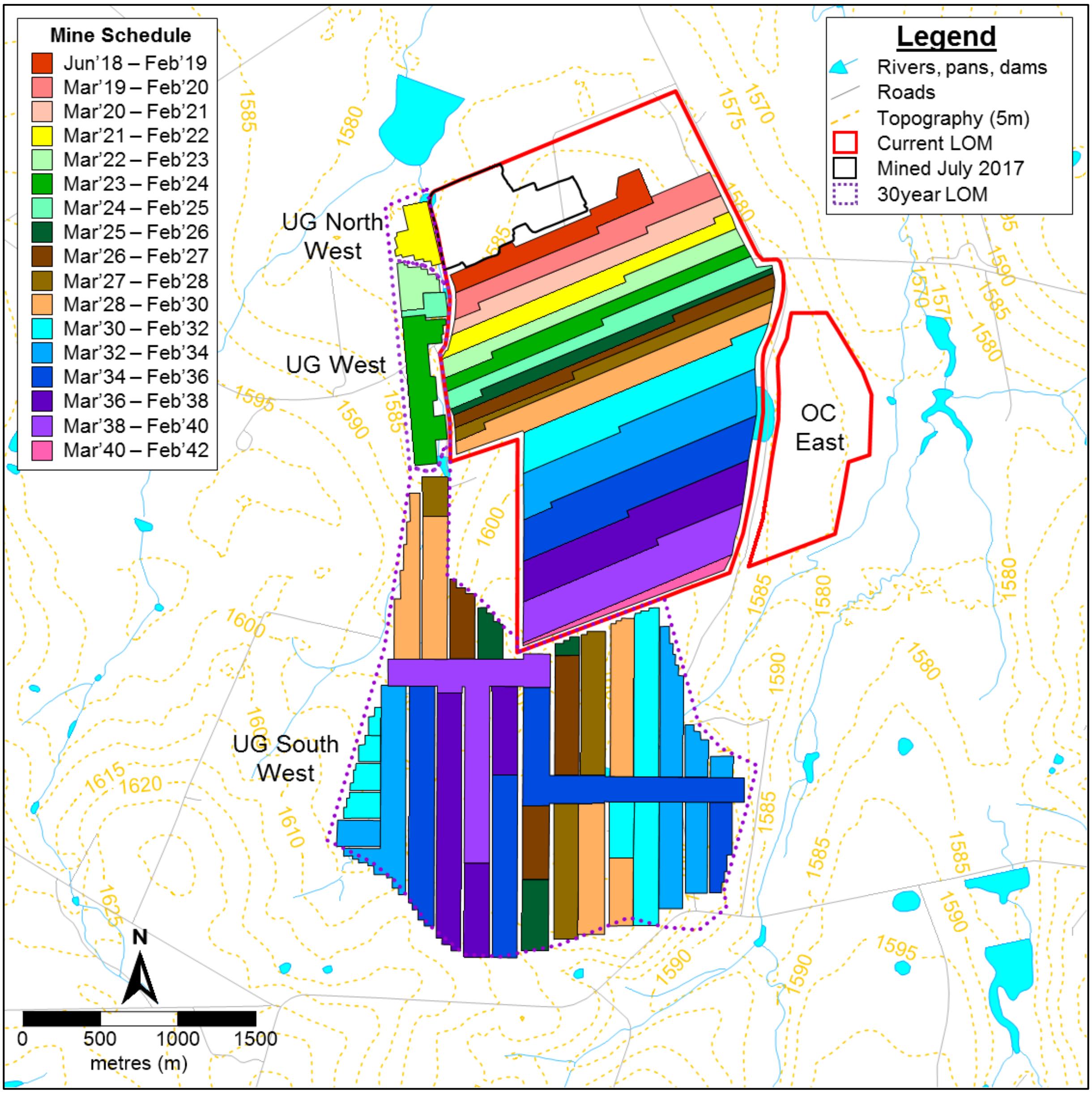


Figure 1.2 Manungu Colliery mine schedule (opencast and underground) indicating the 30year LOM extension areas

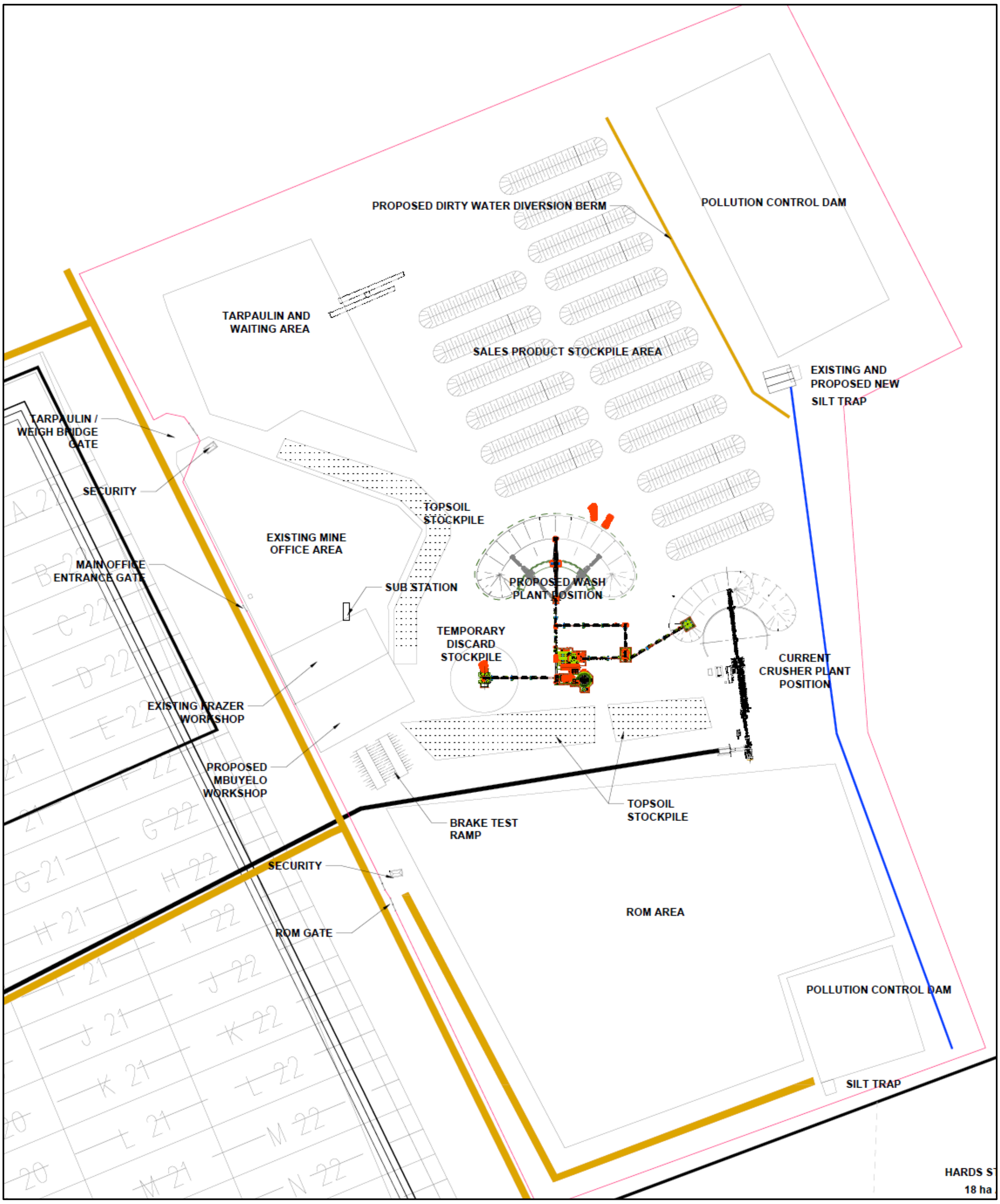


Figure 1.3 Concept design of Plant (Ref: BEAL, 2018)

2. GEOGRAPHICAL SETTING

2.1. Topography and Drainage

As can be seen in Figures 1.2 and 2.1, the topographical elevations in the local surrounding range 65m from the highest lying ground (1615mamsl) to the lowest elevations (1550mamsl) at the confluence of the two non-perennial streams which flank the Manungu coal resource.

The highest elevation (1612mamsl) in the opencast mining area is in the south, and the lowest along the north-western, and north-eastern corners (1579mamsl = decant elevation); ranging 36m.

The average topographical slope in the mining area is 2.5%; with smaller gradients of <1% observed in the northern part of the Phase-1 mining area. Steeper gradients exceeding 6% exist to the west and east. Interestingly, very shallow gradients exist along the floodplains which are associated with the local rivers.

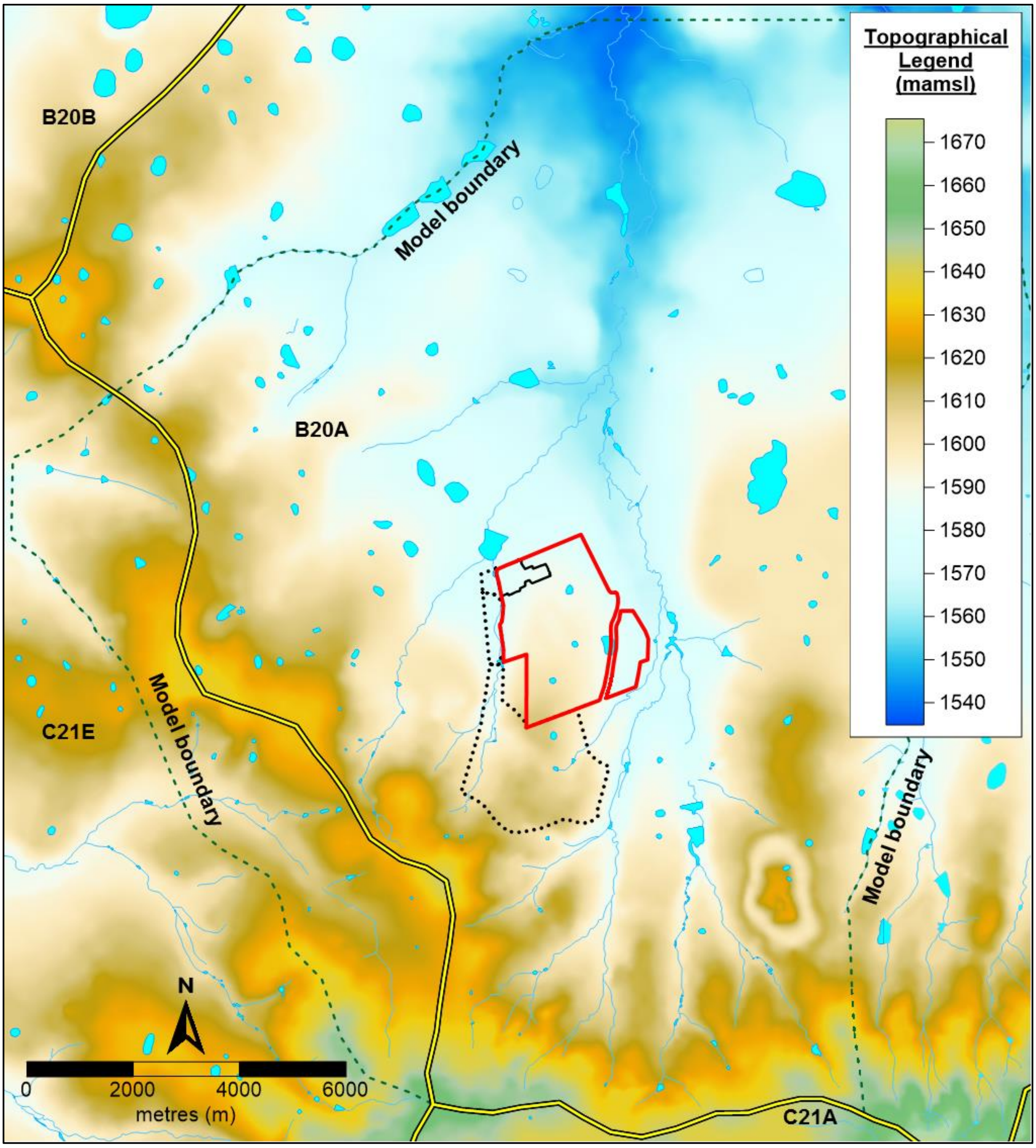


Figure 2.1 Thematic depiction of regional surface topography

Two north-flowing non-perennial streams flank the Manungu Colliery to the west (nearest point adjacent to pit, <30m) and east (nearest points at 100m distance for smaller branch of stream and 250m for larger branch of stream). These two streams confluence 2km north of Manungu and then confluence 7km to the north, directly east of Delmas Town, with another non-perennial stream which joins from the west. Eventually, these streams join the Bronkhorstspruit River approximately 14km north of Manungu Colliery.

No upstream areas have been impacted by coal mining activities, but mining is currently underway 3km northwest (*Kangala* Colliery), and 5km northeast (*Exxaro*, Leeuwpan Colliery).

2.2. Climate

The Manungu Colliery is situated in quaternary catchments B20A (see Figure 2.1). According to the WRC (1994), this catchment has a Mean Annual Precipitation (MAP) of 661mm/a. It is bounded by quaternary catchments B20B (north, MAP=663mm/a), C21E (west, MAP=691mm/a) and C21A (south, MAP=674).

A MAP of 700mm/a applied to all relevant calculations in this study.

According to the WRC (1994), the mean annual evaporation varies between 1600mm/a and 1700mm/a.

3. SCOPE OF WORK

The following scope of work summarises the appointments by *Groundwater Square* to perform the Manungu groundwater impact assessments during the various phases of groundwater work between 2015 and 2018:

- Attend start-up meetings, site visits and workshops;
- Desktop study, generate baseline infrastructure information and maps;
- Collect data relevant to the study, including:
  - Geology;
  - Geometry (XYZ) of coal seam floors;
  - Current and LOM mine layouts;
  - Relevant site information from visual inspection and discussions;
- Collect field data:
  - Perform geophysical surveys (during two phases), in addition to Mine aeromagnetic survey (magnetic, gravity and resistivity to investigate the occurrence of dykes and preferential flow zones/cavities in critical areas);
  - Drill hydrogeological boreholes (based on mine plan, geophysics, structural geology and potential impacts) during two phases:
    - 8x "deep" boreholes (86 to 175m deep);
    - 10x "medium" boreholes (26m to 35m deep);
    - 6x "shallow" boreholes (6m to 10m deep), associated with certain "medium" or "deep" boreholes;
  - Perform EC profiling on borehole water columns;
  - Perform water sampling of boreholes, springs, surface water and private boreholes;
  - Perform aquifer and borehole hydraulic testing:
    - Slug-tests on all newly drilled boreholes (surrounding boreholes might be included);
    - A combination of yield tests, step-tests and long-term tests on a selection of borehole(s);
  - Laboratory analysis of sampled water:
    - Minimum pH, EC, TDS, Ca, Mg, Na, K, Cl, SO_4, NO_3, T.Alk, Si, F, Al, Fe, Mn;
- Evaluate data in the context of geological information provided by the mine:
  - Computerise/analyse/interpret field test data;
  - Interpret/describe aquifer conditions and hydraulic attributes;
- Review project objectives and modelling scenarios, and discuss with Mine Management;
- Geochemical assessment for opencast operation and Wash Plant:
  - Analyse client database of mineralogical and elemental composition of the rock/coal material;
  - Perform laboratory analysis on core/pulp/drill samples for e.g. ABA/XRD/XRF/NAG/%S;
  - Determine the potential for acidic mine drainage over the long term;
  - Specifically evaluate the option of placing discard from the planned Wash Plant back into the pit;
  - Perform oxygen diffusion and geochemical trend numerical modelling to determine the expected variations in mine water quality:

    - During mining;
    - Post-mining;
- Perform groundwater modelling assessment:
    - Compile conceptual model;
    - Compile and calibrate detailed numerical 3D model(s) to quantify/assess impacts;
    - Incorporate geochemical assessment data in numerical models, to enable prediction of contaminant movement;
- Groundwater impact calculations:
    - Identify/describe/calculate impacts on the groundwater environment through analytical equations and numerical modelling;
    - Propose mitigation/management measures;
    - Identify data gaps and focus areas for additional research if required;
- Provide guidance on:
    - Water monitoring;
    - Mitigation measures;
- Interact with project team and provide feedback;
- Compile report.

A waste classification study was compiled by another consultant.

Disclaimer – The current state of hydrogeological knowledge was presented as accurately as possible using available information and new information generated during the exploration and groundwater data gathering phases. *Groundwater Square* exercised due care and diligence in gathering and evaluating relevant information. *Groundwater Square* will not accept any liability in the event of encountering unexpected aquifer conditions during mining or additional groundwater studies. Any unauthorized dissemination or reuse of the groundwater specialist impact assessment report will be at the user's sole risk and with the condition that *Groundwater Square* will not accept any liability for any and all claims for losses or damages and expenses arising out of or resulting from such unauthorized disclosure or reuse.

4. METHODOLOGY

The groundwater impact assessment relied primarily on numerical groundwater modelling, supplemented by spreadsheet calculations, geochemical laboratory testing and modelling. The basis of these assessments were field studies consisting of the original 2007 hydro-census, the 2017 hydro-census revisit, various geophysical surveys, two phases of hydrogeological drilling, geochemical sampling/analyses/modelling, various aquifer test, including falling head tests, slug tests and pump testing, as well as groundwater monitoring.

Assessments were continually upgrade with the new geological information and mine designs.

4.1. Desk Study

This desk study, apart from the recent Phase-1 “Manungu Colliery WUL Commitment – Groundwater Model” study (Ref: GW2_327b_Manungu, August 2017), also incorporated assessment of the following studies:

- The original groundwater impact study report was compiled during 2007 (Ref: FeElo/07/247, by Geo Pollution Technologies, compiled for Ferret Mining, June 2007);
- Denner E. J, De Villiers E. Gemecs, 19 June 2015. “Manungu Competent Persons Resource & Reserve Report”. Project No: GMXP14060;
- Brummer K, Campbell G, Mutobo K. “Interpretation of high resolution aeromagnetic and radiometric survey data over the Welgevonden and Weilaagte prospect area, Mpumalaga Province.” On behalf of Tshedza Mining Resources (Pty) Ltd. GAP Geophysics, August 2014;
- Letsolo Water and Environmental Services cc, June 2017 “Tshedza Mining Resources (Pty) Ltd – Manungu - Manungu Colliery Water and Salt Balance”, Ref: LWES 409;
- Digby Wells & Associates, November 2009. “Wolvenfontein - Kangala: Hydrologeogical Investigation Report”;
- Meyer R, March 2010. “Hydrogeology of Groundwater Region 10: The Karst Belt (WRC Project No. K5/1916)”. WRC Report No. TT 553/14;
- Button, A., 1969, "Stratigraphic Analyses of the Transvaal Sequences in the Irene-Delmas-Devon Area, Transvaal", Economic Geology Research Unit, Univ. Witwatersrand, Johannesburg, Information Circular No.51, February 1969;
- Button, A., 1970, "Subsurface Stratigraphic Mapping of the Witwatersrand Sequences in the Irene-Delmas-Devon Area, Transvaal", Economic Geology Research Unit, Univ. Witwatersrand, Johannesburg, Information Circular No.59, October 1970;
- Werdmuller V.W, Pretorius D. A, Poulos D.J, Hansen L. C, 1990, "A Partial Listing of Witwatersrand Boreholes", Economic Geology Research Unit, Univ. Witwatersrand, Johannesburg, Information Circular No.225, October 1990;
- The 2017 updated Gemecs geological model.

4.2. Hydrocensus

The 2007 hydrocensus, within a 1km radius of the larger Manungu reserve area across Weilaagte 271 IR and Welgevonden 272 IR, performed by Geo Pollution Technologies as part of the original groundwater impact study was revisited and updated during March 2017 (Manungu Phase-1 groundwater study). All hydrocensus information is summarised in Tables 4.1A-D.

Table 4.1A Hydrocensus - Owner Information

Map Nr	Name of Owner	Contact Person	Phone Numbers	Farm Name	Farm Number
MBH1	Tshedza Mining Resources Pty Ltd	Manungu Coal Mine	013 648 8934	Weilaagte	271/9
MBH2	Tshedza Mining Resources Pty Ltd	Manungu Coal Mine	013 648 8934	Weilaagte	271/9
MBH3	Tshedza Mining Resources Pty Ltd	Manungu Coal Mine	013 648 8934	Weilaagte	271/7
MBH4	Tshedza Mining Resources Pty Ltd	Manungu Coal Mine	013 648 8934	Weilaagte	271/7
MBH4R	Tshedza Mining Resources Pty Ltd	Manungu Coal Mine	013 648 8934	Weilaagte	271/7
MBH6	J Z Moolman Boerdery CC	Jurgens	083 327 4914	Weilaagte	271/10
MBH7	Werda Handel Pty Ltd	Jurgens	083 327 4914	Weilaagte	271/11
MBH8	Werda Handel Pty Ltd	Jurgens	083 327 4914	Weilaagte	271/11
MBH9	J Z Moolman Boerdery CC	Jurgens	083 327 4914	Weilaagte	271/10
MBH10	J Z Moolman Boerdery CC	Jurgens	083 327 4914	Weilaagte	271/10
MBH11	Werda Handel Pty Ltd	Jurgens	083 327 4914	Weilaagte	271/11
MBH12	Cowenburg Boerdery CC	Louis	083 676 1164	Welgevonden	272/4
MBH13	Lategan Hendrik Daniel	Hennie	083 711 1261	Welgevonden	272/8
MBH14	Unknown			Goede Hoop	290/1
MBH15	Kallie Madel Trust	Martinus	060 868 4594	Weilaagte	271/2
MBH16	Cowenburg Boerdery CC	Francois	083 676 1158	Welgevonden	272/11
MBH17	Koos Uys & Seun Boerdery	Koos Uys	082 316 3151	Weilaagte	271/4
MBH18	Liplek Kuikens Pty Ltd	Kobus Oelofse	082 787 1789	Weilaagte	271/12
MBH18B	Liplek Kuikens Pty Ltd	Kobus Oelofse	082 787 1789	Weilaagte	271/12
MBH19	Tshedza Mining Resources Pty Ltd	Kobus Oelofse	0827871789	Weilaagte	271/8
MBH20	Louis Rossouw	Louis Rossouw	0727398176	Leeuwpan	246
MBH20A	Louis Rossouw	Louis Rossouw	0727398177	Leeuwpan	246
MBH20B	Louis Rossouw	Louis Rossouw	0727398178	Leeuwpan	246
MBH21	Louis Rossouw	Louis Rossouw	0727398178	Leeuwpan	246
MBH22				Leeuwpan	246/2
MBH23	Hannes Potgieter	Shaun	078 290 1666	Vlakplaas	268/1
MBH24	Morgan Beef			Goede Hoop	290/4
MBH25	Ernst	Ernst	071 472 0676	Puntstaan	289
MBH26				Syferfontein	288/11
MBH27	Rappard Frans Johannes	Gustaf Rappard	083 226 1882	Syferfontein	288/4
MBH28	Rappard Frans Johannes	Gustaf Rappard	083 226 1882	Syferfontein	288/4
MBH29	Janus Oosthuizen	Janus Oosthuizen	082 445 2368	Stompiesfontein	273/35
MBH30	Philippie	Phillipie	082 788 2344	Stompiesfontein	273/19
MBH31	Philippie	Phillipie	082 788 2344	Stompiesfontein	273/10
MBH32	Gunter	Gunter	072 116 1884	Stompiesfontein	273/3
MBH33	Gunter	Gunter	072 116 1884	Stompiesfontein	273/41
MBH34	Gunter	Gunter	072 116 1884	Stompiesfontein	273/41
MBH35	Andries Lategaan	Andries Lategaan	083 729 4770	Welgevonden	272/9
MBH36A	Reinhold Probst	Reinhold Probst	072 40 20184	Welgevonden	272
MBH36B	Reinhold Probst	Reinhold Probst	072 402 0185	Welgevonden	272
MBH40	Gustaf Rappard	Gustaf Rappard	083 226 1882	Syferfontein	288/4
MBH41	Jaco Oosterhuis	Jaco Oosterhuis	083 283 2716	Wolwefontein	244/5
MBH42	Jaco Oosterhuis	Jaco Oosterhuis	083 283 2716	Wolwefontein	244/5
MBH44	Louis Rossouw	Louis Rossouw	072 739 8178	De Denne	256
MBH45	Philippie	Phillipie	082 788 2345	Stompiesfontein	273/20
MBH46	Philippie	Phillipie	082 788 2346	Stompiesfontein	273/20
MBH47	Pieter Fleischmann	Pieter Fleischmann	082 924 3966	Stompiesfontein	273/26
G37016	DWS	Kobus Oelofse	082 787 1790	Strydpan	243/35
G37017	DWS			Strydpan	243/30
G37018	DWS	Universal Coal	076 786 3739	Wolwefontein	244/1
G37030	DWS	Cowenburg Boerdery CC	082 927 9596	Welgevonden	272/3
KAM01	Kangala Coal Mine	Puis	076 786 3739	Wolwefontein	244/1
KAM02	Kangala Coal Mine	Puis	076 786 3739	Wolwefontein	244/2
KGA14	Universal Coal	Puis	076 786 3739	Wolwefontein	244/1
KGA15	Schoeman Boerdery	Solomon	082 388 1009	Wolwefontein	244/2
KGA17	Oosterhuis Johannes Jocobus	Jaco Oosterhuis	083 283 2716	Wolwefontein	244/4
KGA17B	Oosterhuis Johannes Jocobus	Jaco Oosterhuis	083 283 2716	Wolwefontein	244/4
MAN-BH1	Tshedza Mining Resources Pty Ltd	Manungu Coal Mine	013 648 8934	Weilaagte	271/9
MBH48	Eloff Mining Co Pty Ltd	Gehard	082 927 9596	Welgevonden	272/10
OC1	Eloff Mining Co Pty Ltd	Gehard	082 927 9596	Welgevonden	272/10

Table 4.1B Hydrocensus – Location information

Map Nr	XCoord WGS84 (Latitude)	YCoord WGS84 (Longitude)	Elevation (mamsl)	Site Type	Site Status	User Application	Equipment
MBH1	26.22456	28.69487	1578.85	Borehole	In use		Submersible
MBH2	26.22400	28.69508	1578.30	Borehole	In use	Domestic – all purposes	Submersible
MBH3	26.22886	28.69595	1582.25	Borehole	Unused		No equipment
MBH4	26.23123	28.69703	1583.45	Borehole	Unused		No equipment
MBH4R	26.23156	28.69783	1583.00	Borehole	In use	Domestic – all purposes	Submersible
MBH6	26.23880	28.73051	1605.40	Borehole	In use	Agricultural & domestic use	Submersible
MBH7	26.24239	28.73364	1610.00	Borehole	Unused		
MBH8	26.24220	28.73180	1611.00	Borehole	Unused		
MBH9	26.24218	28.74617	1494.90	Borehole	-	-	
MBH10	26.23940	28.73688	1609.50	Borehole	Unused		
MBH11	26.24150	28.73069	1608.35	Borehole	Unused		
MBH12	26.25900	28.69771	1587.40	Borehole	In use	Agricultural & domestic use	Submersible
MBH13	26.27770	28.71000	1595.00	Borehole	In use	Domestic – all purposes	Submersible
MBH14	26.26810	28.74852	1590.00	Borehole	Destroyed		No equipment
MBH15	26.24970	28.73188	1613.60	Borehole	In use	Domestic – all purposes	Submersible
MBH16	26.26532	28.68764	1607.00	Borehole	In use	Agricultural & domestic use	Submersible
MBH17	26.22436	28.70062	1567.50	Borehole	In use	Agricultural & domestic use	Submersible
MBH18	26.24264	28.71501	1585.80	Borehole	Unused		No equipment
MBH18B	26.24235	28.71588	1586.43	Borehole	In use	Agricultural & domestic use	Submersible
MBH19	26.22856	28.69684	1580.00	Borehole	In use	Agricultural & domestic use	Submersible
MBH20	26.21252	28.74054	1602.00	Borehole	In use	Agricultural & domestic use	Submersible
MBH20A	26.21106	28.73859	1602.00	Borehole	In use	Agricultural & domestic use	Submersible
MBH20B	26.21290	28.73601	1589.00	Borehole	In use	Agricultural & domestic use	Submersible
MBH21	26.21810	28.73605	1594.00	Borehole	In use	Agricultural & domestic use	Submersible
MBH22	26.20550	28.72372	1594.00	Borehole	Unused		No equipment
MBH23	26.21661	28.76258	1593.00	Borehole	In use	Agricultural – irrigation	Submersible
MBH24	26.27850	28.76117	1594.00	-	-	-	-
MBH25	26.29482	28.72866	1613.00	Borehole	In use	Agricultural & domestic use	Submersible
MBH26	26.29255	28.69990	1599.00	-	-	-	-
MBH27	26.28010	28.71542	1589.00	Borehole	Unused		No equipment
MBH28	26.28045	28.71376	1591.00	Borehole	In Use	-	Submersible
MBH29	26.28358	28.66032	1626.00	Borehole	In use	Agricultural & domestic use	Submersible
MBH30	26.26790	28.64737	1620.00	Borehole	In use	Agricultural – stock watering	Submersible
MBH31	26.26665	28.64936	1621.00	Borehole	In use	Domestic – all purposes	Submersible
MBH32	26.23692	28.66129	1589.00	Borehole	In use	Agricultural & domestic use	Submersible
MBH33	26.23224	28.65540	1605.00	Borehole			-
MBH34	26.23465	28.65672	1603.00	Borehole			-
MBH35	26.27257	28.71876	1594.50	Borehole	In use	Agricultural & domestic use	Submersible
MBH36A	26.28398	28.68740	1604.90	Borehole	In use	Agricultural & domestic use	Mono -type
MBH36B	26.28566	28.68692	1606.20	Borehole	Unused		Windmill
MBH40	26.28940	28.71273	1596.00	Borehole	In use	Agricultural & domestic use	Submersible
MBH41	26.19694	28.71645	1587.00	Borehole	In use	Agricultural – stock watering	Submersible
MBH42	26.19683	28.71343	1586.00	Borehole	In use	Agricultural & domestic use	Submersible
MBH44	26.19813	28.74189	1593.00	Borehole	In use	Domestic – all purposes	Submersible
MBH45	26.26927	28.65341	1619.00	Borehole	In use	Domestic – all purposes	Submersible
MBH46	26.27109	28.65185	1625.00	Borehole	In use	Agricultural – stock watering	Submersible
MBH47	26.27683	28.65543	1628.00	Borehole	In use	Agricultural & domestic use	Submersible
G37016	26.24934	28.63293	1628.00	Borehole	Unused		No equipment
G37017	26.23053	28.64877	1605.00	Borehole	Unused		No equipment
G37018	26.20297	28.67848	1575.00	Borehole	Unused		No equipment
G37030	26.25884	28.69279	1596.10	Borehole	Unused		No equipment
KAM01	26.19756	28.67773	1611.49	Borehole	In use	Industrial - mining	No equipment
KAM02	26.21273	28.67163	1591.98	Borehole	In use		-
KGA14	26.20238	28.67720	1575.00	Borehole	In use	Domestic – all purposes	Submersible
KGA15	26.20622	28.68375	1568.00	Borehole	In use	Domestic – all purposes	Submersible
KGA17	26.20380	28.70122	1563.00	Borehole	Unused		Submersible
KGA17B	26.20132	28.70061	1559.00	Borehole	Unused		Submersible
MAN-BH1	26.22369	28.69895	1569.79	Borehole	In use	Domestic – all purposes	Submersible
MBH48	26.25688	28.67919	1597.00	Borehole	Unused		No equipment
OC1	26.25786	28.67449	1592.00	Outcrop	Unused		No equipment

Table 4.1C Hydrocensus – Water related information

Map Nr	Collar Height (m)	Depth (m)	Date	Previous Water level (mbc)	Date	Time	Water level (mbc) 2017	Reported Yield (l/s)	Sampled (Yes/No)
MBH1	0.43	74			20170322	1057	7.52		Yes
MBH2	0.00	35.7	20070530	7.00	20170322	1105	5.23		No
MBH3		40			20170322				No
MBH4					20170322		8.68	0.28	No
MBH4R		100						2.50	No
MBH6	0.00	80	20070531	9.00	20170313	1500	11.55	0.28	Yes
MBH7	0.50	183			20170313			0.67	No
MBH8	0.00	110	20070531	42.30	20170313				No
MBH9					20170322				No
MBH10	0.34				20170322		80.56		No
MBH11			20070531	3.20	20170313				No
MBH12	0.14				20170314	1430	56.80	0.14	Yes
MBH13	0.24	20	20070531	30.00	20170314	1248	3.88	0.11	Yes
MBH14			20070531	5.00	20170320	1400			No
MBH15	0.40	80	20070531	6.00	20170314	1600	31.43	0.28	Yes
MBH16	0.40	100			20170314			5.56	No
MBH17	0.00	80	20070531	24	20170322	1330	5.85	2.78	Yes
MBH18		80	20070531	24	20170314	730		4.17	No
MBH18B	0.19				20170314	830	28.48	0.28	Yes
MBH19	0.34	115	20070531	20	20170322			5.00	No
MBH20	0.07	30			20170315	1145		0.69	Yes
MBH20A	0.20	30			20170315	1155		0.42	Yes
MBH20B	0.10	30			20170315	1210		0.69	Yes
MBH21		60			20170315	1244		2.22	No
MBH22	0.28	85	20071206	38.13	20170315	1044	39.10		No
MBH23	0.13	240			20170322		71.74		No
MBH24			20071206	10.04	20170320				No
MBH25	0.21				20170320	1436		0.56	Yes
MBH26			20071206	9.35	20170320				No
MBH27	0.23		20071206	8.05	20170322	1255	6.56		Yes
MBH28	0.17				20170322		1.14		No
MBH29	0.00				20170320	1100	11.26		Yes
MBH30	0.25	100			20170320	920		0.42	No
MBH31	0.14	65			20170320	1000		0.33	Yes
MBH32		55	20071206	30.00	20170314	745		5.56	Yes
MBH33		190			20170314	730		33.33	No
MBH34					20170314	730			No
MBH35	9.00	35			20170320	1330	27.21	0.28	Yes
MBH36A					20170320	1210		0.28	Yes
MBH36B	0.19				20170320	1150	15.41		No
MBH40	0.20	30			20170314	1400	3.33	2.78	Yes
MBH41	0.29	90			20170315	850	11.20	7.50	Yes
MBH42		85			20170315	900		4.44	No
MBH44	0.00				20170315	1300		0.69	No
MBH45	0.41	65			20170320	845	9.91	0.42	Yes
MBH46	0.38	110			20170320	1007	75.75	0.42	Yes
MBH47	0.19	130			20170320	1030	12.63	3.33	Yes
G37016	0.08	171	20050309	90.00	20170314	930	60.16	3.00	No
G37017	0.38	213	20010105	52.77	20170313	1200		30.00	No
G37018	0.07	188	20050309	46.03	20170313	1005	42.24	40.00	Yes
G37030		180	19960711	35.25	20170314	1505		8.00	No
KAM01	0.47	80	20090611	11.59	20170313	1045	11.48	11.05	Yes
KAM02		60	20091026	11.2	20170313			0.45	No
KGA14	0.19				20170313	900	11.80		Yes
KGA15	0.10				20170313	1545	10.41		Yes
KGA17	0.03	90			20170315				No
KGA17B	0.21	90			20170315				No
MAN-BH1		80	20140711	15.91	20170322			0.28	No
MBH48	0.27				20170823	1145	3.72		No
OC1					20170803				No

Table 4.1D Hydrocensus – Water related information

Map Nr	COMMENTS: P=People; LSU=Large Stock; SSU=Small Stock; D=Dairy; G=Garden; N=Nursery
MBH1	Not linked to reservoir, ave k = 0.02885m/d, contrasting yield 2.78l/s reported during 2007 census. Low yielding.
MBH2	Mine Office supply, meter reservoir in-take 630m^3, meter reservoir output 3650m^3, 4 x 5000L JoJo tanks, Abs rate roughly 0.34l/s.
MBH3	Not found, possibly destroyed.
MBH4	Trollop Mining water supply, pumping at 0.26l/s, 2 x 5000L JoJo Tanks, meter reading 5229m^3, pumping water level. Poor yielding capacity. Borehole replaced during November 2017.
MBH4R	Drilled 27/11/2017. Replaces MBH-4, equipment moved across. Solid casing = 36m. Water strike = 81-82mbs.
MBH6	Wire Factory (Draad Trek), Feed lot occasionally up to 3000 sheep, boreholes BH7, BH8 & BH11 not in use.
MBH7	Not in use.
MBH8	Not in use.
MBH9	No access, wet road overgrown.
MBH10	Old hole, with base plate. Not in use.
MBH11	Not in use.
MBH12	Supplies 2 households.
MBH13	Supplies 1 household, Hole collapsed from 50m to 20m.
MBH14	Destroyed.
MBH15	1 Household, 9 People.
MBH16	Need Permission from MORGAN BEEF for access (Tel: 013 688 9300).
MBH17	Two households on farmstead.
MBH18	Not in use, water turned brown.
MBH18B	Household use. Pumps backup water for chicken coops 5 x 20000L Tanks on standby.
MBH19	Abstraction yielding capacity down from 12,000L/hour to 3 000L/hour, pump to new chicken coups to the south.
MBH20	Sample combination of BH20, 20A, 20B.
MBH20A	BH20, 20A, 20B and BH21A. P =18, LSU = 300, SSU + 500.
MBH20B	
MBH21	No access, covered with heavy metal box.
MBH22	Abandoned farmhouse, open hole.
MBH23	Cosmo Farm. Pump to large irrigation dam, large diameter borehole, high yielding.
MBH24	Does not exist - Water to property is pumped from Morgan Beef (Tel: 013 688 9300).
MBH25	1 Household, LSU = 300.
MBH26	No access gate locked.
MBH27	Grab sample at 10m.
MBH28	Down gradient from dam wall.
MBH29	Brookefield Beef.
MBH30	Hole blocked, water for farm animals and goats (about 50).
MBH31	Household use, Sample taken from house across road.
MBH32	1 Household, LSU = 1000. No water level measurement- permission denied.
MBH33	Permission denied.
MBH34	Permission denied.
MBH35	1 Household, barn with chickens, 30 pigs.
MBH36A	1 Household, goats, horses. Sample tank overflow. Supply to house has water filtration system.
MBH36B	Unused.
MBH40	Supplies 1 household, 700 cattle, 300 sheep.
MBH41	Water for approximately 100 000 chickens.
MBH42	Supplies about 300 cattle and 40 people, backup for chicken houses. Bees. Alternative number KGA18.
MBH44	Louis Roussouw's brother in law.
MBH45	Use at workshop, 20 people.
MBH46	Sample from dam next to BH31, cattle 250.
MBH47	Ternus veekraal, 2 households, feedlot 2000 cattle.
G37016	Dept. Water & Sanitation monitoring borehole. Hole Blocked. Alternative number B2N0057.
G37017	Blocked. Alternative number B2N0075.
G37018	Dept. Water & Sanitation monitoring borehole. Grab sampled at 100m. Alternative number B2N0073.
G37030	Dept. Water & Sanitation monitoring borehole. Bees. Alternative number B2N0074.
KAM01	Observation borehole, grab sample at 75m.
KAM02	Wet road no access.
KGA14	Training facility for Universal Coal, old farmhouse, 1 permanent resident and up to 12 trainees during day.
KGA15	Okkie 071 678 3740. Previous resident might have more info on borehole.
KGA17	Previously used for agricultural irrigation [Mariwija Boerdery].
KGA17B	Previously used for agricultural irrigation, bees.
MAN-BH1	Overgrown, 2 x 5000L JoJo tanks, mine office supply, tillite 41m - 44m, water strike 49m - 50m 0.28l/s.
MBH48	Sealed borehole, old wind pump, stand and equipment removed.
OC1	Dolerite sill outcrop in intermittent stream, water ponding, baseflow rainy season.

The external users' borehole localities in relation to the Manungu reserve, the current as well as 30year LOM extension, depicted against a backdrop of the contoured residual gravity results pertaining to the recent geophysical survey, are presented in Figure 4.1. A photograph record of the external users' borehole is attached in Appendix I.

The survey of 59 points included four of the Department Water and Sanitation's (DWS) hydrostatic monitoring stations. Thirty-five boreholes were found to be in use for water supply. Water level measurements were recorded (28) ranging between 1m and 80m deep. The reported yielding capacities ranged between 0.11L/s and 40L/s. Borehole depths (48) were recorded ranging between 20m and 240m below surface (median of 80m). The average yielding capacity for the boreholes <80m in depth was 1.3L/s, while the average for the boreholes deeper than 80m was 8.5L/s. It is important to note that the information consisted of both shallow weathered Karoo aquifers, deep fractured Karoo aquifers as well as the underlying dolomitic aquifer. The more productive dolomitic aquifer areas are located ±2.8km north of the current Manungu mining area on Wolwefontein, as well as >2.2km west on Stompiesfontein and Strydpan (see gravimetric geophysical survey results).

A dolerite sill outcrop was surveyed in an intermittent stream on Portion 10 of the farm Welgevonden.

Groundwater samples (24) were submit to a water laboratory for water quality analyses.

DWS's Water Authorisation and Registration Management System (WARMS) information (2007) indicates one registered groundwater use volume of 90,200 m^3/annum as well as two surface water use registrations totalling 686,600m^3/annum for Weilaagte 271 IR (after Meyer, March 2014).

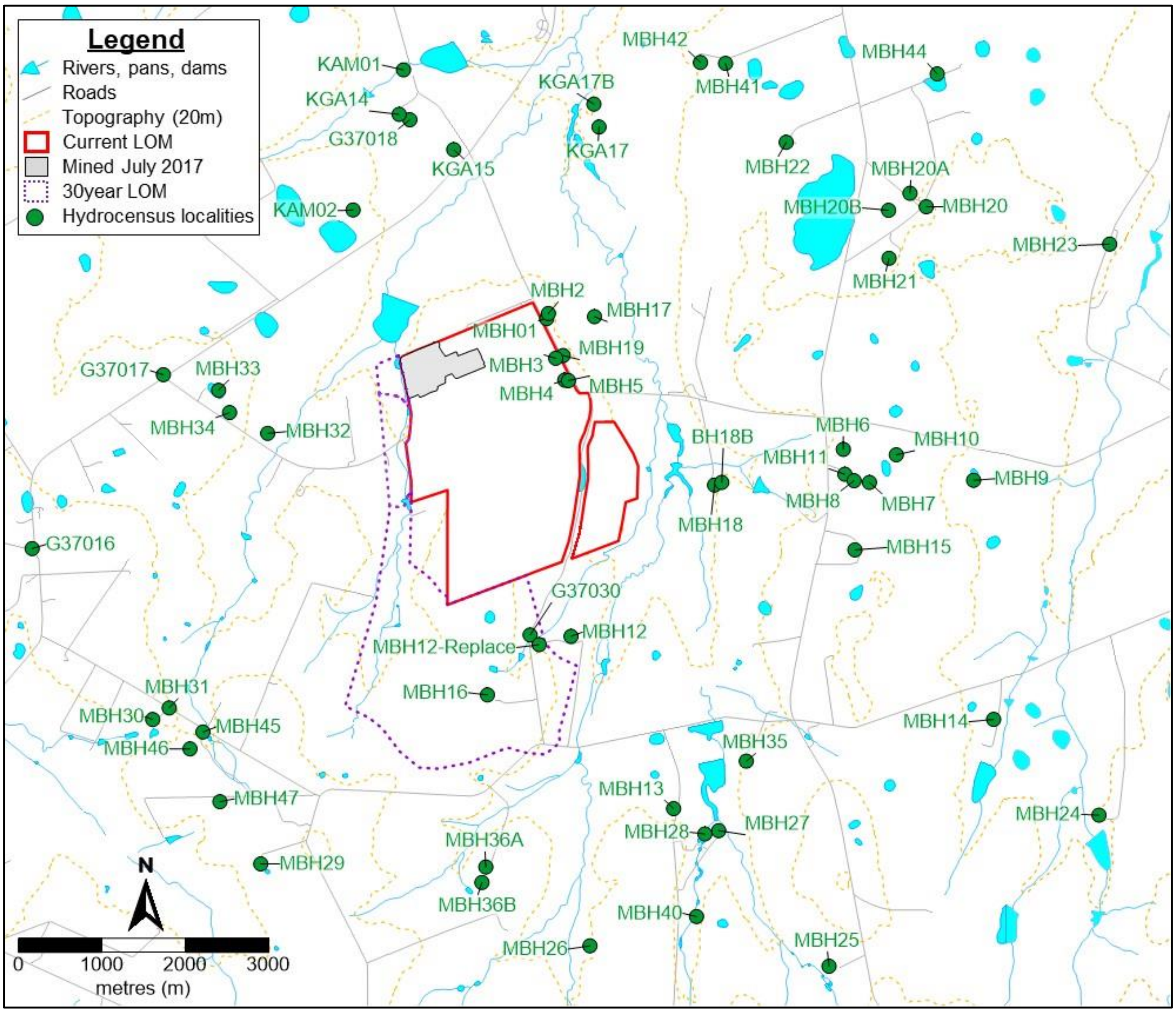


Figure 4.1 Hydrocensus localities

4.3. Geophysical Survey and Results

Existing information in the form of the interpretation of the June 2014 high resolution aeromagnetic and radiometric survey over the Welgevonden and Weilaagte reserve area (GAP Geophysics, August 2014) was sourced from the client.

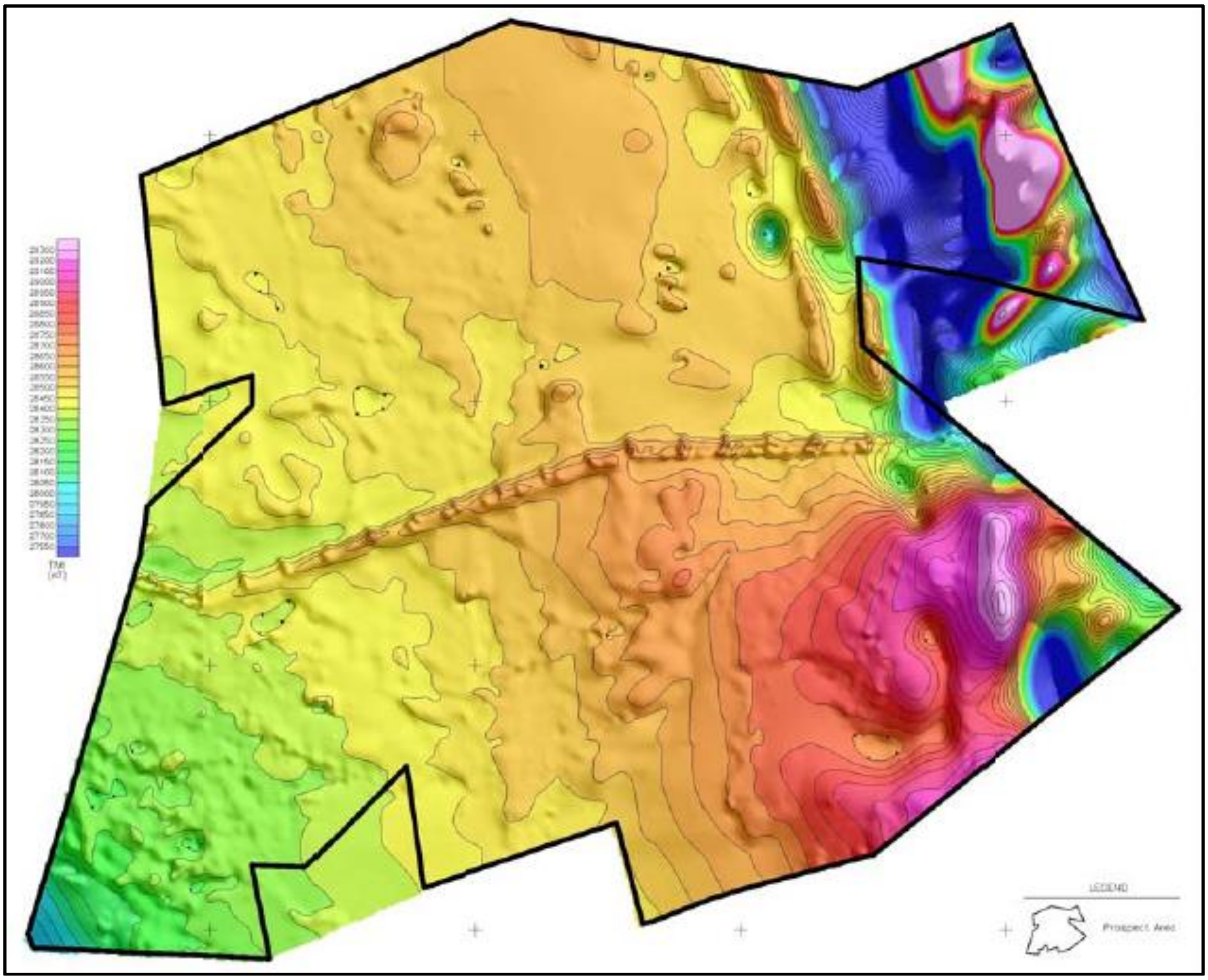


Figure 4.2 Total Magnetic Field Image (GAP Geophysics, August 2014)

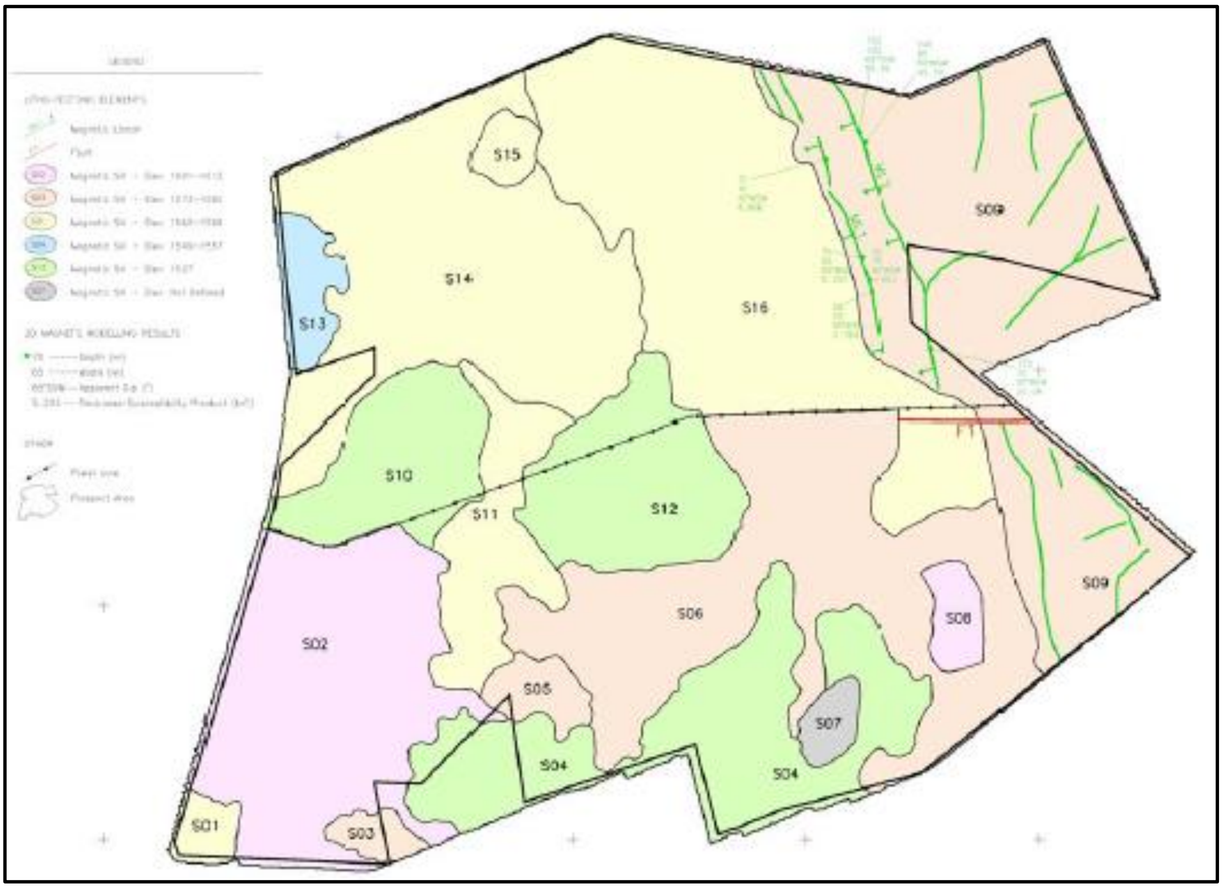


Figure 4.3 Geophysical Interpretation Map (GAP Geophysics, August 2014)

The airborne survey (Figures 4.2 & 4.3) indicated the Prospect Area to be underlain by up to 16 broad irregularly shaped dolerite sills at different depths. It is also stated that the prominent NS striking dyke-like magnetic anomaly responses in the eastern sector of the Prospect Area mask the near surface magnetic responses of the sills in the eastern sector. These are characterized by apparent dips within 35º of the vertical and apparent widths of 60m to 95m. An EW trending fault is interpreted based on the break in the dykes within the eastern sector.

As part of the Manungu Phase-1 groundwater study, a gravimetric geophysical survey (Figures 4.4 to 4.7) comprising a total of 310 stations were acquired along two north-south and four east-west profiles across the larger reserve area at 100m intervals (30.5 km). The survey results indicated a residual Bouguer gravity high around the centre of the surveyed area, roughly where the mayor NS and EW profiles intersect. The high extends across the existing mining area as well as the intended extension to the south. There is a significant drop-off to the extreme east (east of the R548, where the two prominent NS striking dyke-like magnetic anomaly responses [aeromagnetic survey] transect the R548), as well as to the far-west (Stompiesfontein & Strydpan).

The second Phase groundwater investigation (Manungu 30year LOM) started off with a Stratagem Magneto Telluric (AMT) geophysical traverse line along the boundary between the existing mining area and the proposed extension to the south which also corresponds with the major central EW gravity survey lined performed during the initial investigation.

The MT data correlated well with the displacement of the coal measures as indicated by the geological model around the southwestern part of the current mining area. Similar displacements were found to the west and further to the east.

Limited areas of more conductive zones are present at the base of the Karoo Sequence; and these appear to be structurally controlled. There does not appear to be a definable resistivity contrast correlation with the base of the Transvaal Sequence.

The broad conductive anomalies around Station 2800m and 3250m can be attributed to cultural effects, while the anomaly associated with Station 2650m were targeted for a replacement borehole for BH4 (see Section 4.2 & 4.3).

The available and newly commissioned geophysical survey reports are attached in Appendix II.

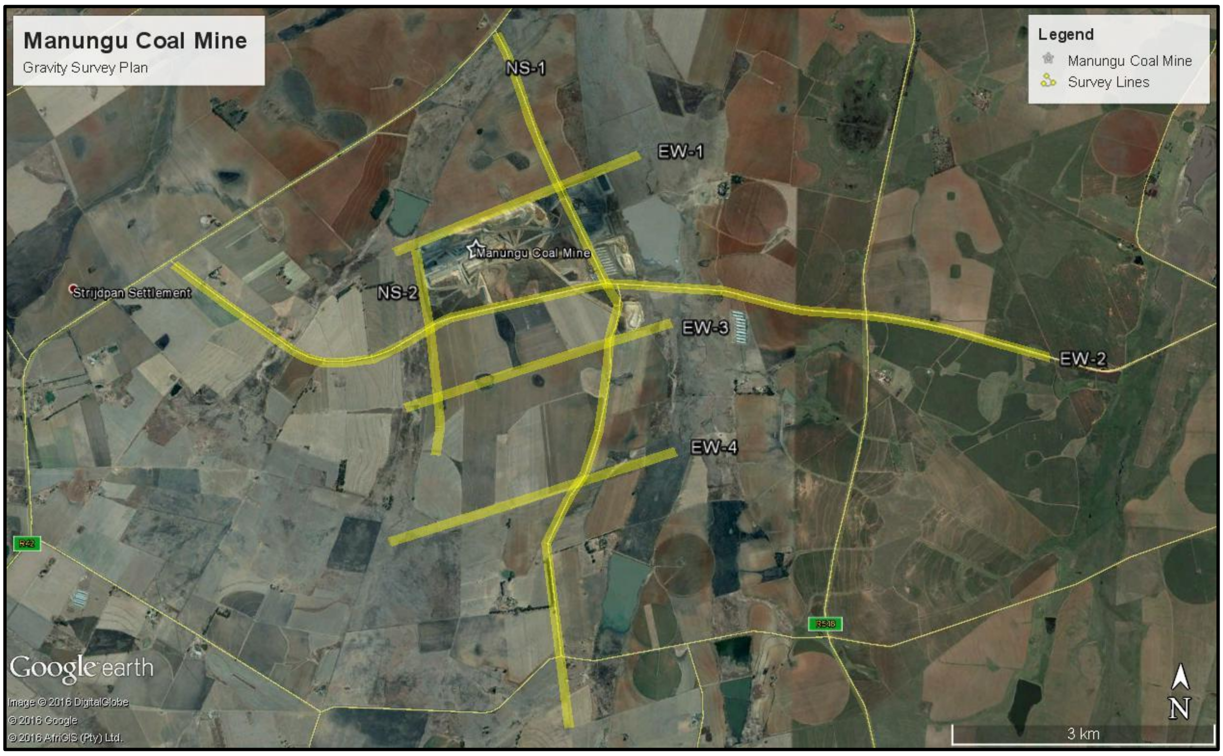


Figure 4.4 Gravity Survey Traverse Lines (GeoFocus, March 2017)

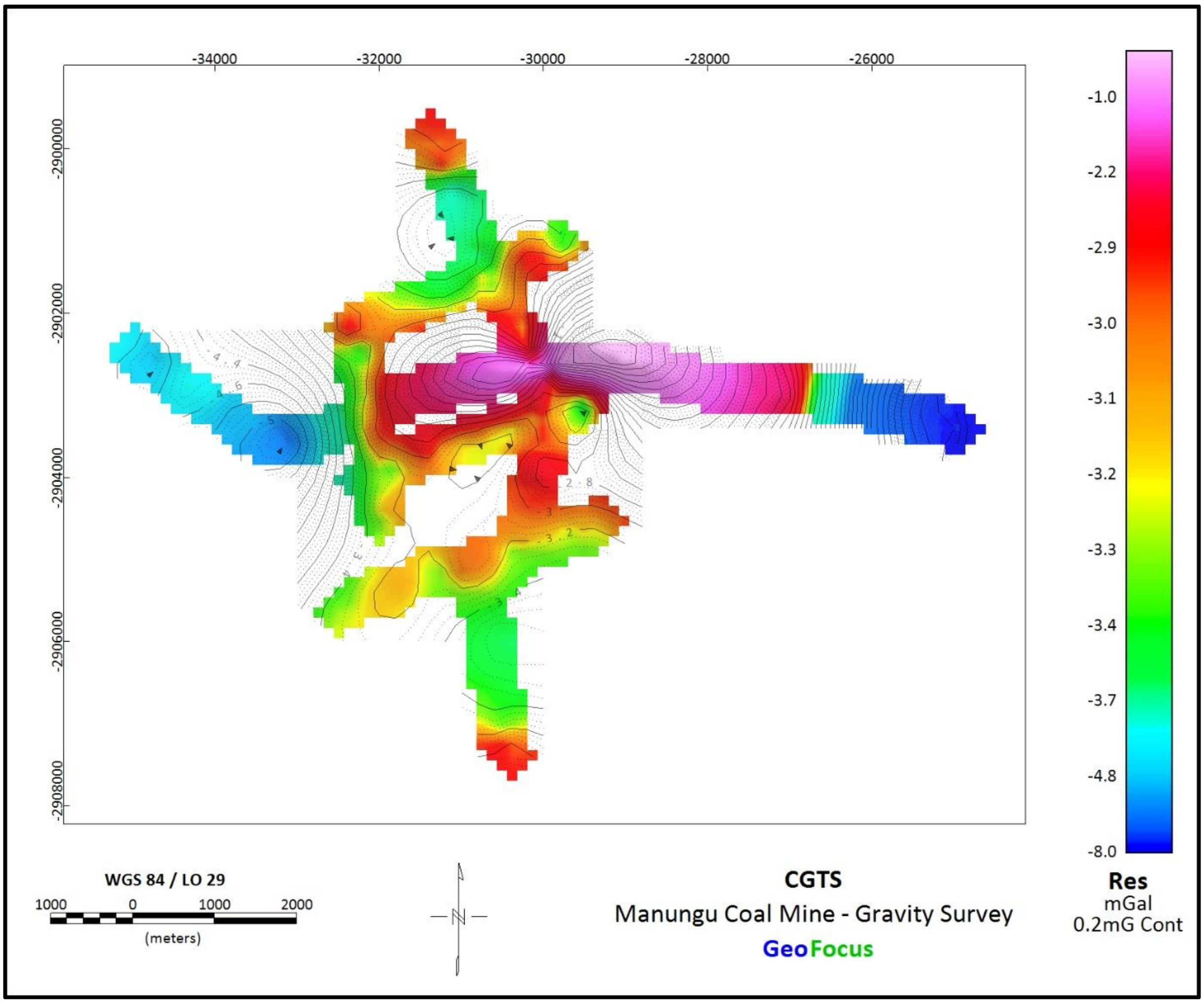


Figure 4.5 Residual Gravity Contour Map (GeoFocus, March 2017)

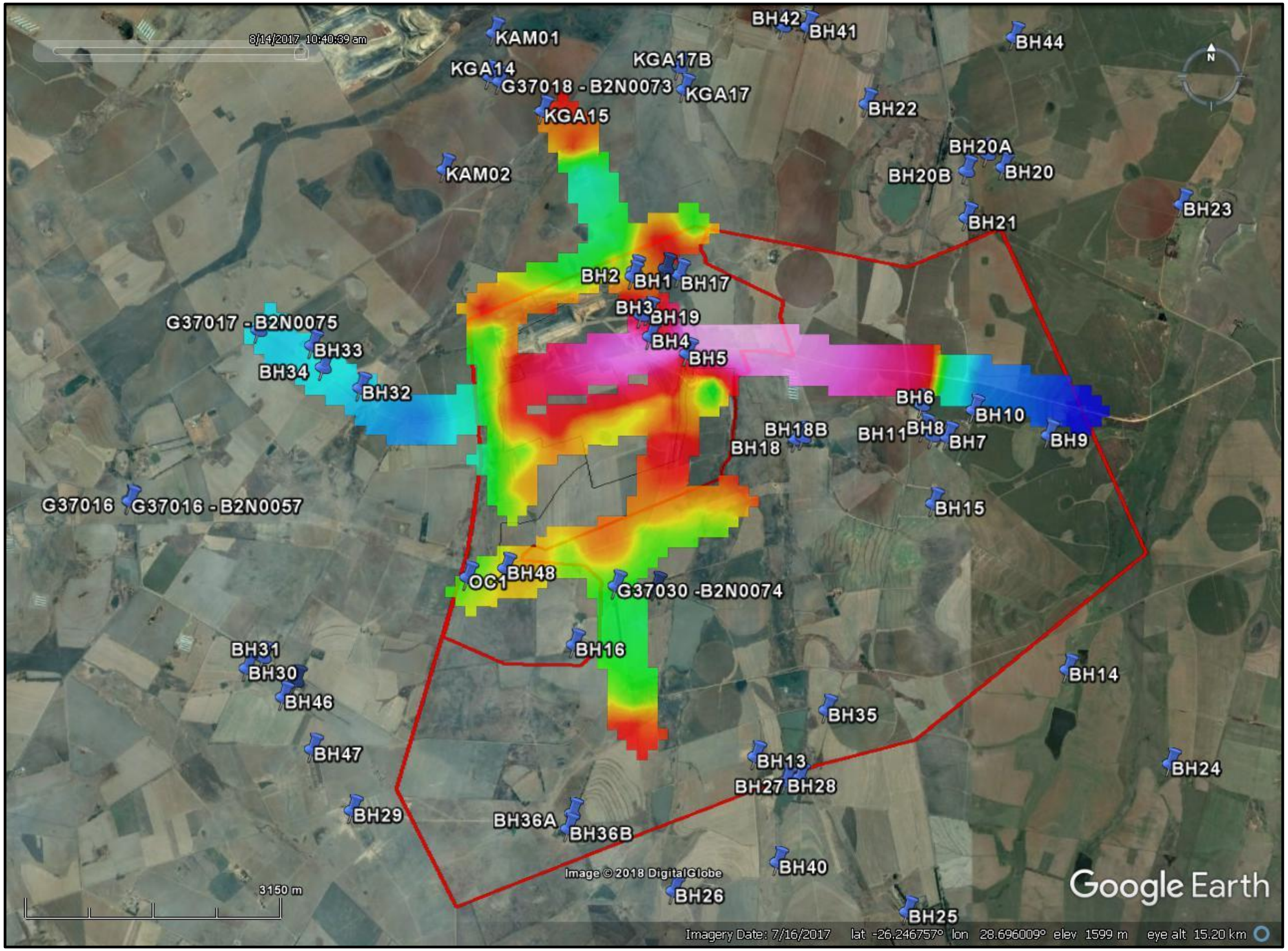


Figure 4.6 Google image with residual gravity overlay indicating external users' borehole localities

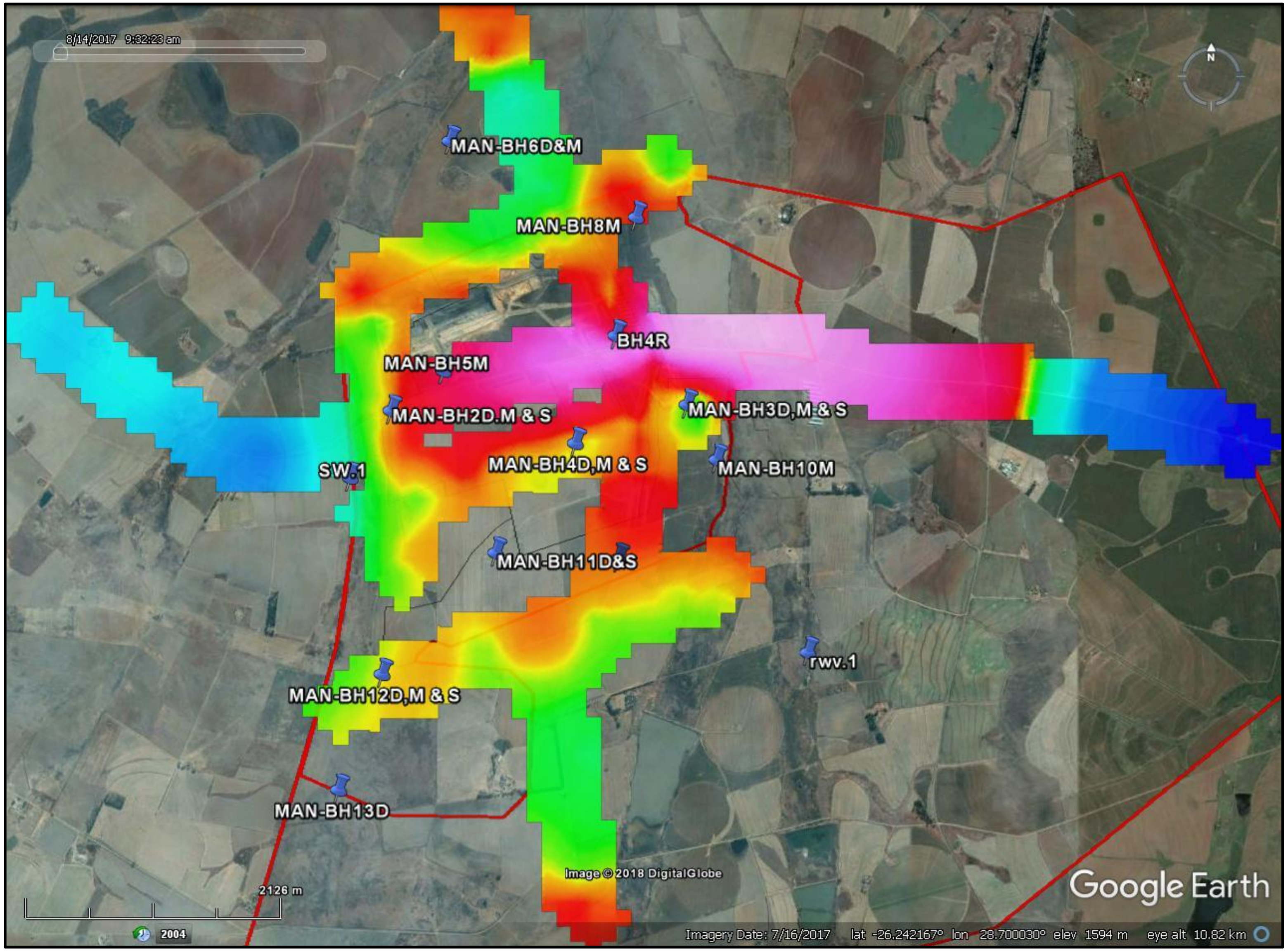


Figure 4.7 Google image with residual gravity overlay indicating geohydrological borehole localities

4.4. Drilling and Siting of Boreholes

In total, 8 "deep" (86m to 101m deep), 10x "medium" (26m to 35m deep) and 6x "shallow" boreholes (6m to 10m deep) were drilling during April and August 2017, as summarised in Tables 4.2A-B; and Figures 4.7 and 9.1.

Six drill sites, consisting of 13 holes were drilled during April 2017 for the first groundwater impact assessment. Borehole locations were based on the geophysical information and the original 18year mine plan.

A further 7 drill sites, consisting of 12 more holes were drilled during July-August 2017 for the Phase-2 groundwater impact assessment. The sites were based on the existing and newly commissioned geophysical (AMT) results, the Phase-1 drilling experience and latest 30year LOM.

MAN-BH2D, 2M&S were sited between the flanking intermittent stream and the western extent of the opencast section planned for April 2022–April 2023 along the edge of the gravity high across the 18year mine plan area, some 290m west of a displacement of the coal measures. This displacement coincides with the boundary between identified dolerite sills S13 and S14 in Figure 4.3. The placement also coincides with the central eastern boundary of the Underground West 30year LOM extension section. MAN-BH2D was drilled to a depth of 101m below surface during the first phase of drilling. A water intersection of 1.09L/s was recorded between 71m-72m (Dwyka – mostly angular chert fractions with Karoo fractions), as well as 0.26L/s between 90m-92m (upper dolerite sill contact, below Dwyka – mostly chert with Karoo fractions), cumulating in a total blow yield of 1.35L/s. The borehole was drilled deeper to an end-of-hole depth of 175m below surface during the second phase of drilling. Dolomite was intersected between sill intrusions at the base of the Karoo sequence (Dwyka – chert with Karoo fractions) at depths of 106m-107m, 136m-156m, 164m-165m and 170m-175m. No additional water intersections were recorded.

An old gold mining exploration borehole (SW.1) located some 600m southwest of MAN-BH2D indicated the base of the Karoo Sequence at a depth of 64m (Figure 4.7). The base of the Transvaal Sequence represented by the Black Reef is indicated at a depth of 242m.

Table 4.2A Pertinent hydrogeological information – physical borehole parameters

Site Name	WGS84 LO29			End of hole (m)	Collar Height (m)	Water Level (m)	Sampling Horizon (m)
	Latitude	Longitude	Elevation (mamsl)				
MAN-BH2D	26.237200	28.679010	1592	175	0.50	34.40	88
MAN-BH2M	26.237160	28.679010	1590	41	0.55	3.54	23
MAN-BH2S	26.237130	28.679020	1590	10	0.57	3.03	5
MAN-BH3D	26.236750	28.703780	1580	100	0.27	26.01	71
MAN-BH3M	26.236730	28.703790	1580	30	0.32	4.18	15
MAN-BH3S	26.236690	28.703820	1580	10	0.3	3.99	7
MAN-BH4D	26.239650	28.694450	1595	90	0.32	28.1	67
MAN-BH4M	26.239630	28.694490	1595	41	0.28	7.23	25
MAN-BH4S	26.239600	28.694530	1596	10	0.24	6.4	8
MAN-BH5M	26.234210	28.683400	1597	40	0.36	4.43	32
MAN-BH6D	26.216920	28.683900	1572	91	0.3	32.6	75
MAN-BH6M	26.216880	28.683880	1572	40	0.42	5.15	30
MAN-BH7M	26.243110	28.682930	1597	36	0.27	6.53	25
MAN-BH8M	26.222640	28.699540	1570	31	0.61	2.77	15
MAN-BH9D	26.248280	28.698050	1593	96	0.43	43.84	66
MAN-BH9M	26.248340	28.698050	1593	46	0.58	8.23	30
MAN-BH9S	26.248370	28.698050	1593	10	0.53	7.82	8.5
MAN-BH10M	26.240870	28.706280	1577	26	0.47	5.23	17
MAN-BH11D	26.247860	28.687810	1606	86	0.46	36	71
MAN-BH11S	26.247850	28.687830	1606	7	0.52	4.18	5.5
MAN-BH12D	26.256870	28.678330	1596	86	0.73	41.17	59
MAN-BH12M	26.256880	28.678300	1596	40	0.75	4.11	28
MAN-BH12S	26.256850	28.678270	1596	7	0.74	3.5	5
MAN-BH13D	26.265620	28.674660	1602	86	0.70	52.22	78

MAN-BH2M recorded water seepage after casing installation as well as between 24-30m. Although the seepage wasn't enough for dust suppression, a final blow yield of 0.125L/s were nevertheless recorded.

MAN-BH3D, 3M&S were sited along the gradient of a small gravity low around the toe of the current overburden (softs) stockpile, just within the northeastern extent of the opencast section planned for the 30year LOM extension, between the dump and the wetland associated with the eastern flanking stream. The roof of the Dwyka Tillite Formation was intersected 20m below surface. Leucocratic, tonelite sill intersections were recorded between 41-64m and 66-73m below surface, followed by interbedded black shale and siliceous quartzite down to a depth of 100m below surface. The placement of this borehole is near, and west of the Black Reef's sub-outcrop (after Button, February 1969) along the western flank of the Winterhoek anticline, indicated to basically coincide with the flanking stream locally. A distinct correlation exists between the lithologies intersected at the base of both MAN-BH3D and the water supply borehole (MAN-BH1) commissioned during 2014, which is located some 1.5km to the northwest, also near west of said outcrop.

A falling head test was performed on MAN-BH3D during drilling. The test section (26m-41m) in borehole MAN-BH3D featured the contact between the Dwyka Tillite Formation and a tonelite sill intrusion.

Table 4.2B Pertinent hydrogeological information – physical and hydraulic parameters

Site Name	Water strike		Lithological Intersections						
	Depth (m)	Yield (L/s)	OBDN (m)	LOW (m)	Coal (m)	Dwyka Roof (m)	Chert Breccia (m)	Dolomite (m)	Intrusions (m)
MAN-BH2D	71-72 90-96	1.09 0.26	5	23	23-24 46-63	63	68-90	106-107 136-156 164-165 170-175	90-101 (D) 101-105 (D) 107-136 (T) 157-163 (T) 165-170 (D)
MAN-BH2M	12-30	0.125	6	24	23-24				
MAN-BH2S			6						
MAN-BH3D	21-22	0.10	11	17	17-20	20			41-64 (T) 66-73 (T)
MAN-BH3M	21-22	0.10	11	17	17-20	21			
MAN-BH3S			10						
MAN-BH4D	25-30	1.45	5	30	43-52	52	56-65		11-13 (D) 20-34.5 (D) 65-90 (T)
MAN-BH4M	23-30	0.77	5	30					
MAN-BH4S			5						
MAN-BH5M			4	27	22-23				32-40 (D)
MAN-BH6D	8.5-16 34-40 64-66 73-75	3.40 0.46 3.01 2.50	6	26	29-31 34-40 42-47	47	65-77		6-25.5 (D) 77-91 (T)
MAN-BH6M	8.5-16	3.40	6	27	29-31 34-40				6-25.5 (D)
MAN-BH7M			6	25	22-23				30-36 (D)
MAN-BH8M			6	15	11-14	15			
MAN-BH9D	30-31 66-67	0.11 1.40	6	30	36-41 66-67	42	47-48	96	6-17 (D) 61-96 (T)
MAN-BH9M	30-31	0.11	6	30	39-43	45			4-18 (D)
MAN-BH9S			6						6-10 (D)
MAN-BH10M	11-17	0.10	7	17	11-17	17			
MAN-BH11D	68-71	2.50	7	31	27-28 48-54	54	64-78	78-80	80-86 (D)
MAN-BH11S			7						
MAN-BH12D			3	28	41-42 56-76	79	82-86		
MAN-BH12M			3	28	41-42				
MAN-BH12S			3						
MAN-BH13D	17-18	1.05	1	18	44-45 58-59 65-78	81	83-86		

* (D=Dolerite; T=Tonelite)

MAN-BH4D,4M&S were sited along the gradient of the central gravity high across the 18year mine plan area's eastern opencast section planned for April 2028–April 2029. Both the deep and medium boreholes featured dolerite intersections between 11-13m and 20-34.5m below surface. Respective water makes of 1.45L/s and 0.77L/s, associated with the lower, weathered, fractured dolerite sill, were

recorded 23-30m below surface. The roof of the Dwyka Tillite Formation was intersected 52m below surface. Between 56-65m the intersection consisted mostly out of chert, followed by a tonelite sill intersection to the base of the borehole at 90m below surface. The upper portion of the sill was noted to be leucocratic. The water strike in the deep hole was cut-off with 36m solid casing installed with a bentonite plug. The final blow yield recorded in the deep borehole was <0.1L/s.
A falling head test was also performed on MAN-BH4D during drilling. The test section (36m-61m) in borehole MAN-BH4D featured the contact between the Vryheid and Dwyka Tillite Formations with the latter consisting mostly of chert below 56m.

MAN-BH5M was drilled across the 18year mine plan area's central opencast section planned for April 2023–April 2024, north of the dirt road between the R42 and the R548, some 200m south of the exiting pit's first bench, as well as some 300m east of the already mentioned displacement of the coal measures. A thin coal intersection was recorded 22-23m below surface, while a dolerite sill was intersected 32m below surface. The borehole was terminated in dolerite at a depth of 40m below surface.

MAN-BH6D and MAN-BH6M were sited across a broad, minor gravity low north of the exiting opencast pit, between the pit and the R42. MAN-BH6D recorded water intersections of 3.01L/s between 64m-66m (chert breccia with carbonaceous shale), as well as 2.50L/s between 73m-75m (fractured chert breccia), with a total blow yield of >5.00L/s. The roof of the Dwyka Tillite Formation was intersected 47m below surface.

Chert breccia was intersected 65-77m below surface, above a tonalite sill intrusion. The hole was terminated in tonalite at a depth of 91m below surface.

MAN-BH6M recorded a water strike of 3.4L/s between 8.5m-16m relating to a (weathered fractured) dolerite sill intersection 6-25.5m below surface. Although the same water make was encountered in MAN-BH6D, it was cased-off with 41m solid steel casing and a bentonite plug.

XRF & XRD samples were collected from MAN-BH3D (55m-56m & 86-87m), MAN-BH4D (75m-76m) and MAN-BH6D (77m-86m). The sill intrusions intersected at the base of the Karoo Sequence and the upper part of the Malmani Subgroup plot as tonalite, using the QAPF or "Quartz, Alkali feldspar, Plagioclase, Feldspathoid (Foid)" diagram of Streckeisen (1973 and 1976), an igneous, plutonic (intrusive) rock of felsic composition, with phaneritic texture. Feldspar is present as plagioclase (typically oligoclase or andesine) with 10% or less alkali feldspar. Quartz is present as more than 20% of the rock.

MAN-BH7M was sited along a gravity gradient along the 18year mine plan area's central, eastern opencast section planned for April 2029 – April 2030. A dolerite intersection was recorded across the last 6m of this 36m deep borehole. No water intersections were recorded.

MAN-8M was sited some 120m north of MAN-BH1 close to the south-eastern corner of the current PCD, below the coal loadout facility. Dwyka tillite with chert fractions were intersected 15-16m below surface above soft, light olive brown, weathered shale. Rocks of the West Rand Group's Hopsital Hill Subgroup is indicated to outcrop to the near east of this borehole.

The placement of MAN-BH9D, 9M&S coincides with the larger gravity high's south-eastern gradient as well as the central area of the opencast section planned for the 30year LOM extension. MAN-BH9D intersected some dolomite along the lower contact of a tonalite sill intersected 61-96m below surface. The hole has been re-drilled on 28/8/2017. Unlike the original borehole, this hole, drilled 9m away, recorded a water strike of 1.40L/s at a depth of 67m below surface, associated with the upper part of the tonalite sill intersected. The Dwyka Tillite Formation (tillite with chert fractions) was intersected between 42m to >60m below surface.

Both borehole MAN-BH9M and 9D intersected a water make of 0.11L/s 30-31m below surface, although this water make was cased-off in the deep hole with 48m solid steel casing and a bentonite plug.

MAN-BH10M was sited close to the eastern flanking stream, some 530m south-southeast of the MAN-BH3D, 3M&S placement, also within the north-eastern extent of the opencast section planned for the 30year LOM extension. A water intersection of some 0.10L/s were encounter along the coal measures intersected above the Dwyka Tillite Formation between 11m-17m below surface.

MAN-BH11D&S were sited across the western part of the opencast section planned for the 30year LOM extension. Borehole MAN-BH11D intersected dolomite between 78m-80m below surface, below chert breccia at the base of the Karoo sequence (64m-78m); and a sill intrusion intersected between 80m and the end-of-hole at 86m. A water strike of 2.51L/s was recorded in the chert between 68m-71m.
The placement of MAN-BH12D, 12M&S coincides with the boundary between the western extent of the opencast section and the Eskom Underground section planned for the 30year LOM extension. It is also located along the south-western gradient of the lager gravity high. MAN-BH12D intersected the roof of

the Dwyka Tillite Formation some 79m below surface. The samples pertaining to the last 5m's drilled up to the end of the hole, consisted largely of chert. No water intersections were encountered.

The placement of MAN-BH13D coincides with the boundary between the western extent of the opencast section and the Eskom Underground section planned for the 30year LOM extension. Man-BH12D intersected the roof of the Dwyka Tillite Formation some 81m below surface. The samples pertaining to the last 3m's drilled up to the end of the hole, consisted solely of chert. No water intersections were encountered. A water strike of 1.05L/s was intersected 17-18m below surface, although this water make was cased-off with 42m solid steel casing and a bentonite plug.

Geochemical samples (79) were collected during drilling for ABA analyses and an additional 10kg ROM sample was collected on 03/08/2017.

The water columns in the boreholes were EC-profiled and sampled after a two-week resting period. A sample of the PCD dam was also collected and submitted to a water laboratory together with the borehole samples.

Slug tests were performed on all the boreholes except borehole MAN-BH6D. The bentonite seal in this borehole (cased to 41m) was not effective and water leaking from the upper part of this borehole was falling down the hole.

During the end of November 2017, BH4, the Trollop Mining water supply borehole was replaced. The replacement borehole (BH4R – 26.23156 28.69783) was sited along Station 2650 of the AMT traverse performed during August 2017. A dolerite sill was reported to be intersected 34-81m below surface. A water strike of 2.50L/s was intersected along the lower contact of this sill with the underlying dolomite.

The Borehole Construction and Geological Log Reports are attached in Appendix III.

4.5. Aquifer Testing

Four of the newly commissioned boreholes were pump tested between June and November 2017.

The data obtained from the pumping tests was analysed using the Flow Characteristic Method (FC Method). This program was developed by the Institute for Groundwater Studies at the University of the Free State, Bloemfontein, South Africa. The program evaluates the sustainable yield of a borehole using derivatives, boundary information, error propagation and influence of other boreholes. It is important to keep in mind that the program simulates a 2-year abstraction scenario, using a zero-recharge rate. In other words, abstraction is calculated but no groundwater recharge from rainfall is factored in. The program is therefore conservative in its recommended abstraction rates. Other hydraulic parameters were determined with Aquifer Test software.

The sustainable safe abstraction rates and abstraction recommendations are summarized in Table 4.3. The Pumping Test Analysis Reports are attached in Appendix IV, and interpretations in Tables 4.4&4.5.

A calibration yield of 3.04L/s was determined for MAN-BH2D (101m deep, before drilled deeper during the second phase drilling program) at the end of the fourth step test. The constant discharge test was performed at an abstraction rate of 1.2L/s, resulting in a drawdown of 41.89m. A slow 70% recovery was achieved after 24 hours. No reaction was observed in boreholes MAN-BH2M and MAN-BH2S during the test. An average transmissivity (T) value of 1.78m^2/day was determined for this borehole. A sustainable safe yield of 0.20L/s (24 hours/day) was determined for this borehole. The recommended sustainable long-term abstraction rate for this borehole is 0.35L/s (1.260m^3/h) for a maximum of 8 hours/day (10.080m^3/day).

A calibration yield of 7.00L/s was recorded for MAN-BH6D at the end of the third step test. The constant discharge test was performed at an abstraction rate of 5.00L/s resulting in a drawdown of 34.66m. A 53% recovery was achieved after 24 hours. The extremely low rate of recovery continued, such that an 86% recovery was achieved only after 165 hours. No drawdown was observed in borehole MAN-BH6M during the test. An average T value of 9.40m^2/day was determined for this borehole. A sustainable safe yield of 0.85L/s (24 hours/day) was determined for this borehole. The recommended sustainable long-term abstraction rate for this borehole is 1.47L/s (3.060m^3/hr) for a maximum of 8 hours/day (24.480m^3/d).

A calibration yield of 2.60L/s was recorded for MAN-BH11D at the end of the fourth step test. The 24-hour constant discharge test was performed at an abstraction rate of 1.60L/s, resulting in a drawdown of 24.10m. A 63% recovery was achieved after 24 hours. The extremely low rate of recovery continued, and 84% recovery was achieved only after 192 hours. No drawdowns were observed in neighbouring shallow and deep boreholes MAN-BH11S and MAN-BH9D (collapsed – before re-drill) during the test.

An average transimissivity (T) value of 4.9m²/d was determined for this borehole. A sustainable safe yield of 0.35L/s (24 hours/day) was determined for this borehole. The recommended sustainable long-term abstraction rate for this borehole is 0.61L/s (2.2m³/hr) for a maximum of 8hours/day (17.568m³/d).

A calibration yield of 2.66L/s was recorded for MAN-BH9D (re-drill) at the end of the fourth step test. The 12-hour constant discharge test was performed at an abstraction rate of 1.6L/s, resulting in a drawdown of 13.23m. A 92.1% recovery was achieved after 12hr. No drawdowns were observed in boreholes MAN-BH9M and MAN-BH9S. An average T value of 6.1m²/d and a sustainable safe yield of 0.60L/s (24 hr/d) was determined for this borehole. The recommended sustainable long-term abstraction rate for this borehole is 1.04L/s (3.7m³/hr) for a maximum of 8 hours/day (29.952m³/d).

Water samples were collected from each of the tested boreholes towards the end of the constant discharge tests.

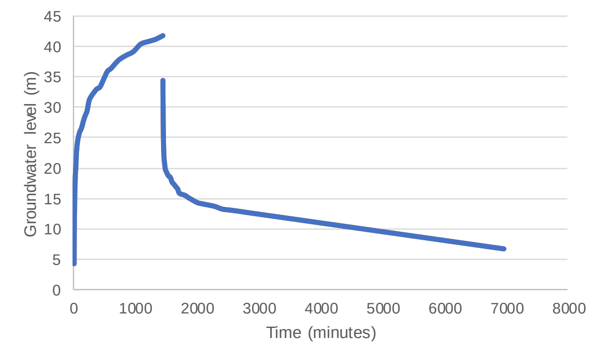
Table 4.3 Sustainable safe yields & abstraction recommendations

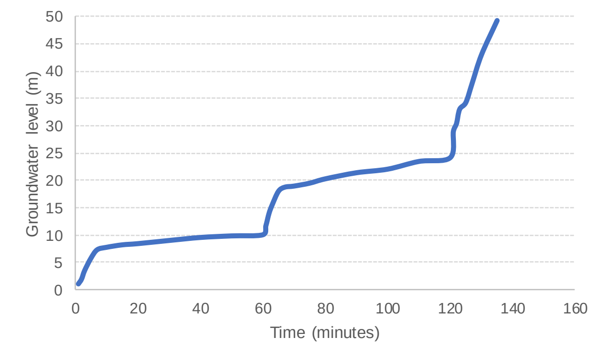
Borehole ID	AD used Specified Maximum Drawdown (m)	Sustainable Safe Yield 24hr/day (L/s)	Abstraction Schedule (hours/day)	Abstraction Rate (L/s)	Abstraction Rate (m³/day)	Installation Depth (m)
MAN-BH2D	35	0.20	8	0.35	10.080	91
MAN-BH6D	30	0.85	8	1.47	24.480	70
MAN-BH9D	17.1	0.60	8	1.04	29.952	64
MAN-BH11D	29.4	0.35	8	0.61	17.568	66

Table 4.4 Pumping test and step test results

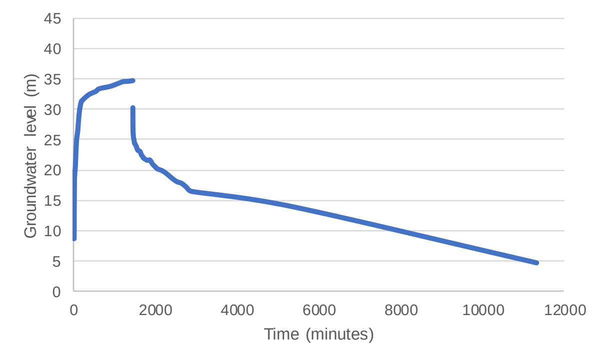
Pumping Test | **Step Test**

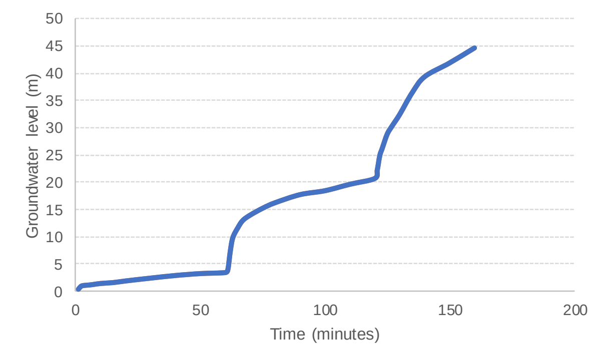
MAN-BH2D



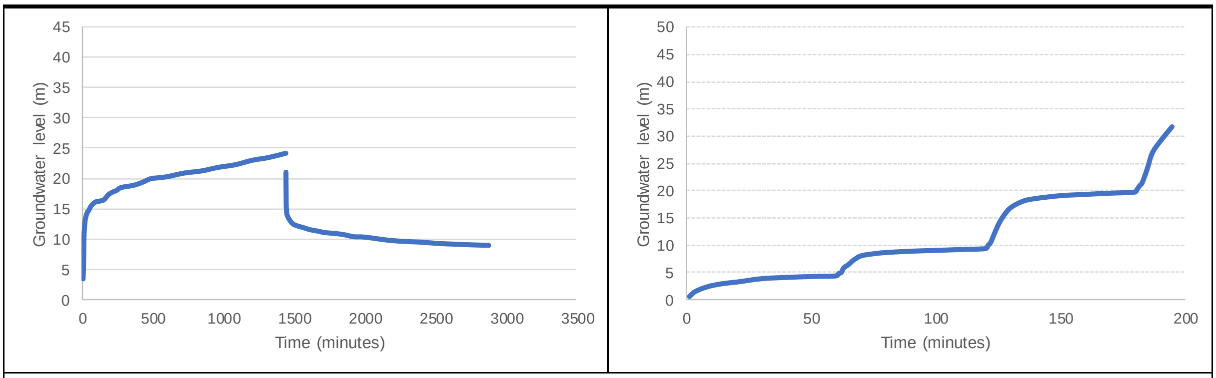


MAN-BH6D





MAN-BH11D



MAN-BH9D

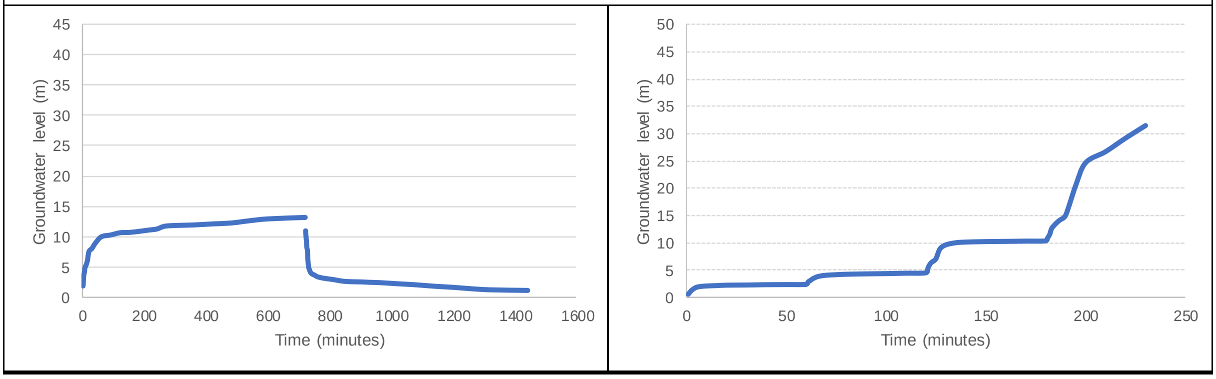


Table 4.5 Summary pumping test analyses

Borehole Number	Drilling information		Slug test hydraulic conductivity (m/d)	Pumping test interpretation		
	Depth (m)	Water-strike		Transmissivity (m^2/d)	Hydraulic conductivity (m/d)	Sustainable yield (L/s)
MAN-BH2D	90.64	71m-72m deep; yielding 1.2L/s	0.068	1.78	0.057	0.20
MAN-BH6D	89.60	63m-66m and 73m-75m deep; yielding 5.0L/s	0.190	9.4	0.26	0.85
MAN-BH11D	87	68m-71m deep; yielding 1.61L/s	0.160	4.9	0.14	0.35
MAN-BH9D	96	66m-67m deep; yielding 1.8L/s	0.024	6.1	0.22	0.60

4.6. Sampling and Chemical Analysis

Groundwater samples (24) taken during the 2017 hydro-census revisit were submitted to Yanka Laboratory for water quality analyses during March 2017.

The water columns in the newly commissioned boreholes were EC-profiled and sampled after a two-week resting period during both phases of drilling. A sample of the PCD dam was also collected during the Phase-1 investigation. The samples were submitted to Yanka Laboratory for water quality analyses towards the end of May 2017 (12) and (11) August 2017. MAN-BH9D was re-drilled towards the end of August 2017. The borehole was EC-profiled and sampled after a two-week resting period and the sampled submitted to Yanks Laboratory during mid-September 2017.

Water samples (4) were also collected from each of the aquifer tested boreholes towards the end of the constant discharge tests performed on them.

The hydro-chemistry results are discussed in Section 5.6.

4.7. Groundwater Recharge Calculations

Recharge values were based on the following:

- Previous hydrogeological assessments in the surrounding coal fields served as a guide for potential recharge, taking cognisance of the specific topographical setting, geological setting;

- The numerical groundwater flow model was calibrated for rainfall recharge of ±2% of MAP (=14mm/a =3.8x10 5m/d), which agrees with hydrogeological assessments in the surrounding coal fields;
- The numerical groundwater flow model was calibrated through simulating observed groundwater levels through the optimum combination of rainfall recharge and aquifer hydraulic conductivity;
- Recharge values are summarised in Section 7.6;
- Rainfall recharge is expected to be in the order of:
  - For rehabilitated mining areas, 12%.

4.8. Groundwater Modelling

The Phase-1 opencast pit (of ±448ha) predominantly targets the Seam-2 over a mining period of 18years till 2033, as depicted in Figures 1.1 and 1.2. A Box-cut was constructed along the north-western perimeter of the opencast. Mining is progressing eastwards, as indicated in Figure 1.2. After the whole west-east strip has been mined, mining will continue to the south in west-east strips.

The following approaches were used in the evaluation of the potential impacts:

- The FEFLOW Finite Element Numerical Groundwater Modelling software package developed by WASY Institute for Water Research Planning in Berlin, Germany, was used to calculate the extent of dewatering, water balance, likely decant volumes and associated contamination plumes:
  - The model domain (depicted in Figure 2.1), consists of 9 layers and 2.1 million mesh elements to accommodate the geometry of the aquifers and coal seams;
  - Seam-2 constituted the bottom of model Layer-4;
  - The cross-sections discussed in Section 7.3 provides an explanation of the aquifer geometry (e.g. depths/elevations of Seam-2 in relation to aquifers);
- Model parameters are listed in Tables 7.1(A-B) and 7.2(A-B);
- Boundary conditions are discussed in Section 7.2;
- The extent of the model grid and cell size (minimum 10m) are believed to be sufficient for the purpose of the groundwater impact assessment;
- Steady state groundwater flow modelling was employed to assess pre-mining and post-mining groundwater flow;
- Transient flow modelling was performed to determine:
  - Groundwater base-flow volumes during mining/operation and post-mining;
  - Dewatering impact zone;
  - Time to decant;
  - Contamination movement;
- Water balance calculations took cognisance of groundwater base-flow/inflow and rainfall recharge;
- Several spreadsheet calculations were performed in support of the numerical model calculations.

Modelling scenarios in Section 7 evaluated the above-mentioned considerations.

4.9. Groundwater Availability Assessment

With reference to DWAF's map: Groundwater Resources of the Republic of South Africa, Sheet 1 & 2, 1995, the following:

- Sheet 1 indicates the nature of the water-bearing rock to be compact arenaceous and argillacecous strata. The lithostratigraphy of the water-bearing rock is indicated as the Ecca Group: shale, sandstone; intruded by dolerite dykes and sheets;
  - The probability of drilling a successful borehole (Accessibility) is indicated as ranging between 40 and 60%. A borehole is deemed successful if upon completion it yields more than 0.1 l/s
  - The probability of drilling a successful borehole, yielding more than 2L/s (Exploitability) is indicated as 20–30%;
- Sheet 2 describes the saturated interstice (storage medium) / aquifer as pores in disintegrated / decomposed, partly decomposed rocks and fractures which are principally restricted to a zone below the ground water table. In fresh rock, water bearing fractures are comparatively sparse. The storage coefficient (order of magnitude only) is indicated as 0.001 to 0.01.

According to the explanation of DWAF's 1: 500 000 Hydrogeological map series of the Republic of South Africa, Sheet 2526 Johannesburg (H. C. Barnard, Oct 2000) the following:

- The groundwater yielding potential for the Vryheid Formation (intergranular & fractured aquifer type -506 records) including intrusive dolerite (intergranular & fractured aquifer type) is classed as low on the basis that 83% of the boreholes on record produce less than 2L/s, while 31.2% range between 2L/s and 5L/s and 6.3% produce more than 5L/s;
  - The map indicates the borehole yield class (median L/s - excluding dry boreholes) the area as ranging between 0.10 and 0.50L/s;
  - The groundwater rest level is generally encountered between 5m and 25m below surface;
- The Dwyka Tillite Formation (34 records - intergranular & fractured aquifer type) comprises glacial deposits (tillite). The permeability of fresh tillite is generally and widely considered as being very low. The groundwater yielding potential is classed as low on the basis that 76% of the boreholes on record produce less than 2L/s, while 23.5% range between 2L/s and 5L/s and 0% more than 5L/s.

Of the 12 newly commissioned drill sites, 6 boreholes intersected water within the shallow weathered zone aquifer, indicating an "Accessibility" of 50%. Only one borehole recorded a water strike more than 2L/s, indicating an "Exploitability" of <10%:

- Two of the larger water intersections were associated with dolerite sill intrusions. The average blow yield of the individual water intersections recorded calculates to 0.93L/s, while the median calculates to 0.45L/s. Taking the two water strikes associated with the dolerite sill intrusions out of the equation, the average comes down to 0.35L/s.

Drilling (including MAN-BH1 and BH4R) indicated an "Accessibility" of >60 for the deep fractured aquifer. An "Exploitability" of <30% was achieved. The average blow yield of the individual water intersections recorded calculates to 1.56L/s, while the median calculates to 1.4L/s.

- Only one water intersection of 0.46L/s was associated with the Karoo strata above the Dwyka Tillite Formation;
- Four of the water intersections recorded were associated with chert breccia at the base of the Dwyka Tillite Formation, the average blow yield of these calculate to 2.28L/s;
- Three water strikes with an average blow yield of 1.39L/s were associated with intrusive sills below the Dwyka Tillite Formation;
- Of 4 boreholes that intersected dolomite, only one water strike of 0.28L/s were associated with slightly fractured dolomite at the base of a dolerite sill intersection:
  - Based on the results of the gravity survey, the hydro-census information, as well as both phases of drilling, the storage medium of the concealed dolomite aquifer which attains a maximum thickness of approximately 200m across the Manungu reserve is described as fractures, with dissolution features absent or poorly developed.

In terms of "A South African Aquifer System Management Classification, WRC Report No KV 77/95, December 1995", (see Section 6.2), both the shallow weathered zone and deep fractured Karoo aquifers, including the transitional chert breccia zone at the base of the Dwyka Tillite Formation, the intrusive zone below the Karoo Sequence, as well as the underlying dolomite, are all classified as minor aquifer systems:

- Dolomite was intersected directly below the chert breccia in one borehole only. Although it is uncertain whether the chert breccia forms part of the Dwyka Tillite Formation or represents the top of the Malmani Subgroup locally, it doesn't influence the aquiver classification and the permeability of overlying tillite is still considered as very low.

5. PREVAILING GROUNDWATER CONDITIONS

5.1. Geology

5.1.1 Regional Geology

It is not the purpose of this report to provide a detailed geological description. However, several regional and local geological aspects are relevant to the hydrogeological evaluation.

Figure 5.1 depicts the surface geology according to the Council for Geoscience (1:250 000 Map Series, 2628 East Rand, 1986). The primary features are dolerite sill outcrops to the north and across the southern extent of the 30year LOM extension area, coal bearing Karoo-Ecca sedimentary strata of the Vryheid Formation in the proposed mining area, Karoo-Dwyka outcrops of the north, Malmani dolomites to the north and rocks of the West Rand Group's Hopsital Hill Subgroup to the northeast and southeast. Alluvium can be seen along the natural surface water drainage lines.

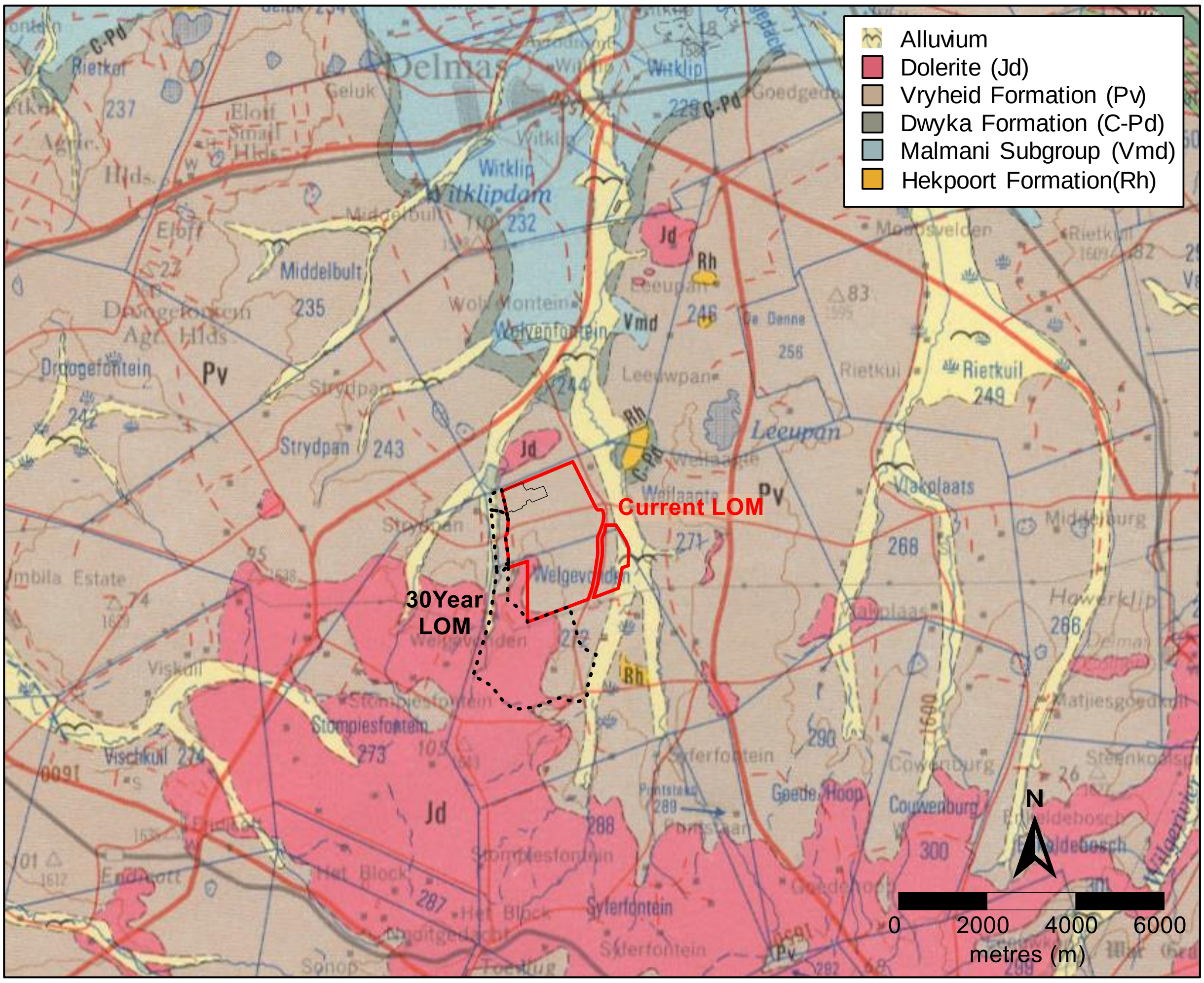


Figure 5.1 Regional geology (Council for Geoscience)

According to Button (1969 & 1970), Witwatersrand rocks are preserved, beneath the Paleozoic Karroo Sequence and Transvaal strata. An extensive area of Lower Witwatersrand rocks and limited areas of Upper Witwatersrand sediments are preserved in an area north of the Devon granite Dome.

The latter are situated along the Delmas Syncline in two small structural basins, the Middelbult and Bultfontein basins which lie southwest and north, respectively, of the town of Delmas.

The isolated outcrops of Witwatersrand quartzite and shale found to the south of Delmas were mentioned by Venter (1934), who correlated these quartzites with the Black Grit Quartzite (Hospital Hill Series) of the Heidelberg area, on the basis of black chert granules found in the quartzite.

An old gold mining exploration borehole (SW.1) located some 600m southwest of MAN-BH2D indicates the base of the Karoo Sequence at a depth of 64m. The base of the Transvaal Sequence represented by the Black Reef is indicated at a depth of 242m (postulated thickness of TVL intersection = 182m). At Borehole SW.1, a horizon which was tentatively correlated with the Main Reef was intersected. This correlation rested on the presence of an amygdaloidal lava found to underlie the Transvaal Sequence. This lava, which could be either of the Bird or Jeppestown amygdaloids, lies at no great distance above or below the Main Reef Horizon. In either case, Borehole SW.1 must be in the proximity of a sub-outcrop of the Main Reef Horizon postulated at a depth of ±352mbs.

A probable basin structure is located between Borehole SW.1 and the Middelbult group of boreholes. Since the same elevation of the key bed occurs in Boreholes SW.1, MB.1, and MB.2, the key bed is either flat-lying between these localities or, more likely; the two are separated by a structural depression.

Some 4.4km to the southeast on Ptn.5 of the farm Welgevonden old gold mining exploration borehole (rwv.1) indicate the base of the Karoo Sequence at a depth of 40m. The base of the Transvaal Sequence represented by the Black Reef is indicated at a depth of 90m (postulated TVL thickness = 50m). This borehole was terminated in rocks of the West Rand Group at a depth of some 537mbs.

Button (1969) indicates the sub-outcrop of the Black Reef within a kilometre of the southwestern southern reserve boundary from where it turns to the north to transect the reserve area east of the central reserve area along the eastern limb of the Delmas Syncline, past and to the immediate west of the Hospital Hill Subgroup outcrop along the reserve's central northern boundary for another 4km before turning east to loop around the Winterhoek anticline.

5.1.2 Local Geology

All five coal seams, typically encountered in the Witbank coal fields (Seam-5, Seam-4, Seam-3, Seam-2 and Seam-1) are present in the Manungu study area. Due to the present-day topography some portions of the upper seams have been eroded away. Although being negatively affected by erosion, the Seam-5 is present. According to Denner (2018), dolerite sill intrusions towards the upper part of the coal sequence have a negative impact on especially the Seam-4, resulting in the Seam-4 either not being present or devolatilised as a result. Although the Seam-3 is fairly well-developed, it is very thin, as is usually the case. The Seam-1 coal seam has an erratic distribution, both in terms of thickness and occurrence, which is mainly due to the undulating pre-Karoo basement underlying the coal seams.

The Seam-2 coal will be the primary target due to its economic thickness and quality. The average depth below surface of the Seam-2 is 48m (57m deep to the Seam-1). See Figure 5.2 (Figures 7.5 and 7.6 reflect the correct project layout)

According to Denner (2018), the thickness and occurrence of the Seam-2 is affected by the pre-Karoo topography, as well as weathering along these basement highs. There is a variation of 70m from west to east in the Dwyka floor elevation, causing the Seam-2 to have a very thick distribution towards the west in the basement valley (around 12m), and a thinner (<5m) or even weathered distribution to the east where the basement reaches its highest elevation. A dolerite sill present across the area, has a limited impact on the Seam-2 in the planned mining area, but elsewhere it can negatively influence the occurrence and quality of the coal seam.

According to Denner (2018), the top portion of the Seam-2 is typically of a poor coal quality with interbedded shales. From a coal quality perspective, this poor coal zone has been identified and separated from the Seam-2 selection; locally renamed as Seam-2T (Top) coal seam. This seam varies in thickness across the property, and is mainly absent towards the east, but increases in thickness to the west where it can reach a thickness of over 4m.

A cross-section of the local lithology is included as Figure 5.4.

A contour map indicating the depth to Seam-2 coal roof is presented in Figure 5.2. A map indicating the locality of a SW-NE orientated geological cross-section across the 18year LOM area is portrayed in Figure 5.3, while the cross section is presented in Figure 5.4.

As can be seen in Figure 5.2, apart from the somewhat isolated basin across the north-western part of the 18year LOM area, Seam-2 coal can be seen to be dipping to the southwest, with the deepest coal located across the 30year LOM Eskom underground extension area.

The distribution of the S14-dolerite sill aeromagnetic interpretation (Section 4.3) above the main economic coal reserves and S13-dolerite sill below them is highlighted in the cross section across the 18year LOM area in Figure 5.4.

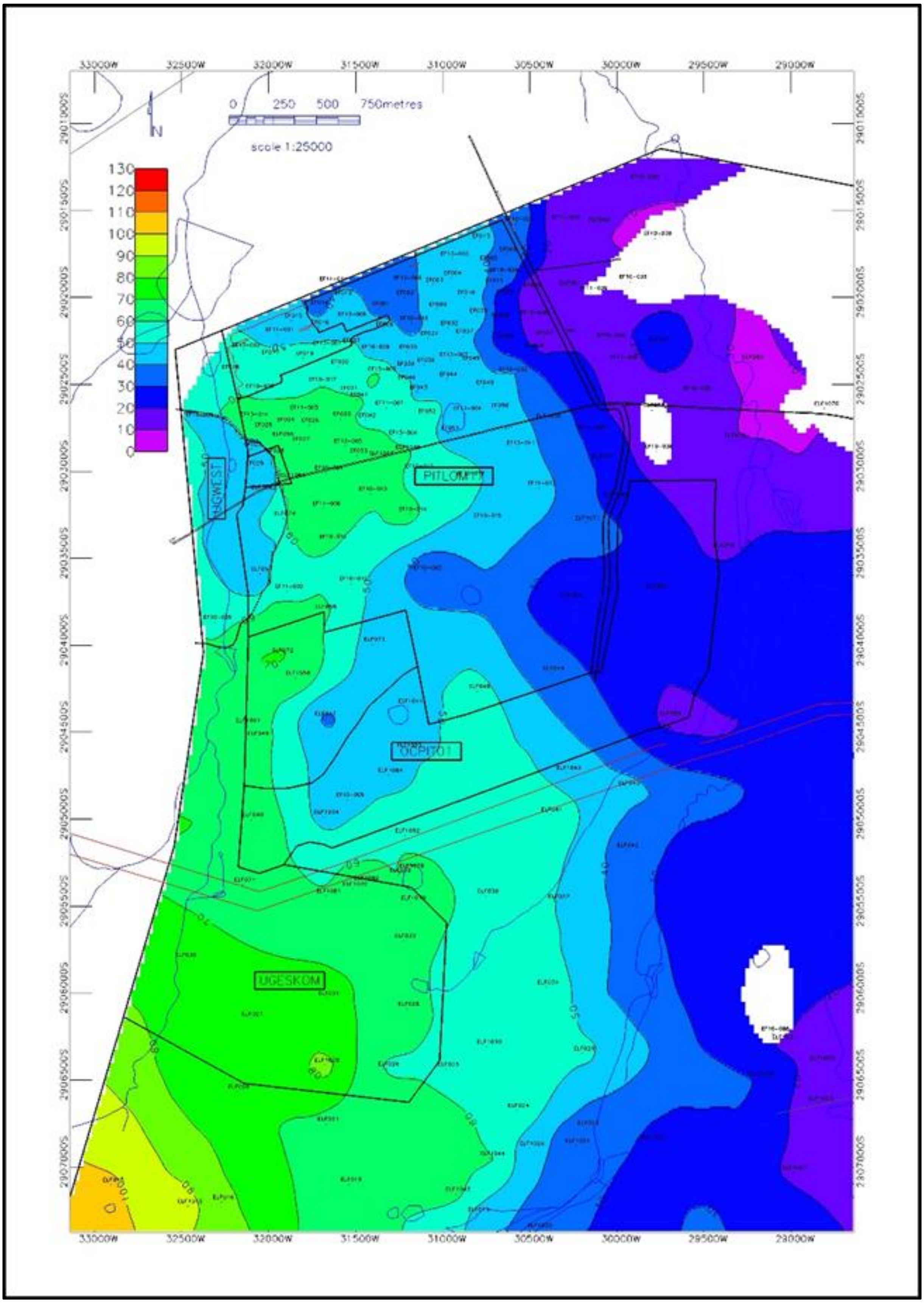


Figure 5.2 ***Depth to Seam-2 coal roof (m); depicted against 2017 mine plan (GEMECS, 2017)***

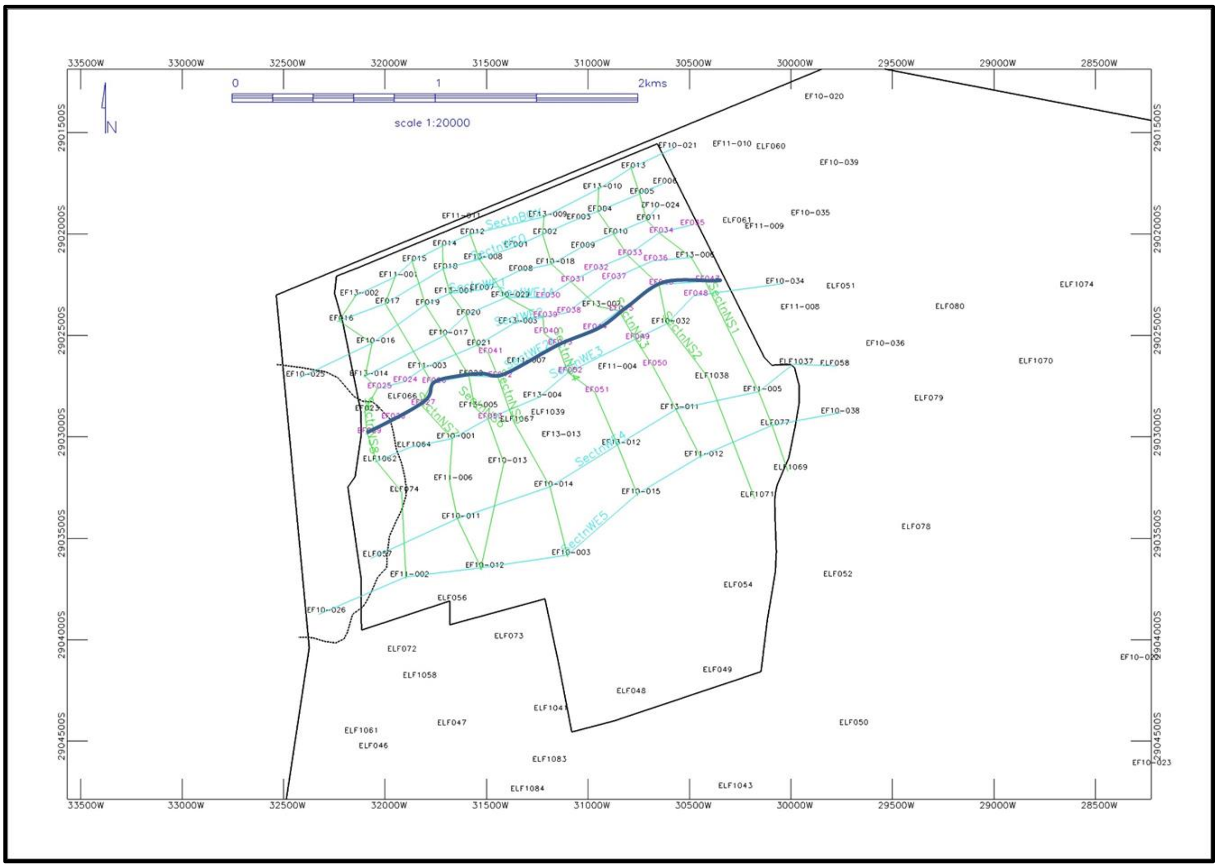


Figure 5.3 ***Locality of SW-NE Cross-section across 18year mine plan area; depicted against 2017 mine plan (GEMECS, 2017)***

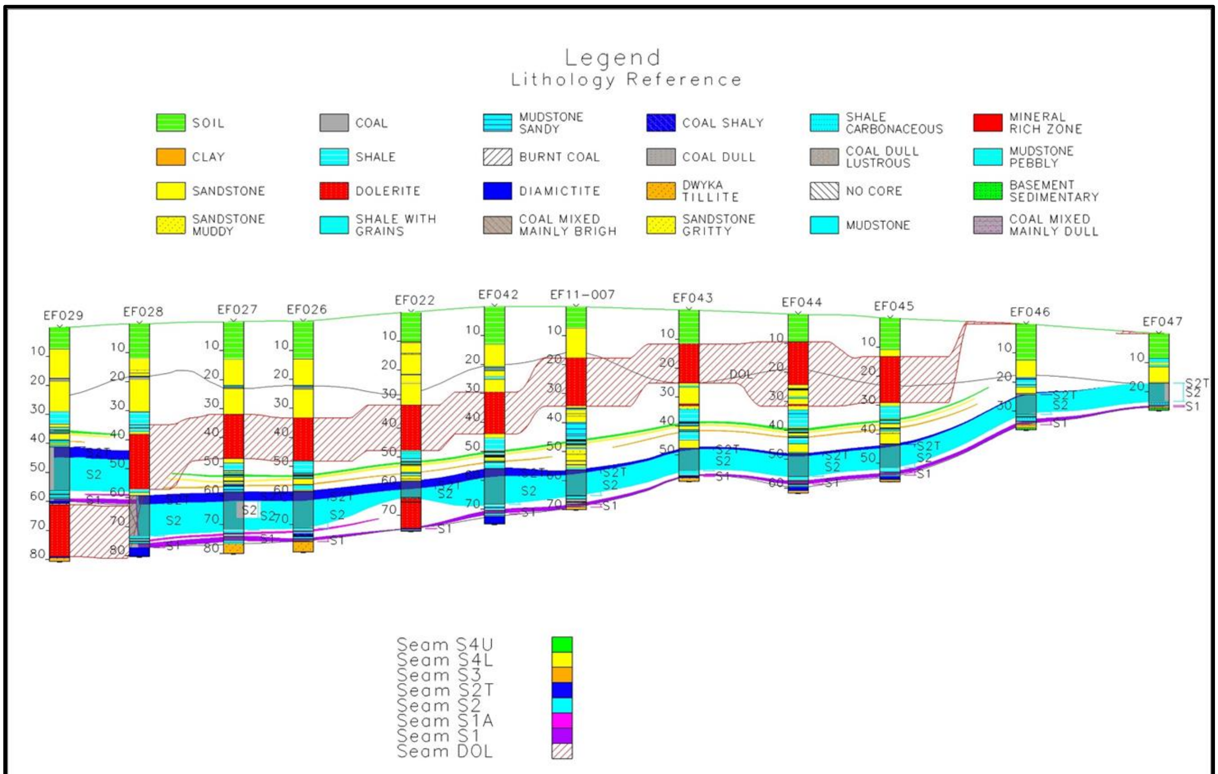


Figure 5.4 ***SW-NE Cross-section across 18year mine plan area; depicted against 2017 mine plan (GEMECS, 2017)***

5.2. Acid Generation Capacity

Initial ABA sample collection was undertaken during February 2017 from two exploration boreholes, EF030 and EF036, drilled immediately south of the active mining area. Eleven and another twenty-three samples were respectively collected from the floor of the coal Seam-2 up to and including the regolith for Acid Base Accounting (ABA) testing. The run of mine coal stockpile was also sampled (3 x 2kg bags) for ABA testing.

Additionally, another 79 geochemical samples were collected for ABA analyses during both phases of drilling the geohydrological boreholes. An additional 10kg ROM sample was also collected on 03/08/2017.

The rehabilitated backfill of the Manungu pit will be a heterogeneous mixture of acid generation and non-acid generation rocks. Approximately 37% of the waste rock samples have a very low sulphide content (%S <0.1%) and will not generate acidic drainage, and 31% have a medium to low sulphide content (therefore a low to very low potential to generate acidic drainage). The remaining 32% of clastic rocks (including especially the carbonaceous shale) do, however, have a significant potential to generate localised acidic drainage and will form localised hot-spots within the backfill. Because of the significant volume of acid generating waste rock, the backfilled pit will generate a high salt load dominated by sulphate.

A full description of samples collected, static geochemical laboratory testing, kinetic geochemical laboratory testing, and geochemical modelling, will be discussed in detail in the final groundwater impact assessment report. Results from the recent geochemical sampling for the 30year LOM plan area, are still being assessed.

The results indicated in Table 5.2 and Figure 5.5 were determined through numerical geochemical modelling of the Phase-1 samples.

Table 5.2 Summary of geochemical model output for SO_4

Time	Short Term	Medium term	Long term
Time after closure	0year to 10years	10years to 30years	30years to 200years
SO_4 in pit water	500mg/L - 3500mg/L	3500mg/L - 3700mg/L	3700mg/L - 2000mg/L

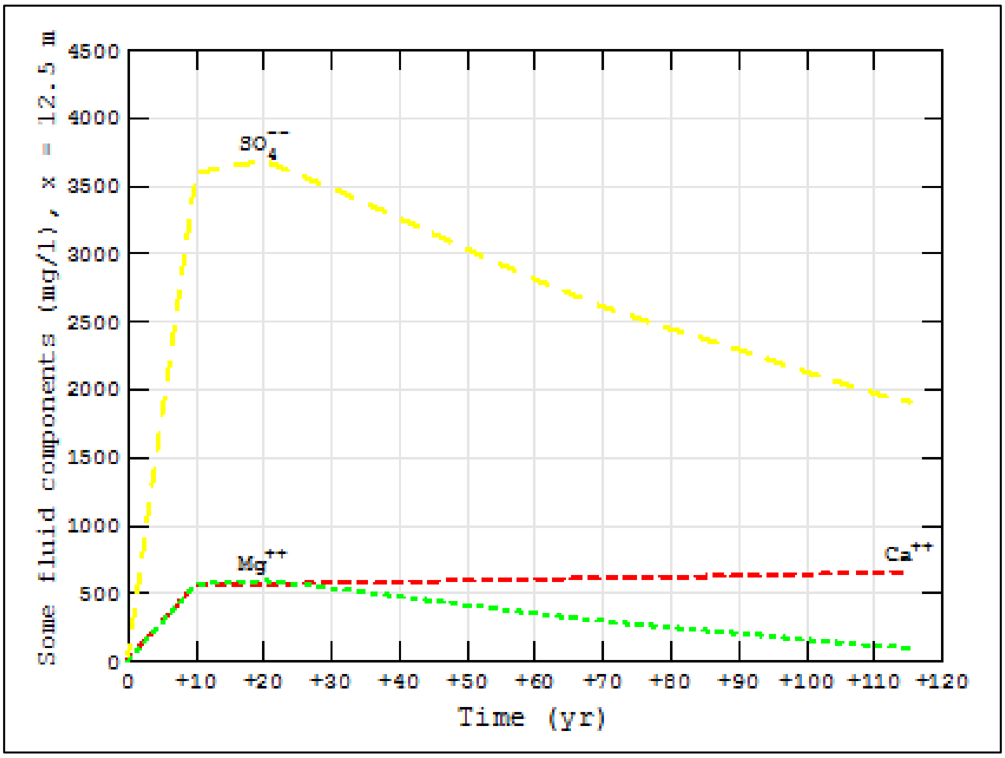


Figure 5.5 Summary of geochemical model output – major contaminant indicators

5.3. Hydrogeology

5.3.1 Unsaturated Zone

The unsaturated zone refers to the zone between the surface topography and the groundwater table. The depth to water table pertaining to the shallow weathered zone aquifer ranged between 2.77m and 8.23m, averaging at 5.24m.

The depth to the groundwater table as observed during various drilling phases is summarised in Figure 5.6 (Section 5.4).

5.3.2 Saturated Zone

The limit of weathering ranged between 15mbs and 31mbs, averaging at 24.64mbs. The depth to water table pertaining to the shallow weathered zone aquifer ranged between 2.77m and 8.23m, averaging at 5.24m. The average thickness of the saturated zone therefore calculates to 19.4m.
As the case for the unsaturated zone, the saturated zone thickness will depend on the type of geology, topographical setting, dewatering due to nearby mining and any groundwater abstraction.

5.3.3 Hydraulic Conductivity

Table 5.3A Summary of aquifer hydraulic parameters

Site Name	Water strike		Lithological Intersections							Test Interval (m)	(k) (m/day)
	Depth (m)	Yield (L/s)	OBDN (m)	LOW (m)	Coal (m)	Dwyka Roof (m)	Chert Breccia (m)	Dolomite (m)	Intrusions (m)		
MAN-BH2D	71-72 90-96	1.09 0.26	5	23	23-24 46-63	63	68-90	106-107 136-156 164-165 170-175	90-101 (D) 101-105 (D) 107-136 (T) 157-163 (T) 165-170 (D)	68-100 68-100# 68-175	8.63E-02 7.88E-02 4.98E-02
MAN-BH2M	12-30	0.125	6	24	23-24					12-40	2.14E-02
MAN-BH2S			6							4-10.77	6.83E-02
MAN-BH3D			11	17	17-20	20			41-64 (T) 66-73 (T)	26-41* 26-100	2.07E-05 4.79E-03
MAN-BH3M	21-22	0.10	11	17	17-20	21				12-30	2.06E-02
MAN-BH3S			10							4.00-10.24	2.05E-02
MAN-BH4D			5	30	43-52	52	56-65		11-13 (D) 20-34.5 (D) 65-90 (T)	36-61* 36-100	7.24E-03 5.71E-03
MAN-BH4M	23-30	0.77	5	30						21-41	3.37E-01
MAN-BH4S			5							6.4-11.09	4.95E-02
MAN-BH5M			4	27	22-23				32-40 (D)	18-40	3.21E-02
MAN-BH6D	34-40 64-66 73-75	0.46 3.01 2.50	6	26	29-31 34-40 42-47	47	65-77		6-25.5 (D) 77-91 (T)	41-91#	1.90E-01
MAN-BH6M	8.5-16	3.40	6	27	29-31 34-40				6-25.5 (D)	6-40	3.72E+00
MAN-BH7M			6	25	22-23				30-36 (D)	24-36	8.63E-02
MAN-BH8M			6	15	11-14	15				10-31	2.06E-02
MAN-BH9D	66-67	1.40	6	30	36-41 66-67	42	47-48	96	6-17 (D) 61-96 (T)	48-96 48-96#	2.84E-01 1.96E-01
MAN-BH9M	30-31	0.11	6	30	39-43	45			4-18 (D)	16-46	3.67E-02
MAN-BH9S			6						6-10 (D)	7.82-10.02	3.29E-02
MAN-BH10M	11-17	0.10	7	17	11-17	17				9-26	2.55E-02
MAN-BH11D	68-71	2.50	7	31	27-28 48-54	54	64-78	78-80	80-86 (D)	60-86 60-86#	1.28E-01 1.88E-01
MAN-BH11S			7							4.18-7.23	8.78E-02
MAN-BH12D			3	28	41-42 56-76	79	82-86			48-86	6.19E-03
MAN-BH12M			3	28	41-42					12-40	2.65E-02
MAN-BH12S			3							3.50-6.99	8.42E-02
MAN-BH13D			1	18	44-45 58-59 65-78	81	83-86			52.22-86	1.17E-02

*# = Pumping Test, * = Falling Head Test, (k) = Hydraulic Conductivity*

Initial aquifer testing was undertaken during February 2017. Five slug tests were performed on exploration boreholes drilled to intersect basement, immediately south of the active mining area. The chert breccia encountered at the base of the Dwyka Formation or the top of the Transvaal sequence proof difficult to drill, resulting in limited intersections. Due to the casing being pulled after drilling, only one hole that was tested (EF036), featured a chert breccia intersection between 38.38m and 44.73m. A hydraulic conductivity of 0.028m/d was determined for the total saturated zone. An average hydraulic conductivity of 0.046m/d was determined for the saturated zone above coal Seam-1 in the other four exploration boreholes.

Falling head tests were performed on MAN-BH3D and MAN-BH4D during drilling. The test section (26m-41m) in borehole MAN-BH3D featured the contact between the Dwyka Tillite Formation and a sill intrusion. An average hydraulic conductivity of 0.000021m/d was determined for this zone. After completion to end-of-hole depth and a two-week resting period, a slug test performed on this borehole determined a hydraulic conductivity value of 0.00479m/d for the full saturated zone (26m-100m).
The test section (36m-61m) in borehole MAN-BH4D featured the contact between the Ecca Group sediments and the Dwyka Tillite Formation, as well as a sill intrusion contact with the latter. An average hydraulic conductivity of 0.00724m/d was determined for this zone. After completion to end-of-hole depth and a two-week resting period, a slug test performed on this borehole determined a hydraulic conductivity value of 0.00571m/d for the full saturated zone (36m-100m).

Slug tests were performed on all the newly commissioned geohydrological boreholes (see Section 4.4) except borehole MAN-BH6D. The bentonite seal in this borehole (cased to 41m) was not effective and water leaking from the upper part of this borehole was falling down the hole.

The test results obtained from the slug tests, falling head tests as well as the pumping tests performed are summarized in Table 5.3A. Statistical analyses of the hydraulic conductivity values determined for the newly commissioned geohydrological boreholes are presented in Tables 5.3B – 5.3D.

Table 5.3B Statistical evaluation of slug test results: Shallow boreholes (7-11m deep)

Site Name	Test Interval (m)	Hydraulic Conductivity k (m/day)	Hydraulic Conductivity k (m/day)
MAN-BH2S	4-10.77	6.83E-02	0.068
MAN-BH3S	4.00-10.24	2.05E-02	0.021
MAN-BH4S	6.4-11.09	4.95E-02	0.050
MAN-BH9S	7.82-10.02	3.29E-02	0.033
MAN-BH11S	4.18-7.23	8.78E-02	0.088
MAN-BH12S	3.50-6.99	8.42E-02	0.084
Average		5.72E-02	0.057
Median		5.89E-02	0.059
Harmonic mean		4.37E-02	0.044
Geometric mean		5.06E-02	0.051

Table 5.3C Statistical evaluation of slug test results: Medium boreholes (26-41m deep)

Site Name	Test Interval (m)	Hydraulic Conductivity k (m/day)	Hydraulic Conductivity k (m/day)
MAN-BH2M	12-40	2.14E-02	0.021
MAN-BH3M	12-30	2.06E-02	0.021
MAN-BH4M	21-41	3.37E-01	0.337
MAN-BH5M	18-40	3.21E-02	0.032
MAN-BH6M	6-40	3.72E+00	3.720
MAN-BH7M	24-36	8.63E-02	0.086
MAN-BH8M	10-31	2.06E-02	0.021
MAN-BH9M	16-46	3.67E-02	0.037
MAN-BH10M	9-26	2.55E-02	0.026
MAN-BH12M	12-40	2.65E-02	0.027
Average		4.33E-01	0.433
Median		2.98E-02	0.030
Harmonic mean		3.39E-02	0.034
Geometric mean		6.15E-02	0.062

Table 5.3D Statistical evaluation of slug test results: Deep boreholes (86-175m deep)

Site Name	Test Interval (m)	Hydraulic Conductivity k (m/day)	Hydraulic Conductivity k (m/day)
MAN-BH2D	68-100 68-100# 68-175	8.63E-02 7.88E-02 4.98E-02	0.086 0.079 0.050
MAN-BH3D	26-41* 26-100	2.07E-05 4.79E-03	0.000021 0.005
MAN-BH4D	36-61* 36-100	7.24E-03 5.71E-03	0.007 0.006
MAN-BH6D	41-91#	1.90E-01	0.190
MAN-BH9D	48-96 48-96#	2.84E-01 1.96E-01	0.284 0.196
MAN-BH11D	60-86 60-86#	1.28E-01 1.88E-01	0.128 0.188
MAN-BH12D	48-86	6.19E-03	0.006
MAN-BH13D	52.22-86	1.17E-02	0.012
Average		1.13E-01	0.113
Median		1.28E-01	0.128
Harmonic mean		1.37E-02	0.014
Geometric mean		4.30E-02	0.043

An average hydraulic conductivity of 0.057m/d was determined for the 6 shallow boreholes. The average of the harmonic and geometric mean values for shallow boreholes was 0.047m/d.

An average hydraulic conductivity of 0.433m/d was determined for the 10 medium boreholes. If the one high-yielding borehole is ignored, the average hydraulic conductivity calculates to 0.067m/d. The observed heterogeneity is typical for shallow weathered zone Karoo aquifers. It is the experience of *Groundwater Square* that the representative hydraulic conductivity for the shallow weathered zone aquifer can be estimated from the harmonic mean and the geometric mean; calculated as 0.048m/d.

The average value of the harmonic and geometric mean values for the shallow boreholes, all the medium boreholes, the medium boreholes without the most significant outlier, as well as the medium boreholes without both obvious outliers, calculated to 0.041m/d.

An average hydraulic conductivity of 0.113m/d was determined for the 8 deep boreholes (slug, falling head and pumping tests). If the three moderate-yielding boreholes are ignored, the average hydraulic conductivity calculates to 0.0071m/d. The average for the 3 moderate-yielding boreholes calculates to 0.197m/day. The average value for all the deep boreholes, the deep boreholes without the outliers and the 3 moderately-yielding boreholes by themselves, calculate to 0.106m/d.

The unique hydraulic conductivity values for each geological unit, are presented in Section 7.6. The major groundwater flow units/aquifers, listed in Tables 7.1A-B and 7.2A-B, were identified and calibrated. Numerical modelling for this study did not indicate that the parameters may be substantially different.

5.4. Groundwater Levels

Thematically highlighted groundwater level depth distribution is indicated in Figure 5.6 (see summary of drill locations and initial groundwater levels in Table 5.4)

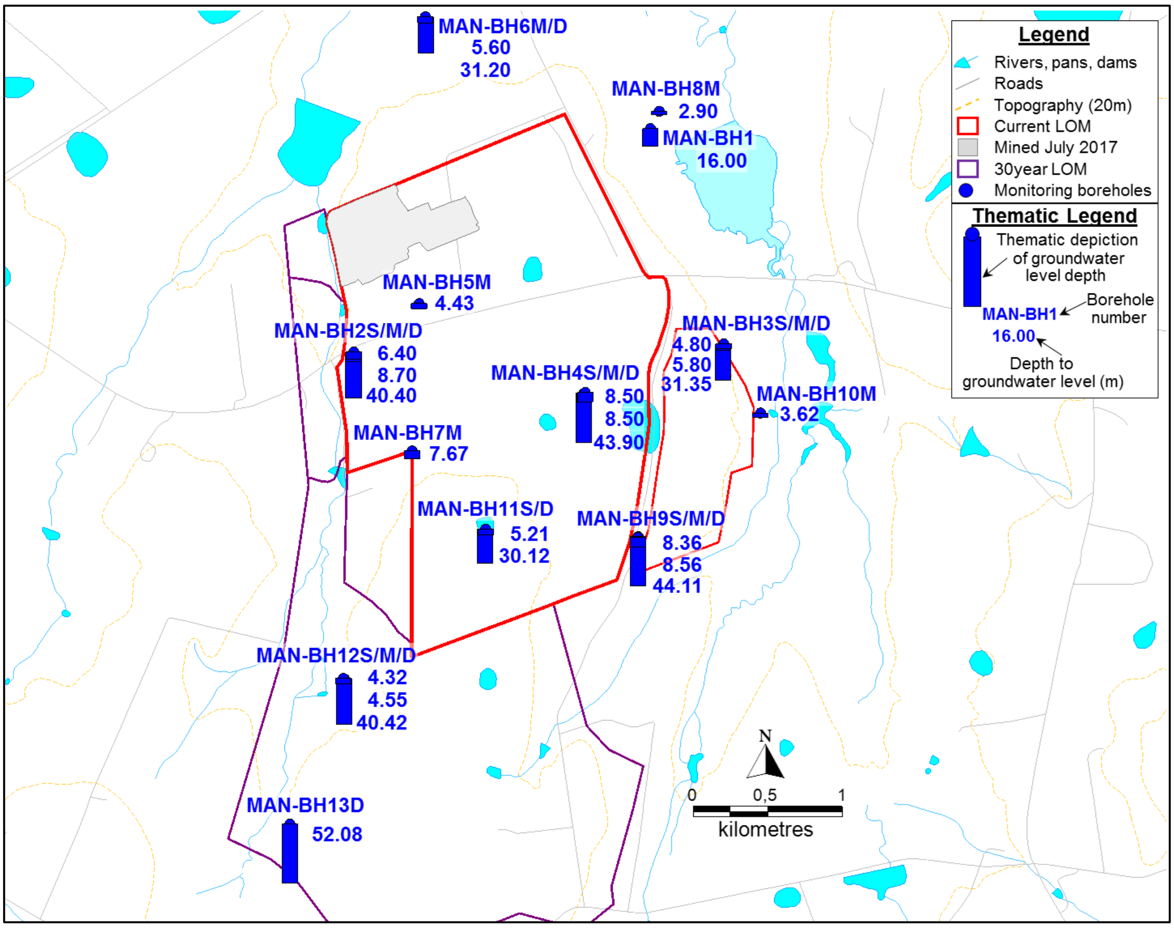


Figure 5.6 Thematic depiction of groundwater level depths(m) for monitoring boreholes

The depth to water table in shallow boreholes (6-11m deep) ranged between 3.0m and 7.8m, averaging at 4.8m.

Medium-depth boreholes in the shallow weathered zone aquifer ranged between 2.8m and 8.2m, averaging at 5.2m. The difference between the depth to water table in the shallow and medium boreholes are insignificant; and are not indicative of perched conditions of any significance.

The depth to water table in deep fractured aquifer ranged between 26.0m and 52.2m, averaging at 36.7m. Interestingly the observed hydraulic head between MAN-BH2D (101m deep) before it was drilled to 175m and after it was deepened differed by 6.11m.

The mining method at Manungu contributes to changes in groundwater levels in the direct vicinity of the mine. This is because, in order to remove coal, groundwater must be pumped out of the mine. Unfortunately, groundwater levels were not recorded in all 2017 hydrogeological boreholes for a while, before Groundwater Square made recommendations in this regard in August 2017. Some monitoring boreholes were equipped with pumps, which made it difficult to measure groundwater levels during this period.

Table 5.4 Drill locations and initial groundwater level

Site Name	Latitude	Longitude	Date	Water Level (m)
MAN-BH1	26.2237	28.6990	2014/08/01	15.91
MAN-BH2D	26.2372	28.6790	2018/10/01	40.40
MAN-BH2M	26.2372	28.6790	2018/10/01	8.70
MAN-BH2S	26.2371	28.6790	2018/10/01	6.40
MAN-BH3D	26.2368	28.7038	2018/10/01	31.35
MAN-BH3M	26.2367	28.7038	2018/10/01	5.80
MAN-BH3S	26.2367	28.7038	2018/10/01	4.80
MAN-BH4D	26.2397	28.6945	2018/10/01	43.90
MAN-BH4M	26.2396	28.6945	2018/10/01	8.50
MAN-BH4S	26.2396	28.6945	2018/10/01	8.50
MAN-BH5M	26.2342	28.6834	2017/05/23	4.43
MAN-BH6D	26.2169	28.6839	2018/10/01	31.20
MAN-BH6M	26.2169	28.6839	2018/10/01	5.60
MAN-BH7M	26.2431	28.6829	2018/07/31	7.67
MAN-BH8M	26.2226	28.6995	2018/10/01	2.90
MAN-BH9D	26.2483	28.6981	2018/07/31	44.11
MAN-BH9M	26.2483	28.6981	2018/07/31	8.56
MAN-BH9S	26.2484	28.6981	2018/07/31	8.36
MAN-BH10M	26.2409	28.7063	2018/07/31	3.62
MAN-BH11D	26.2479	28.6878	2018/07/31	30.12
MAN-BH11S	26.2479	28.6878	2018/07/31	5.21
MAN-BH12D	26.2569	28.6783	2018/07/31	40.42
MAN-BH12M	26.2569	28.6783	2018/07/31	4.55
MAN-BH12S	26.2569	28.6783	2018/07/31	4.32
MAN-BH13D	26.2656	28.6747	2018/07/31	52.08

5.5. Groundwater Potential Contaminants

The main indicator for groundwater contamination is sulphate. During the various stages of geochemical transformation, sulphate will be associated with sodium, calcium and magnesium. Total Dissolved Solids (TDS) or Electrical Conductivity (EC), indicates the total salt load.

Other contaminant indicators associated with sulphate, are pH levels. When low-pH conditions prevail, increased metals concentrations may manifest, such as iron (but they also include additional metals as indicated in the geochemical assessment, Appendix VI).

5.6. Groundwater Quality

The hydrochemistry can be discussed at hand of the samples taken during the recent hydrocensus as well as the samples taken after the two drilling phases and during the pumping tests.

The water quality compliance and distribution will be discussed using Standards South Africa's, (a division of SABS) specification for Drinking Water, SANS 241-1:2015 Edition 2, as compliance criteria.

For visual inspection of hydro-chemical data the results of the analysis were plotted on tri-linear Piper Durov and Expanded Durov diagrams (Figures 5.9A-D). The diagrams permit the cation and anion compositions of samples to be represented on single graphs in which major groupings or trends in the data can be discerned visually.

Table 5.5A indicates the measured physical, macro and micro-determinants for the samples taken from the external users' boreholes, during the revisit of the hydrocensus, all to be compliant with the SANS 241-1:2015 physical, aesthetic and chemical numerical limits for lifetime consumption except for the following exceedances:

- The nitrate concentrations for boreholes MBH13, MBH29, MBH47, KGA14 and KGA15 all exceeded the acute health limit;
- Borehole MBH29 also exceeded the aesthetic and acute health limits for EC, TDS, Cl and SO4.

Elevated sulphate concentrations were noted for MBH31 (72.3mg/L) and MBH47 (127mg/L). Elevated chloride concentrations (>42) were noted for boreholes MBH6, 17, 25, 31, 36A, 40, 45, 46 and MBH47. Elevated sodium concentrations (>100mg/L) were noted for MBH12 and MBH17.

The hydrocensus (revisit) samples all exhibit a calcium / magnesium bicarbonate character and plot as unpolluted on the Expanded Durov Diagram (except for MBH12, 17 and 36A, which exhibit a sodium / potassium bicarbonate character, as well as MBH29, which is representative of a calcium / sodium sulphate water and a sample from MBH5 with a magnesium sulphate character.

Table 5.5B indicates the measured physical, macro and micro-determinants for the samples taken from the newly commissioned geohydrological boreholes, all to be compliant with the SANS 241-1:2015 physical, aesthetic and chemical numerical limits for lifetime consumption except for the following exceedances:

- The nitrate concentrations for boreholes MAN-BH9M&S exceeded the acute health limit;
- The ammonia concentrations for boreholes MAN-BH2M&S, MAN-BH4S, MAN-BH5M, 8M, 9M, 10M as well as MAN-BH12D, M&S exceeded the aesthetic limit.

An elevated sulphate concentration (92.61mg/L) was noted for MAN-BH12S. Elevated chloride concentrations (>42) were noted for boreholes MAN-BH11D & S, as well as MAN-BH12S and MAN-BH13D. Elevated sodium concentrations (>100mg/L) were noted for MAN-BH2D (stratified sample), MAN-BH11D, 12D and 13D. The sodium concentration for the sample taken from MAN-BH2D towards the end of the constant discharge test performed on this borehole was reported as 76.6mg/L.

The average TDS for the shallow boreholes (7-11m deep) calculated to 274mg/L, while the average for the medium (26-41m deep) and deep boreholes (86-175m deep, respectively calculated to 231.93mg/L and 410.63mg/L.

The samples from the shallow boreholes exhibit a calcium/magnesium bicarbonate character and plot as unpolluted on the Expanded Durov Diagram.

The samples from the medium boreholes exhibit a calcium/magnesium bicarbonate character and plot as unpolluted on the Expanded Durov Diagram, except for MAN-BH12M, which exhibits a sodium / potassium bicarbonate character.

In terms of the deep boreholes, only MAN-BH4D, MAN-BH9D and MAN-BH6D exhibit a calsium / magnesium bicarbonate character and plot as unpolluted on the Expanded Durov Diagram. The plotting positions of the rest (MAN-BH2D, 3D, 11D, 12D & 13D) exhibits a sodium / potassium bicarbonate character.

Except for borehole MBH29 and apart from the noted exceedances for nitrate, the external users' groundwater quality is generally of a good quality. The noted exceedances and elevated concentrations are attributed to agricultural and domestic impacts.

In terms of the newly commissioned boreholes, apart from the noted exceedances for nitrate and ammonia, the groundwater quality is generally of a good quality. The noted exceedances and elevated concentrations are also attributed to agricultural and domestic impacts.

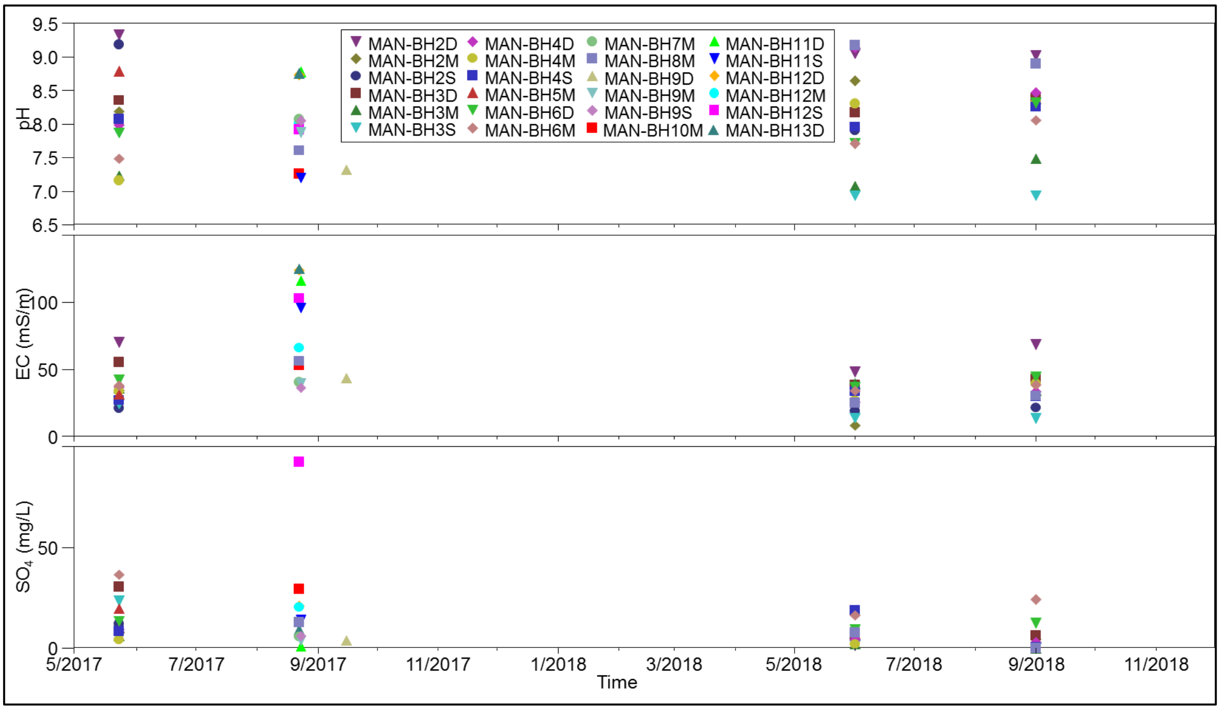


Figure 5.8 ***pH, Electrical conductivity (mS/m), pH and Sulphate (mg/L) concentration for monitoring boreholes***

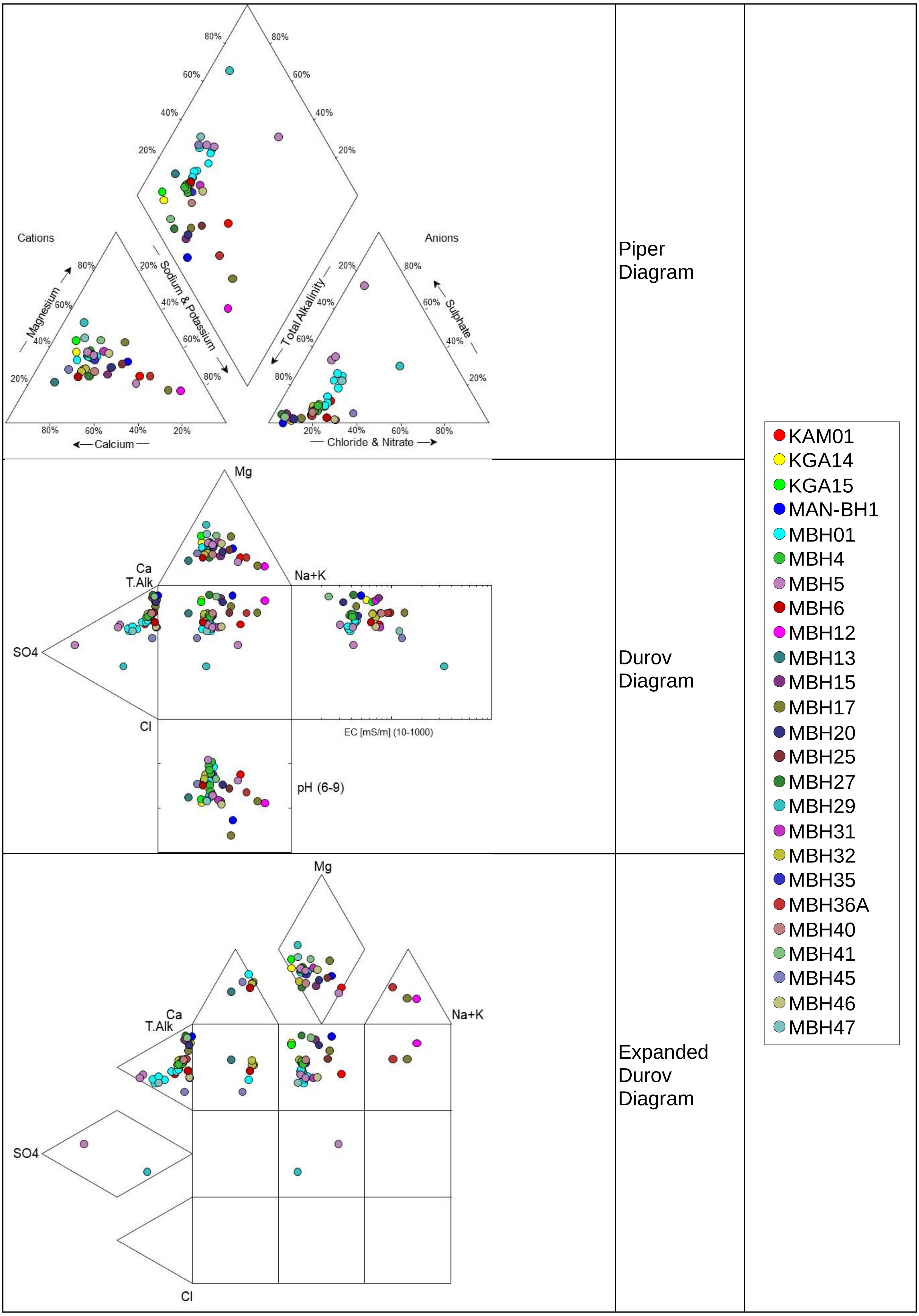


Figure 5.9A Piper/Durov/Expanded Durov plots of Hydrocensus qualities

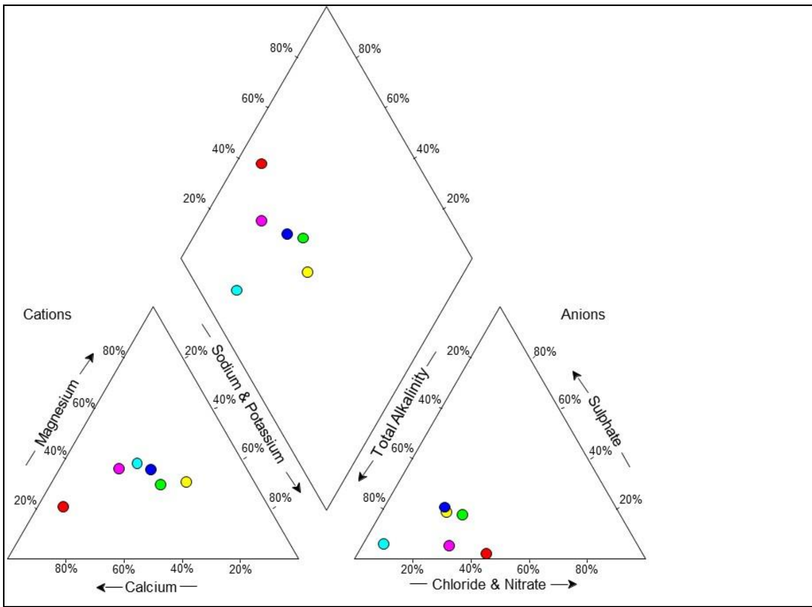
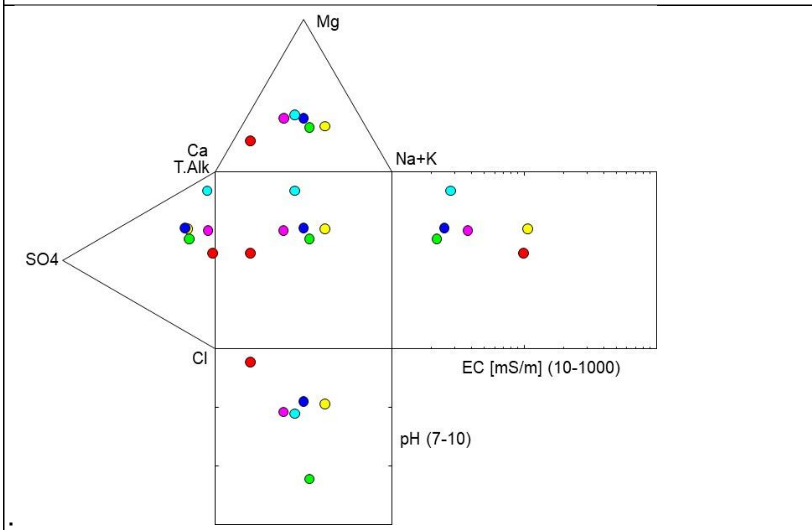
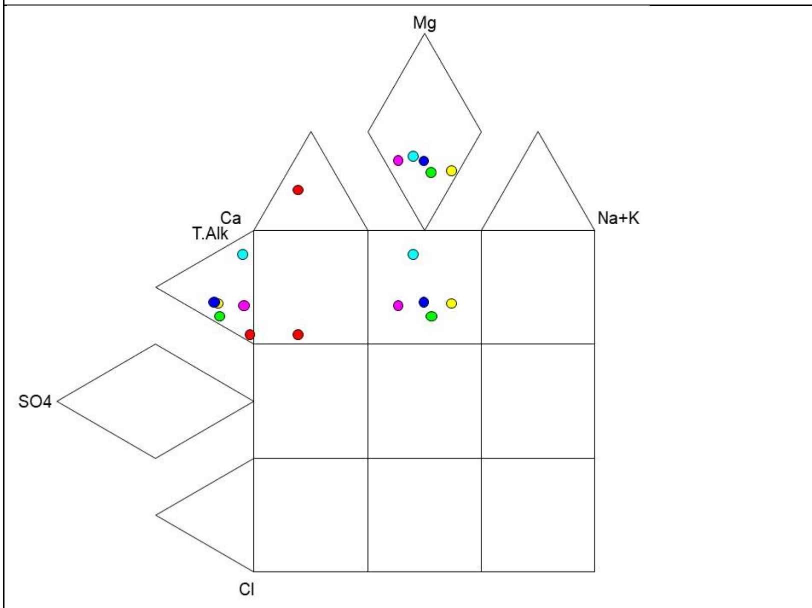
	Piper Diagram	
	Durov Diagram	MAN-BH2S MAN-BH3S MAN-BH4S MAN-BH9S MAN-BH12S MAN-BH11S
	Expanded Durov Diagram	

Figure 5.9B Piper/Durov/Expanded Durov plots of shallow groundwater borehole water qualities

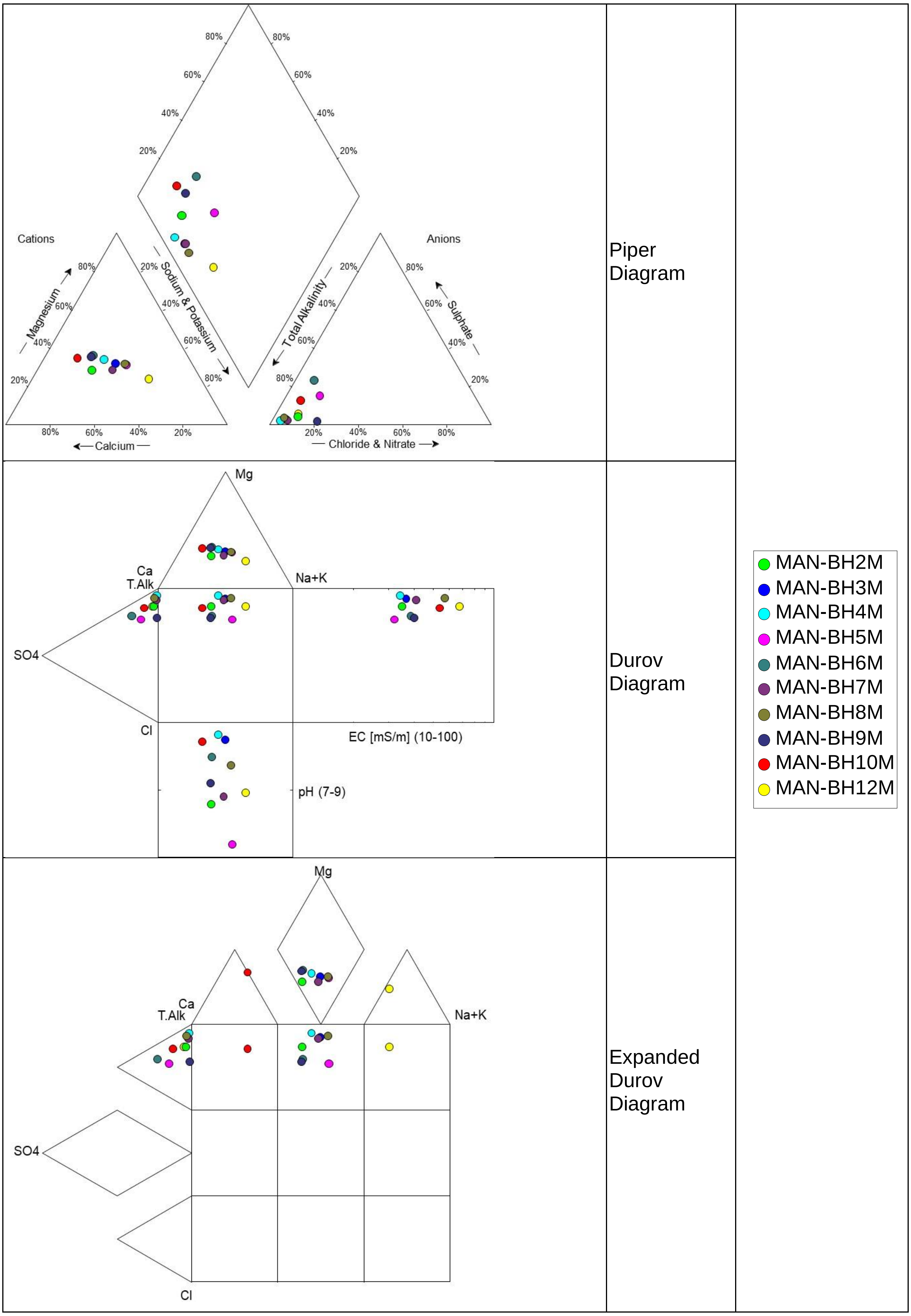
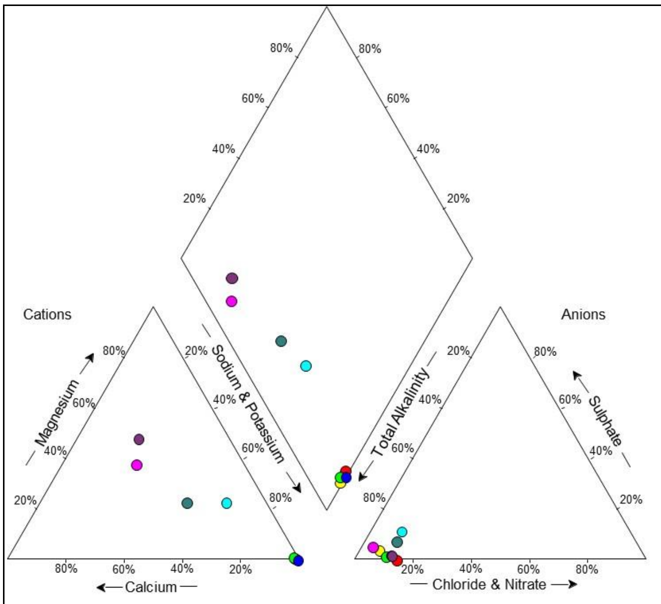
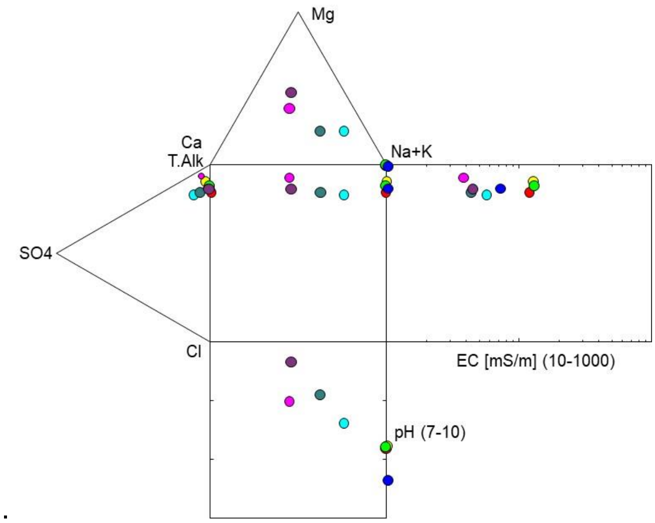


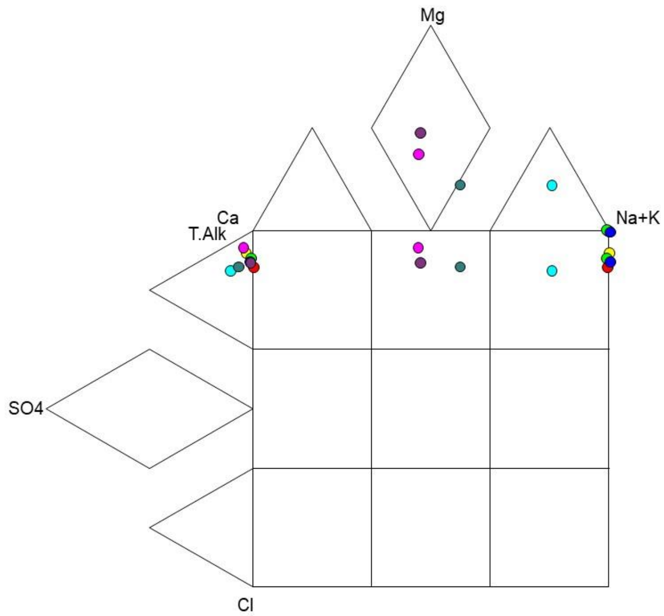
Figure 5.9C ***Piper/Durov/Expanded Durov plots of medium groundwater borehole water qualities***



Piper Diagram



Durov Diagram



Expanded Durov Diagram

Figure 5.9D Piper/Durov/Expanded Durov plots of deep groundwater borehole water qualities

Table 5.5A Water Quality Results: Hydro-census

	MBH1	MBH6	MBH12	MBH13	MBH15	MBH17	MBH18B	MBH20	MBH25	MBH27	SANS 241-1:2015 Standard Limits
Sample date	22/03/2017	13/03/2017	14/03/2017	14/03/2017	14/03/2017	22/03/2017	14/03/2017	15/03/2017	20/03/2017	22/03/2017	
pH – Value	7.04	7.46	7.86	7.73	7.81	7.81	7.78	7.44	7.53	6.99	≥ 5.0 to ≤ 9.5
Electrical Conductivity (EC mS/m)	35.40	60.60	66.90	74.80	72.20	131.00	38.30	31.80	93.60	40.30	≤ 170
Total Dissolved Solids (TDS mg/L)	198.25	312.39	356.39	420.99	389.48	725.23	187.52	171.32	494.32	206.87	≤ 1200
Calcium (Ca mg/L)	25.80	62.10	15.66	99.70	59.47	47.10	32.40	22.36	60.10	40.40	
Magnesium (Mg mg/L)	13.70	17.20	14.17	20.30	23.17	29.90	16.10	10.93	36.70	12.50	
Sodium (Na mg/L)	12.60	20.20	104.00	15.30	49.02	197.00	16.30	18.90	77.50	22.00	≤ 200
Potassium (K mg/L)	7.23	9.88	2.82	5.25	9.24	5.31	3.69	5.81	4.30	1.94	
Silicon (Si mg/L)	31.10	22.00	5.19	22.30	15.80	7.58	6.61	29.10	11.50	16.40	
Total Alkalinity (mg/L)	78.80	198.00	308.00	251.00	330.00	542.00	161.00	119.00	370.00	191.00	
Chloride (Cl mg/L)	17.10	48.10	21.40	38.40	13.90	83.40	13.20	9.76	56.10	4.82	≤ 300
Sulphate (SO^4 mg/L)	29.80	9.56	11.40	21.00	20.70	32.70	9.09	3.83	23.20	10.60	≤ 500
Nitrate as N (mg/L)	10.10	5.99	0.36	15.90	3.58	0.97	<0.35	6.33	3.22	<0.35	≤ 11
Fluoride (F mg/L)	<0.09	<0.09	0.52	<0.09	0.12	0.32	0.14	0.11	0.15	<0.09	≤ 1.50
Chemical Oxygen Demand (COD mg/L)	<1.00	3.00	3.00	<1.00	6.00	6.00	1.00	<1.00	4.00	<1.00	
Oxygen Absorbed (AO4 mg/L)											
Oxygen Dissolved (DO mg/L)	6.49	6.62	6.64	6.71	6.83	6.78	6.68	6.81	6.82	6.77	
Ammonia as Ammonium (N mg/L)	<0.450	<0.450	<0.450	<0.450	<0.450	<0.450	<0.450	<0.450	<0.450	<0.450	≤ 1.5
Phosphate as P (mg/L)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.05	<0.03	<0.03	
Aluminium (Al ppm)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.30
Arsenic (As ppm)	<0.01	<0.01	0.01	0.01	0.01	0.02	0.01	<0.01	0.01	0.01	≤ 0.01
Chromium (Cr mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.05
Cobalt (Co mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.5
Copper (Cu mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 2
Cyanide (CN mg/L)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	<0.01	<0.01	0.01	≤ 0.2
Iron (Fe mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 2
Lead (Pb mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.01
Manganese (Mn mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	≤ 0.4
Nickle (Ni mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.07
Uranium (U mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.03
Zinc (Z mg/L	<0.01	0.01	0.02	<0.01	<0.01	<0.01	<0.01	0.02	0.01	<0.01	≤ 5

Ion Difference (%)	-0.04	-0.03	-0.04	-0.01	-0.03	-0.02	0.00	-0.03	-0.01	-0.01	

Table 5.5A Water Quality Results: Hydro-census (continued)

	MBH29	MBH31	MBH32	MBH35	MBH36A	MBH40	MBH41	MBH45	MBH46	MBH47	SANS 241<1:2015 Standard Limits
Sample date	20/03/2017	20/03/2017	14/03/2017	20/03/2017	20/03/2017	14/03/2017	15/03/2017	20/03/2017	20/03/2017	20/03/2017	
pH – Value	7.79	7.79	7.48	7.21	7.61	7.67	7.31	7.43	7.88	7.81	≥ 5.0 to ≤ 9.5
Electrical Conductivity (EC mS/m)	325.00	74.00	63.00	44.70	87.90	76.30	22.90	123.00	67.30	116.00	≤ 170
Total Dissolved Solids (TDS mg/L)	2166.30	378.43	332.88	236.23	449.08	405.47	124.47	660.20	335.78	676.20	≤ 1200
Calcium (Ca mg/L)	302.00	52.27	59.30	35.30	36.80	70.37	15.52	140.00	44.10	99.20	
Magnesium (Mg mg/L)	259.00	33.26	21.40	17.00	25.90	25.97	11.88	43.00	28.70	65.80	
Sodium (Na mg/L)	76.00	39.34	25.50	18.80	98.20	44.32	8.83	38.20	38.70	33.40	≤ 200
Potassium (K mg/L)	1.53	2.75	7.10	5.45	4.89	2.06	2.77	1.47	3.11	2.61	
Silicon (Si mg/L)	23.30	15.90	21.40	21.60	9.53	12.30	25.10	20.60	13.70	24.70	
Total Alkalinity (mg/L)	435.00	239.00	232.00	146.00	346.00	301.00	89.60	357.00	218.00	316.00	
Chloride (Cl mg/L)	545.62	72.30	34.30	24.40	54.10	46.40	3.66	153.00	64.40	87.70	≤ 300
Sulphate (SO^4 mg/L)	516.92	8.22	23.80	16.40	20.60	24.20	3.89	34.80	8.38	127.00	≤ 500
Nitrate as N (mg/L)	46.10	6.07	5.03	7.06	<0.35	2.54	5.43	8.02	3.97	16.00	≤ 11
Fluoride (F mg/L)	<0.09	<0.09	<0.09	<0.09	0.31	0.12	0.11	<0.09	<0.09	<0.09	≤ 1.50
Chemical Oxygen Demand (COD mg/L)	14.00	<1.00	2.00	<1.00	1.00	2.00	3.00	2.00	5.00	4.00	
Oxygen Absorbed (AO4 mg/L)											
Oxygen Dissolved (DO mg/L)	6.80	6.81	6.75	6.60	6.82	6.71	6.87	6.81	6.77	6.88	
Ammonia as Ammonium (N mg/L)	<0.450	<0.450	<0.450	<0.450	0.520	<0.450	<0.450	<0.450	<0.450	<0.450	≤ 1.5
Phosphate as P (mg/L)	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	
Aluminium (Al ppm)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.30
Arsenic (As ppm)	0.01	0.01	0.01	0.01	0.01	0.01	<0.01	0.01	0.01	0.01	≤ 0.01
Chromium (Cr mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.05
Cobalt (Co mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.05	≤ 0.5
Copper (Cu mg/L)	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 2
Cyanide (CN mg/L)	0.01	<0.01	0.02	0.01	0.05	0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.2
Iron (Fe mg/L)	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 2
Lead (Pb mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.01
Manganese (Mn mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.4
Nickle (Ni mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.07

Uranium (U mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.03
Zinc (Z mg/L	0.01	0.01	<0.01	<0.01	<0.01	0.18	<0.01	<0.01	<0.01	0.01	≤ 5
Ion Difference (%)	0.02	-0.02	-0.03	-0.04	-0.03	-0.02	-0.03	-0.02	-0.02	-0.03	

Table 5.5A Water Quality Results: Hydro-census (continued)

	B2N073	KAM01	KGA14	KGA15							SANS 241-1:2015 Standard Limits
Sample date	13/03/2017	13/03/2017	13/03/2017	13/03/2017							
pH – Value	9.43	7.22	7.84	7.77							≥ 5.0 to ≤ 9.5
Electrical Conductivity (EC mS/m)	33.40	72.80	54.60	62.80							≤ 170
Total Dissolved Solids (TDS mg/L)	175.52	374.49	300.58	346.73							≤ 1200
Calcium (Ca mg/L)	2.58	36.67	52.50	58.20							
Magnesium (Mg mg/L)	12.41	21.11	24.80	33.40							
Sodium (Na mg/L)	46.60	73.80	13.10	11.90							≤ 200
Potassium (K mg/L)	1.26	3.16	4.11	3.25							
Silicon (Si mg/L)	4.56	13.70	19.20	19.30							
Total Alkalinity (mg/L)	91.80	235.00	211.00	230.00							
Chloride (Cl mg/L)	13.26	55.80	15.20	18.00							≤ 300
Sulphate (SO^4 mg/L)	12.34	42.60	4.91	7.76							≤ 500
Nitrate as N (mg/L)	3.39	<0.35	13.40	17.20							≤ 11
Fluoride (F mg/L)	0.18	0.31	<0.09	<0.09							≤ 1.50
Chemical Oxygen Demand (COD mg/L)	4.00	4.00	<1	3.00							
Oxygen Absorbed (AO4 mg/L)											
Oxygen Dissolved (DO mg/L)	6.88	6.77	6.73	6.76							
Ammonia as Ammonium (N mg/L)	<0.45	<0.45	<0.45	<0.45							≤ 1.5
Phosphate as P (mg/L)	<0.03	<0.03	<0.03	<0.03							
Aluminium (Al ppm)	<0.01	<0.01	<0.01	<0.01							≤ 0.30
Arsenic (As ppm)	<0.005	0.01	<0.005	<0.005							≤ 0.01
Chromium (Cr mg/L)	<0.01	<0.01	<0.01	<0.01							≤ 0.05
Cobalt (Co mg/L)	<0.01	<0.01	<0.01	<0.01							≤ 0.5
Copper (Cu mg/L)	<0.01	<0.01	<0.01	<0.01							≤ 2
Cyanide (CN mg/L)	<0.01	<0.01	<0.01	<0.01							≤ 0.2
Iron (Fe mg/L)	<0.01	<0.01	<0.01	<0.01							≤ 2
Lead (Pb mg/L)	<0.01	<0.01	<0.01	<0.01							≤ 0.01

Manganese (Mn mg/L)	<0.01	0.04	<0.01	<0.01							≤ 0.4
Nickle (Ni mg/L)	<0.01	<0.01	<0.01	<0.01							≤ 0.07
Uranium (U mg/L)	<0.01	<0.01	<0.01	<0.01							≤ 0.03
Zinc (Z mg/L	<0.01	<0.01	<0.01	0.02							≤ 5
Ion Difference (%)	-0.01	-0.02	-0.03	-0.02							

Table 5.5B Water Quality Results: Newly commissioned boreholes

	MAN-BH2D	MAN-BH2D	MAN-BH2M	MAN-BH2S	MAN-BH3D	MAN-BH3M	MAN-BH3S	MAN-BH4D	MAN-BH4M	MAN-BH4S	SANS 241-1:2015 Standard Limits
Sample date	23/05/2017	03/07/2017	23/05/2017	23/05/2017	23/05/2017	23/05/2017	23/05/2017	23/05/2017	23/05/2017	23/05/2017	
pH – Value	9.33	7.23	8.19	9.19	8.36	7.23	7.87	7.99	7.16	8.08	≥ 5.0 to ≤ 9.5
Electrical Conductivity (EC mS/m)	70.30	68.80	34.40	21.20	55.40	36.10	24.20	37.10	33.70	27.00	≤ 170
Total Dissolved Solids (TDS mg/L)	389.12	361.69	175.33	109.44	300.93	188.95	125.35	196.16	167.44	135.28	≤ 1200
Calcium (Ca mg/L)	0.28	43.50	30.62	12.00	15.00	27.10	15.50	29.50	26.78	18.30	
Magnesium (Mg mg/L)	0.16	15.10	11.48	6.76	15.50	15.50	10.30	18.40	14.51	11.70	
Sodium (Na mg/L)	163.00	76.60	15.04	13.00	77.80	25.10	14.80	18.00	15.10	8.29	≤ 200
Potassium (K mg/L)	4.36	2.76	4.56	4.54	5.47	6.61	3.08	8.31	9.69	10.10	
Silicon (Si mg/L)	0.34	9.60	5.38	0.14	4.92	14.60	1.21	10.80	15.90	1.24	
Total Alkalinity (mg/L)	318.00	326.00	140.00	66.80	225.00	169.00	67.60	168.00	154.00	115.00	
Chloride (Cl mg/L)	22.80	17.40	11.52	13.70	20.20	6.70	16.50	4.88	3.58	5.94	≤ 300
Sulphate (SO^4 mg/L)	5.40	2.64	7.74	12.20	30.50	6.24	23.40	9.36	4.24	8.39	≤ 500
Nitrate as N (mg/L)	<0.35	1.73	1.64	0.51	<0.35	<0.35	<0.35	1.54	<0.35	<0.35	≤ 11
Fluoride (F mg/L)	1.37	0.36	0.11	0.21	0.82	0.17	0.26	<0.09	0.11	0.16	≤ 1.50
Chemical Oxygen Demand (COD mg/L)	4.00	1.00	4.00	4.00	2.00	<1	2.00	3.00	<1	<1	
Oxygen Absorbed (AO4 mg/L)	1.36	<0.02	3.06	0.30	1.40	<0.1	0.98	1.04	0.08	<0.02	
Oxygen Dissolved (DO mg/L)	5.82	6.88	6.78	6.84	5.91	7.25	5.64	5.88	5.24	5.28	
Ammonia as Ammonium (N mg/L)	0.670	<0.45	2.300	3.190	0.490	<0.45	0.670	<0.45	0.640	2.520	≤ 1.5
Phosphate as P (mg/L)	<0.03	<0.03	<0.03	0.18	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	
Aluminium (Al ppm)	0.05	0.04	<0.01	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.30
Arsenic (As ppm)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	≤ 0.01
Chromium (Cr mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.05
Cobalt (Co mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.5
Copper (Cu mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 2
Cyanide (CN mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.2

Iron (Fe mg/L)	0.04	0.03	0.01	0.02	<0.01	<0.01	0.01	0.07	<0.01	<0.01	≤ 2
Lead (Pb mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.01
Manganese (Mn mg/L)	<0.01	<0.01	0.02	<0.01	<0.01	0.13	0.08	0.02	0.20	0.15	≤ 0.4
Nickle (Ni mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.07
Uranium (U mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.03
Zinc (Z mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 5
Ion Difference (%)	0.01	-0.027	0.00	0.01	-0.014	0.03	0.02	0.03	0.03	0.01	

Table 5.5B Water Quality Results: Newly commissioned boreholes (continued)

	MAN-BH5M	MAN-BH6D	MAN-BH6D	MAN-BH6M	MAN-BH7M	MAN-BH8M	MAN-BH9D	MAN-BH9D	MAN-BH9M	MAN-BH9S	SANS 241-1:2015 Standard Limits
Sample date	23/05/2017	23/05/2017	28/06/2017	23/05/2017	22/08/2017	22/08/2017	15/09/2017	16/09/2017	23/08/2017	23/08/2017	
pH – Value	8.79	7.87	7.23	7.49	8.08	7.61	7.32	8.14	7.88	8.05	≥ 5.0 to ≤ 9.5
Electrical Conductivity (EC mS/m)	31.40	42.10	68.40	37.90	40.40	56.10	43.50	45.80	39.60	36.40	≤ 170
Total Dissolved Solids (TDS mg/L)	173.67	227.62	351.08	231.18	203.55	299.84	222.55	246.41	234.79	212.70	≤ 1200
Calcium (Ca mg/L)	17.00	22.30	48.60	33.30	29.40	33.80	27.20	38.52	34.10	28.31	
Magnesium (Mg mg/L)	10.90	11.60	17.40	17.40	13.90	21.90	25.80	20.76	17.11	14.20	
Sodium (Na mg/L)	19.10	45.40	63.30	15.20	23.60	43.20	18.10	28.11	12.23	9.31	≤ 200
Potassium (K mg/L)	9.06	3.47	2.71	4.86	9.99	6.36	4.72	2.19	9.17	8.58	
Silicon (Si mg/L)	1.44	14.30	10.40	23.40	1.19	6.01	6.50	0.23	10.66	2.81	
Total Alkalinity (mg/L)	108.00	152.00	323.00	108.00	181.00	279.00	186.00	221.00	132.00	68.80	
Chloride (Cl mg/L)	12.90	14.10	16.40	8.59	8.65	8.47	18.20	12.08	23.90	21.97	≤ 300
Sulphate (SO^4 mg/L)	19.60	13.50	<0.5	36.50	5.73	12.80	3.88	4.87	3.91	6.15	≤ 500
Nitrate as N (mg/L)	3.25	5.71	1.93	11.40	0.76	0.44	2.53	1.41	11.22	18.50	≤ 11
Fluoride (F mg/L)	0.16	0.51	0.27	<0.09	<0.09	0.10	0.72	0.57	<0.09	0.26	≤ 1.50
Chemical Oxygen Demand (COD mg/L)	<1	<1	<1	<1	34.00	3.00	2.00	<1	4.00	7.00	
Oxygen Absorbed (AO4 mg/L)	0.40	0.66	<0.02	1.58			1.30	<0.02			
Oxygen Dissolved (DO mg/L)	6.31	7.11	6.94	6.99	6.10	6.02	7.85	6.97	6.41	5.70	
Ammonia as Ammonium (N mg/L)	4.450	<0.45	<0.45	<0.45	<0.45	2.870	0.630		3.410	<0.45	≤ 1.5
Phosphate as P (mg/L)	<0.03	0.05	<0.03	<0.03	<0.03	<0.03	0.06	0.04	<0.03	<0.03	
Aluminium (Al ppm)	<0.01	<0.01	0.03	<0.01	0.03	<0.01	0.01	<0.01	0.01	0.15	≤ 0.30
Arsenic (As ppm)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	≤ 0.01
Chromium (Cr mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.05
Cobalt (Co mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.5

Copper (Cu mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 2
Cyanide (CN mg/L)	<0.01	<0.01	<0.01	<0.01			<0.01	<0.01			≤ 0.2
Iron (Fe mg/L)	<0.01	0.06	0.02	0.03	0.24	<0.01	0.08	0.02	1.04	0.51	≤ 2
Lead (Pb mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.01
Manganese (Mn mg/L)	0.01	0.03	<0.01	<0.01	0.04	0.16	0.04	0.02	0.03	0.03	≤ 0.4
Nickle (Ni mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.07
Uranium (U mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.03
Zinc (Z mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 5
Ion Difference (%)	-0.01	0.00	-0.03	-0.01	-0.01	-0.03	-0.01	0.00	0.00	-0.03	

Table 5.5B Water Quality Results: Newly commissioned boreholes (continued)

	MAN-BH10M	MAN-BH11D	MAN-BH11D	MAN-BH11S	MAN-BH12D	MAN-BH12M	MAN-BH12S	MAN-BH13D	SANS 241-1:2015 Standard Limits
Sample date	22/08/2017	15/08/2017	23/08/2017	23/08/2017	22/08/2017	22/08/2017	22/08/2017	22/08/2017	
pH – Value	7.26	8.47	8.78	7.20	8.74	8.02	7.92	8.76	≥ 5.0 to ≤ 9.5
Electrical Conductivity (EC mS/m)	52.80	116.00	116.00	95.90	124.00	66.30	103.00	125.00	≤ 170
Total Dissolved Solids (TDS mg/L)	289.22	678.63	616.91	526.52	651.66	355.39	537.95	684.84	≤ 1200
Calcium (Ca mg/L)	53.40	3.53	2.20	143.00	1.61	31.20	45.60	2.84	
Magnesium (Mg mg/L)	22.80	2.19	0.99	26.30	0.68	19.50	37.00	1.69	
Sodium (Na mg/L)	15.40	277.21	249.00	14.40	271.00	74.80	99.30	260.27	≤ 200
Potassium (K mg/L)	2.70	3.44	3.69	7.31	2.98	5.33	4.42	6.78	
Silicon (Si mg/L)	10.30	3.52	1.95	6.02	4.35	2.69	2.90	26.18	
Total Alkalinity (mg/L)	181.00	559.80	509.00	270.00	538.00	288.00	297.00	562.00	
Chloride (Cl mg/L)	11.00	53.30	53.84	156.25	25.40	22.60	77.22	42.90	≤ 300
Sulphate (SO^4 mg/L)	29.40	<0.5	0.99	14.07	21.10	20.49	92.61	9.23	≤ 500
Nitrate as N (mg/L)	9.84	<0.35	<0.35	0.35	0.86	0.99	<0.35	<0.35	≤ 11
Fluoride (F mg/L)	<0.09	1.86	<0.09	<0.09	0.19	<0.09	<0.09	7.40	≤ 1.50
Chemical Oxygen Demand (COD mg/L)	6.00	13.00	0.00	85.00	8.00	0.00	11.00	32.00	
Oxygen Absorbed (AO4 mg/L)		0.30							
Oxygen Dissolved (DO mg/L)	6.38	6.62	6.02	4.74	6.68	6.38	6.15	6.59	
Ammonia as Ammonium (N mg/L)	1.670	0.830	<0.45	<0.45	1.610	1.617	2.683	0.750	≤ 1.5
Phosphate as P (mg/L)	<0.03	0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.04	
Aluminium (Al ppm)	<0.01	0.02	0.05	<0.01	0.01	0.07	<0.01	14.46	≤ 0.30
Arsenic (As ppm)	<0.005	0.01	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	≤ 0.01
Chromium (Cr mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.05

Cobalt (Co mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.5
Copper (Cu mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 2
Cyanide (CN mg/L)		<0.01							≤ 0.2
Iron (Fe mg/L)	<0.01	0.04	0.75	0.64	<0.01	2.08	<0.01	0.99	≤ 2
Lead (Pb mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.01
Manganese (Mn mg/L)	0.17	<0.01	<0.01	1.00	<0.01	0.06	0.14	<0.01	≤ 0.4
Nickle (Ni mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.07
Uranium (U mg/L)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 0.03
Zinc (Z mg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	≤ 5
Ion Difference (%)	0.02	-0.01	-0.03	0.00	0.00	-0.01	0.00	0.02	

6. AQUIFER CHARACTERISATION

6.1. Groundwater Vulnerability

The aquifer(s) underlying the study area were classified in accordance with "A South African Aquifer System Management Classification, WRC Report No KV 77/95, December 1995."

With reference to the Map: Aquifer Classification of South Africa, the following regional characteristics:

The vulnerability, or the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer is classified as **moderate**.

Aquifer susceptibility, a qualitative measure of the relative ease with which a groundwater body can be potentially contaminated by anthropogenic activities and which includes both aquifer vulnerability and the relative importance of the aquifer in terms of its classification is classified as **medium**.

6.2. Aquifer Classification

Classification was done in accordance with the following definitions for Aquifer System Management Classes:

Sole Aquifer System:

An aquifer which 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 formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good (less than 150*mS/m* Electrical Conductivity).

Minor Aquifer System:

These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.

Non-Aquifer System:

These are formations with negligible permeability that are regarded as not containing ground water in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, ground water flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

Ratings for the Aquifer System Management and Second Variable Classifications:

Aquifer System Management Classification		
Class	**Points**	**Project Area**
Sole Source Aquifer System:	6	-
Major Aquifer System:	4	-
Minor Aquifer System:	2	2
Non-Aquifer System:	0	-
Special Aquifer System:	0 - 6	-
Second Variable Classification Weathering/Fracturing		
Class	**Points**	**Project Area**
High:	3	-
Medium:	2	-
Low:	1	1
Note:		

Ratings for the Ground Water Quality Management Classification System:

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

The project area aquifer(s), in terms of the above definitions, is classified as a **minor aquifer system** (see Section 4.9).

6.3. Aquifer Protection Classification

Level of ground water protection based on the Ground Water Quality Management Classification:

GQM Index = Aquifer System Management x Aquifer Vulnerability

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

The ratings for the Aquifer System Management Classification and Aquifer Vulnerability Classification yield a Ground Water Quality Management Index of 4 for the project area, indicating that **medium** level ground water protection may be required.

In terms of DWAF's overarching water quality management objectives which is ***(1)*** protection of human health and ***(2)*** the protection of the environment, the significance of this aquifer classification is that if any potential risk exists, measures must be put in place to limit the risk to the environment, which in this case is the protection of the Primary Underlying Aquifer, the streams which drain the study area, and the External Users' of ground water in the area.

7. GROUNDWATER MODELLING

7.1. Software Model Choice

The FEFLOW finite element numerical groundwater flow and transport software package was used to perform various scenarios and calculate aspects such as:

- Groundwater flow directions;
- Decant areas/volumes/quality;
- Mine water balance.

7.2. Model Set-up and Boundaries

The following describes the numerical model:

- The numerical model grid consisted of 9 layers and 2.1 million mesh elements to accommodate the complex geometry of the coal seams and aquifer layers:
    - Karoo-Ecca aquifers listed in Tables 7.1A-D, 7.2A-D, were incorporated as the top 4 model-layers;
    - The underlying Dwyka was represented by model-layer-5;
    - Intrusive rocks were represented by model-layer-6;
    - A layer to minimum 70m deep, below the intrusive rocks were represented by model-layer-7;
    - The Black Reef was represented by model-layer-8;
    - The bottom layer of the model, to a depth of 305m was represented in model-layer-9;
    - Model-layers were incorporated/adapted to reflect the expected changing aquifer hydraulics with depth for both the Karoo- and non-Karoo geology;
    - All underground mining areas were incorporated as discrete elements, which enabled the simulation of free-flow;
- Post-mining aquifer parameters were incorporated as follows:
    - Opencast mining was assumed to have an aquifer hydraulic conductivity of 100m/d;
    - Recharge on all rehabilitated opencast mining was assumed 12% of MAP;
    - The extent of the model grid and cell size of minimum 12m in model sensitive zones, were believed to be sufficient to simulate groundwater flow accurately enough for this report;
- Steady-state groundwater flow modelling was performed to simulate pre-mining groundwater level elevations and flow directions;
- Steady-state and transient groundwater flow modelling were performed to simulate post-mining groundwater level elevations and flow directions;
- Transient flow modelling was performed to determine:
    - Groundwater base-flow volumes during mining/operation and post-mining;
    - Dewatering impact zone;
    - Time to decant;
    - Contamination movement;
- Water balance calculations took cognisance of groundwater base-flow/inflow and rainfall recharge;
- Several spreadsheet calculations were performed in support of the numerical model calculations.

Rivers and non-perennial streams serve as hydraulic boundaries to the local groundwater flow system. Aquifers discharge into these features (i.e. groundwater base-flow), especially during the rainy season when groundwater levels rise due to rainfall recharge. Internal to the model domain, such features were incorporated as drainage boundary conditions.

The extent of the model domain (as indicated in Figure 2.1), were chosen along local non-perennial streams, rivers and local topographical highs, which are located far enough from the Manungu Colliery, to have no influence on the model accuracy (8km to the west, 9km to the north, 6km to the west, and 6km to the east).

7.3. Groundwater Elevation and Gradient

Pre-mining groundwater flow directions/gradients are presented in Figure 7.1. Post-mining groundwater flow directions/gradients for the August 2018 mine design are presented in Figure 7.2 for aquifer depths of 35m below surface. These elevations are almost identical to the groundwater levels at the level of the coal floor.

Prior to mining, groundwater flow directions were primarily northeast across the pit, with a northwestern component in the northwestern region of the Pit. Two northward-draining non-perennial streams flank the Manungu Pit to the west and east. The western spruit appears to have a smaller effect on groundwater flow direction than the eastern spruit, because groundwater flow from the west, is also toward this eastern spruit. The combined effect of both streams prior to mining was that the groundwater levels in the pit area were a relatively flat. During mining, the Pit will draw groundwater flow from all sides in its proximity. After mining, the regional groundwater flow directions will similar to the pre-mining environment, but locally, groundwater flow will be altered significantly as described in Section 8.

During the pre-mining situation, groundwater gradients west and southwest of the Pit were 0.8%, and 1% to the east of the Pit near the eastern stream. Within the pre-mined Pit, groundwater gradients were ≤0.5%.

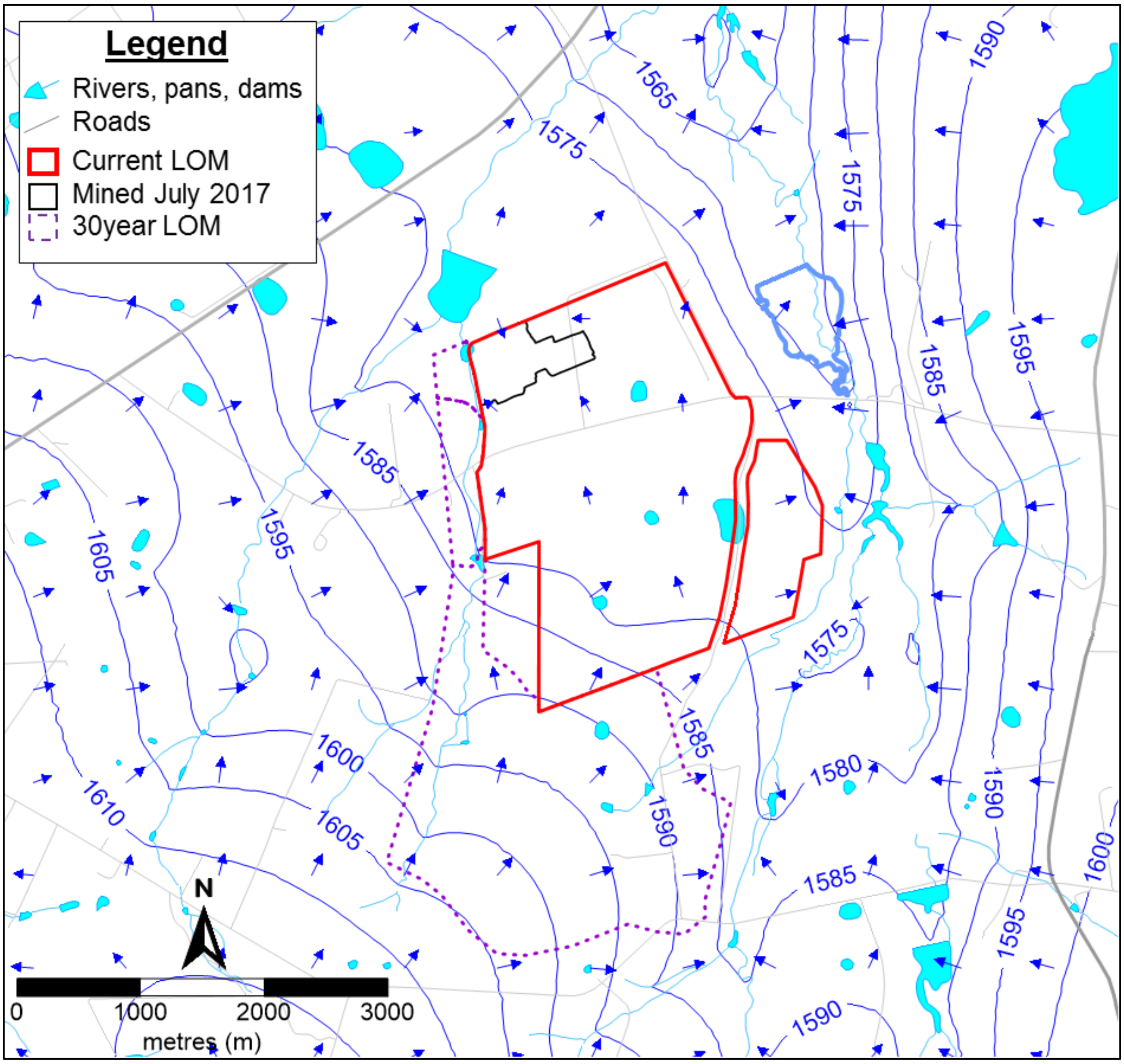


Figure 7.1 Steady state pre-mining groundwater levels (mamsl) and flow directions

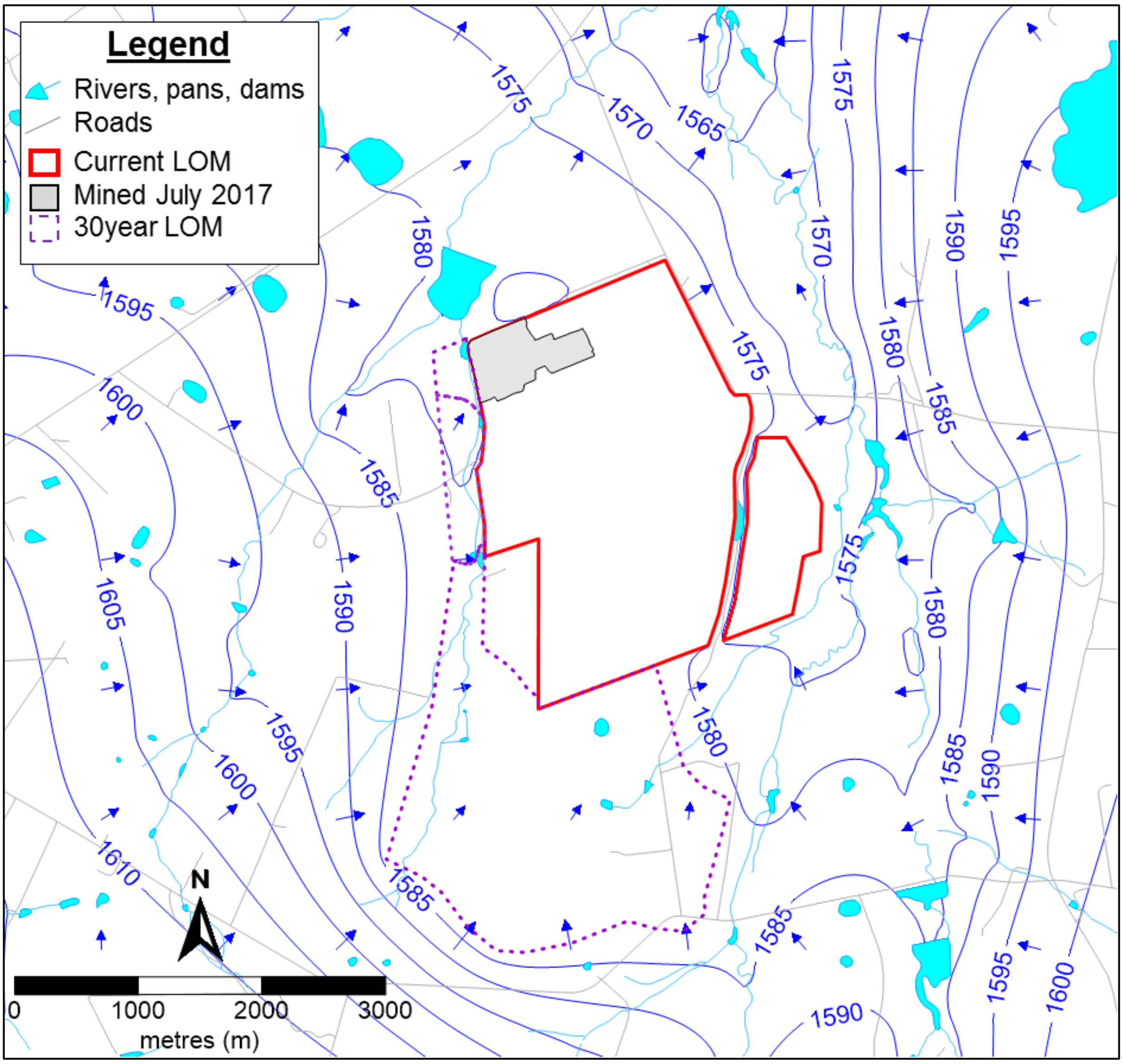


Figure 7.2 ***Long-term post-mining groundwater levels (mamsl) and flow directions in the Karoo aquifers approximately 35m below surface***

7.4. Geometric Structure of the Model

One of the primary concerns in a post-mining situation is decant of contaminated mine water. In this regard, the elevations of the coal seam in relation to the surface topography and surrounding streams are very important, i.e. aquifer geometry. Cross-sections are included as Figure 7.4 (see location of cross-section lines in Figure 7.3). Elevations and the depth to the coal seam floor are indicated in Figures 7.5 and 7.6 respectively.

It is clear that the dolerite sills in the area will have major influence of rainfall recharge to the deeper aquifers.

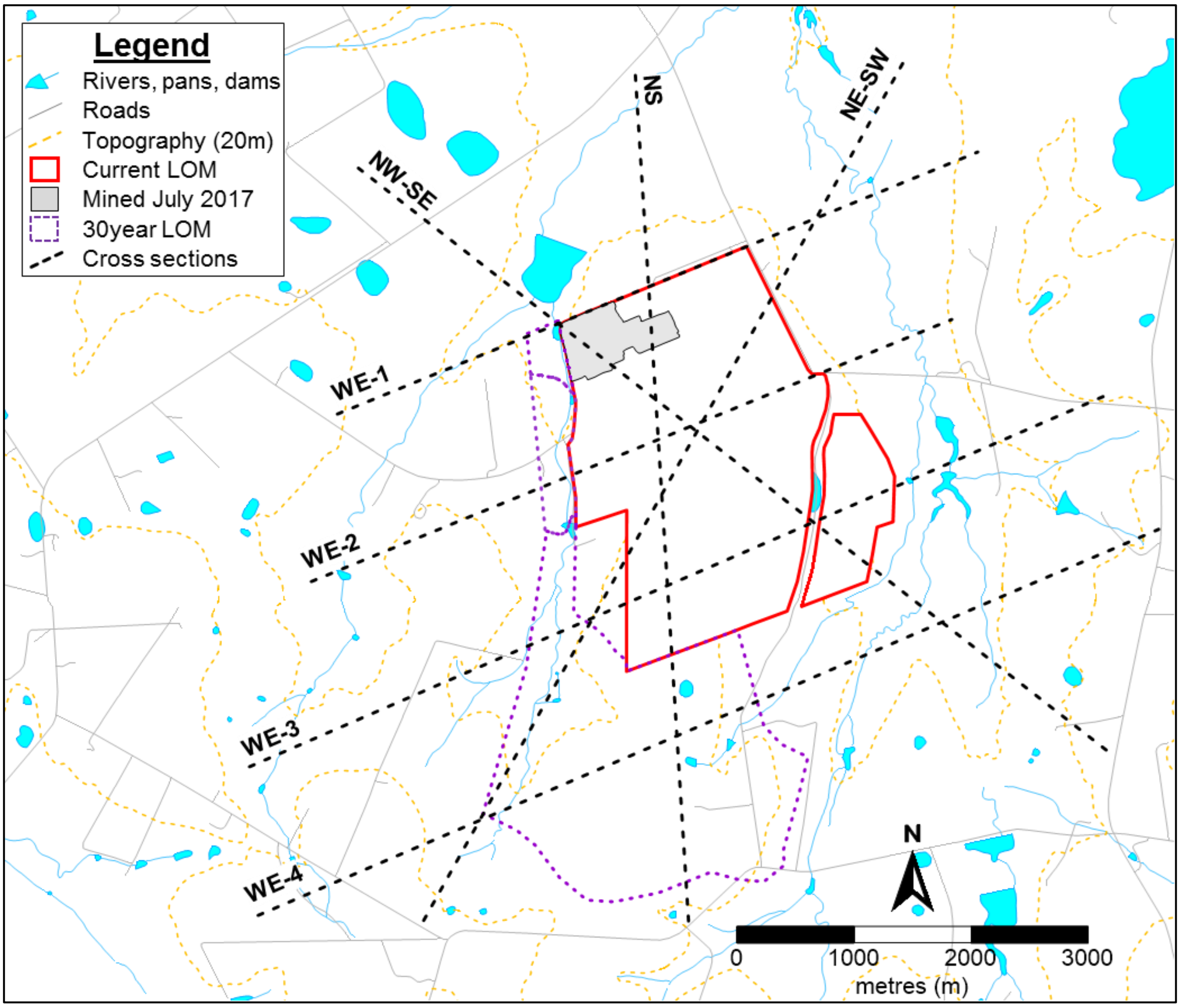
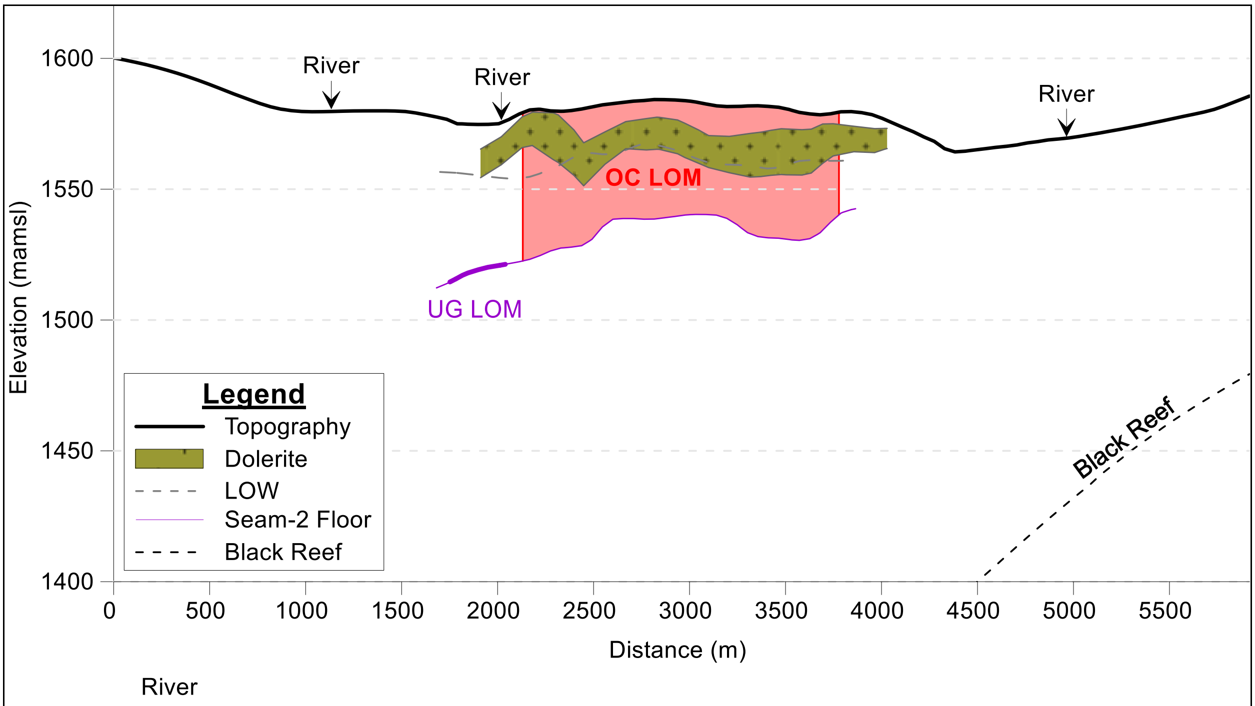
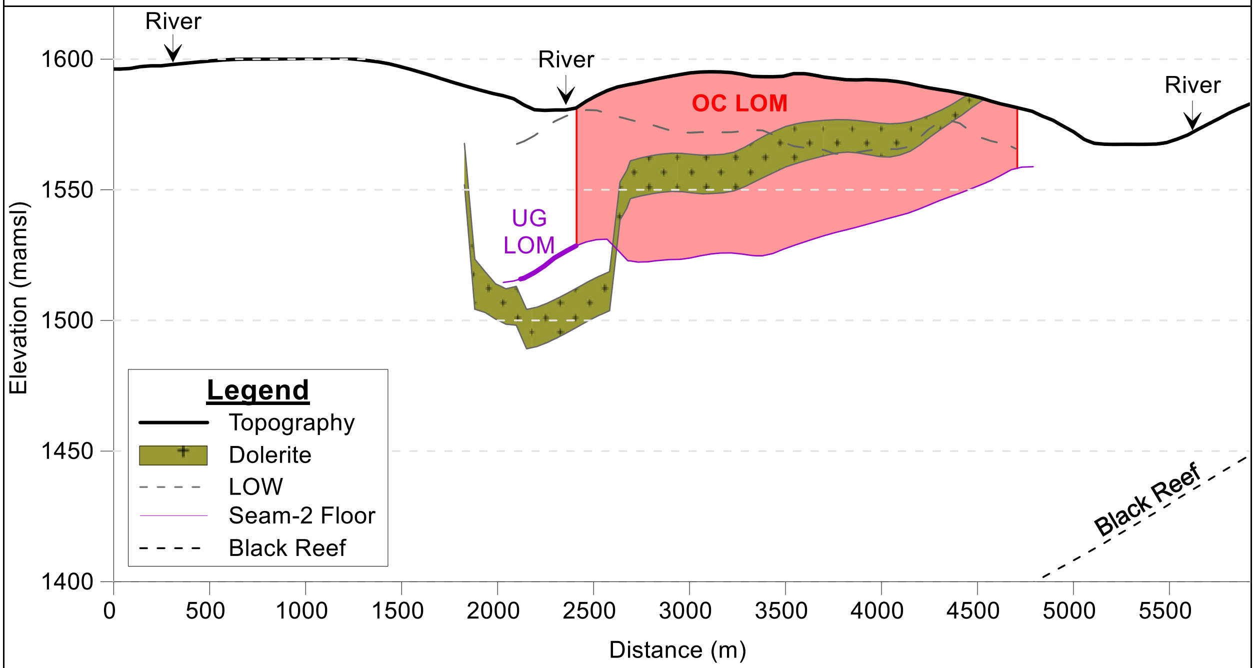


Figure 7.3 Location of cross-sections



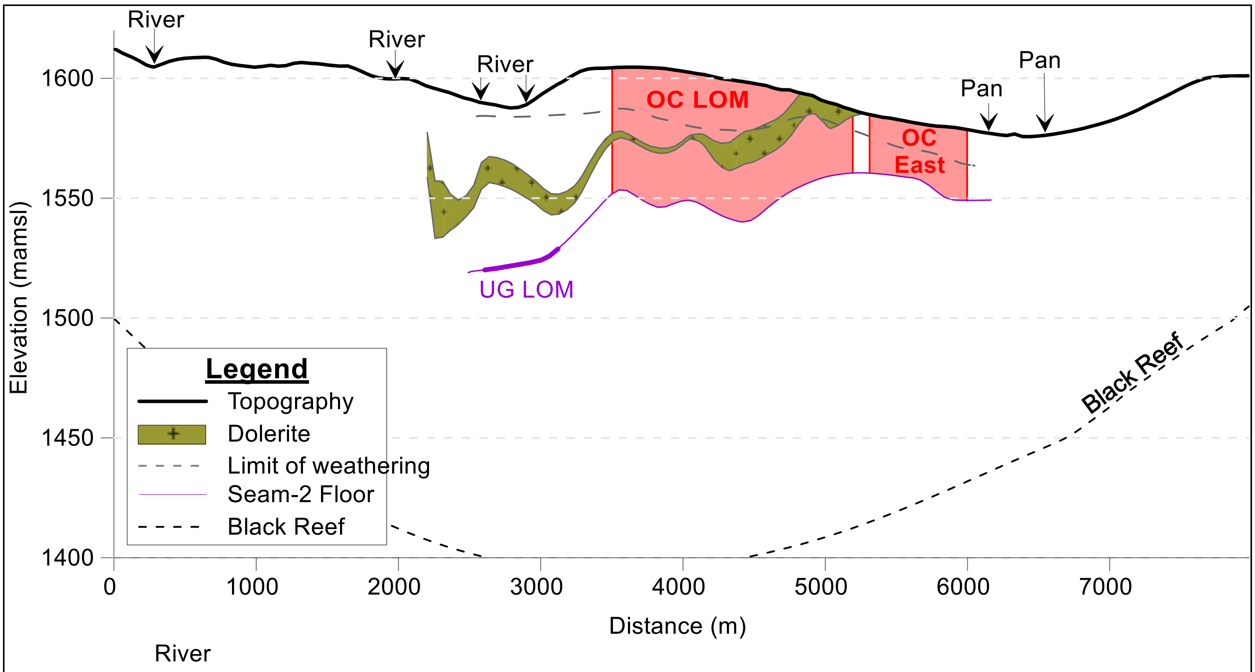
Elevation (mamsl)
1600
1550
1500
1450
1400
River
River
River
OC LOM
UG LOM
Black Reef
Legend
Topography
Dolerite
LOW
Seam-2 Floor
Black Reef
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Distance (m)
River

WE-1

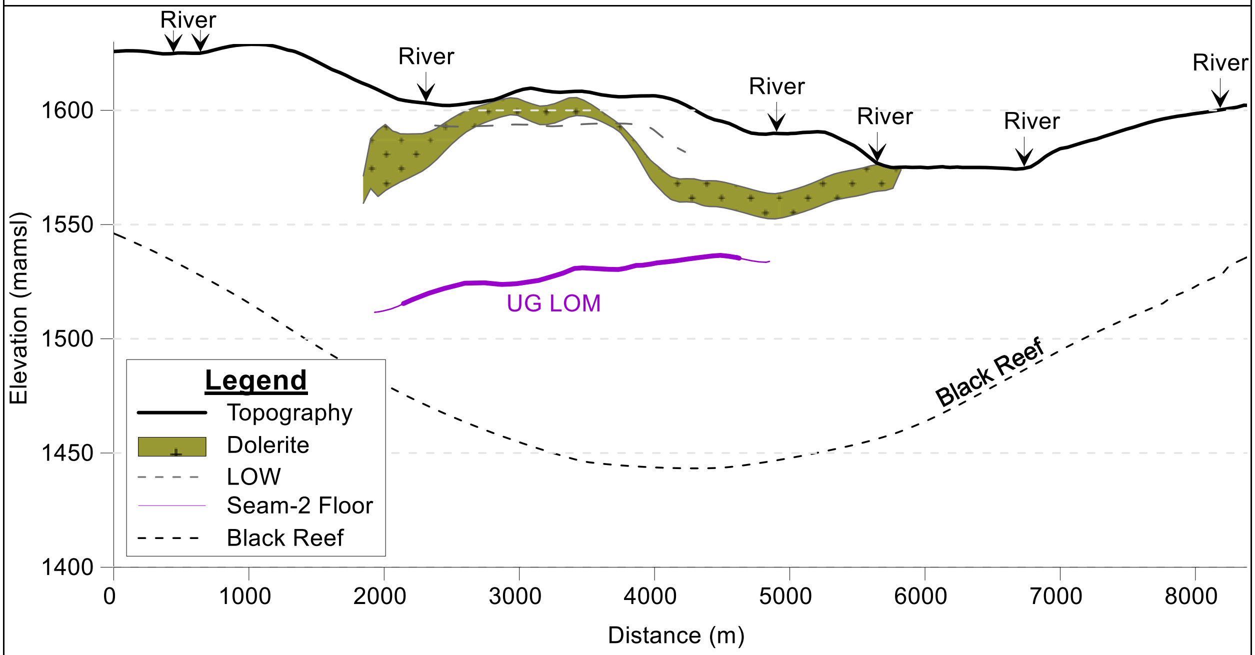


Elevation (mamsl)
1600
1550
1500
1450
1400
River
River
River
OC LOM
UG
LOM
Black Reef
Legend
Topography
Dolerite
LOW
Seam-2 Floor
Black Reef
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
Distance (m)

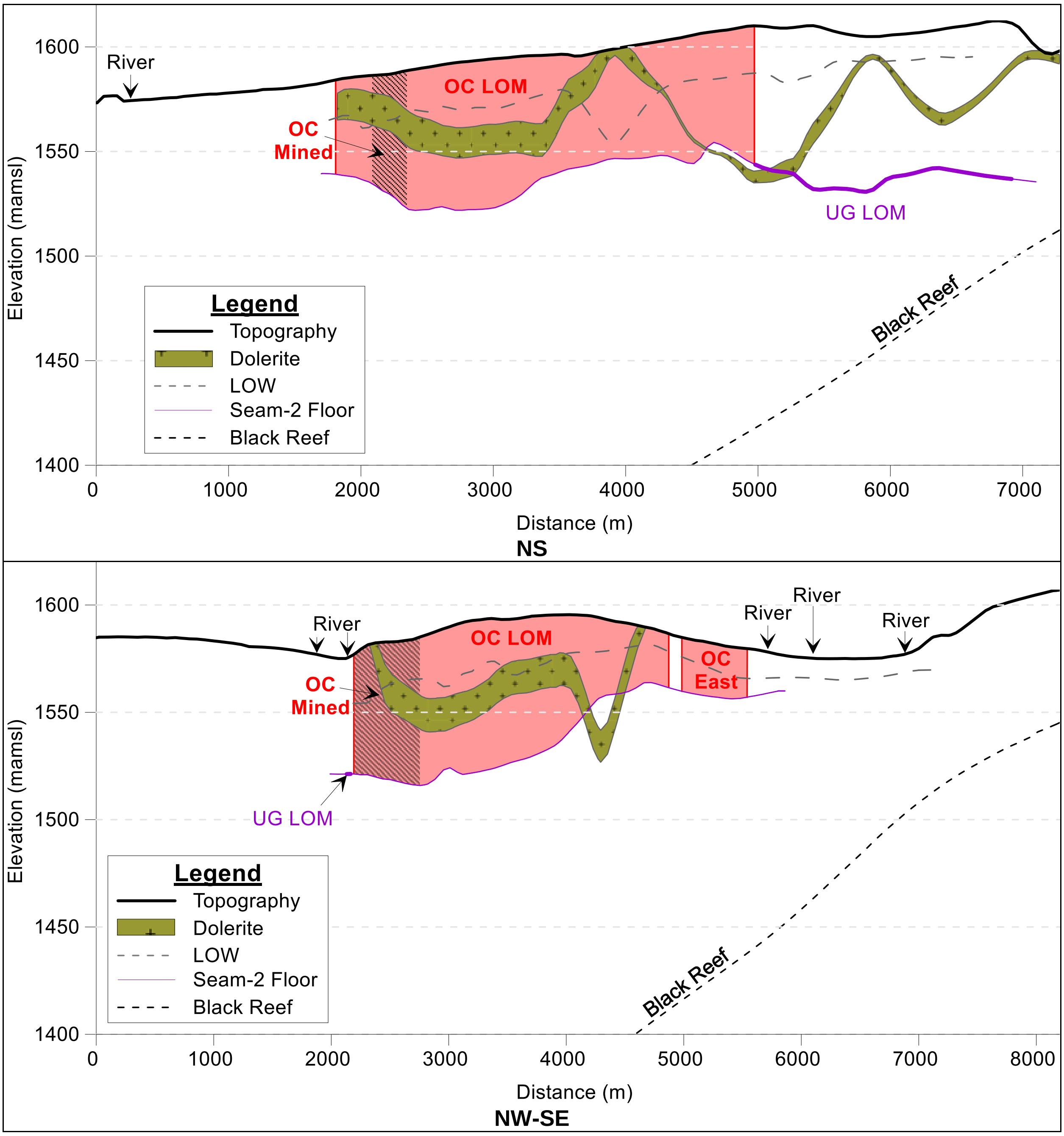
WE-2


River
River
River
Pan
Pan
OC LOM
OC East
UG LOM
Black Reef
Elevation (mamsl)
1600
1550
1500
1450
1400
Legend
Topography
Dolerite
Limit of weathering
Seam-2 Floor
Black Reef
0
1000
2000
3000
4000
5000
6000
7000
Distance (m)
River

WE-3


River
River
River
River
River
River
UG LOM
Black Reef
Elevation (mamsl)
1600
1550
1500
1450
1400
Legend
Topography
Dolerite
LOW
Seam-2 Floor
Black Reef
0
1000
2000
3000
4000
5000
6000
7000
8000
Distance (m)

WE-4


River
OC LOM
OC
Mined
UG LOM
Black Reef
Legend
Topography
Dolerite
LOW
Seam-2 Floor
Black Reef
Elevation (mamsl)
Distance (m)
NS
River
River
River
River
OC LOM
OC
East
OC
Mined
UG LOM
Black Reef
Legend
Topography
Dolerite
LOW
Seam-2 Floor
Black Reef
Elevation (mamsl)
Distance (m)
NW-SE

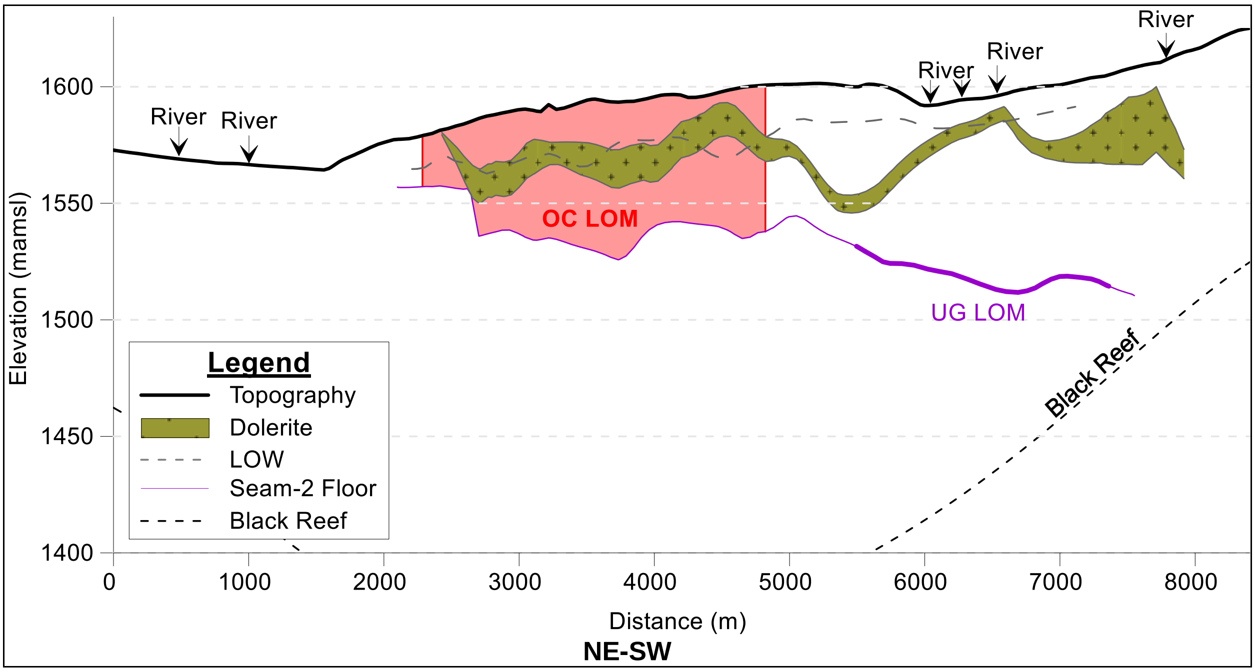


Figure 7.4 Cross-sections (see location of cross-section in Figure 7.3)

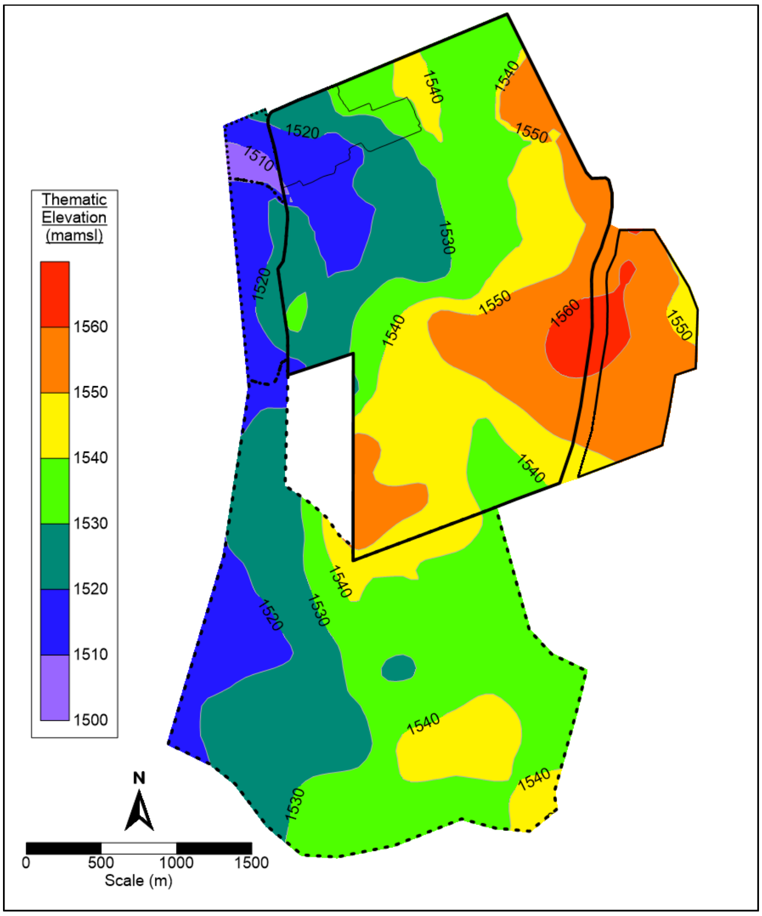


Figure 7.5 Thematic depiction of coal Seam-2 elevations (mamsl)

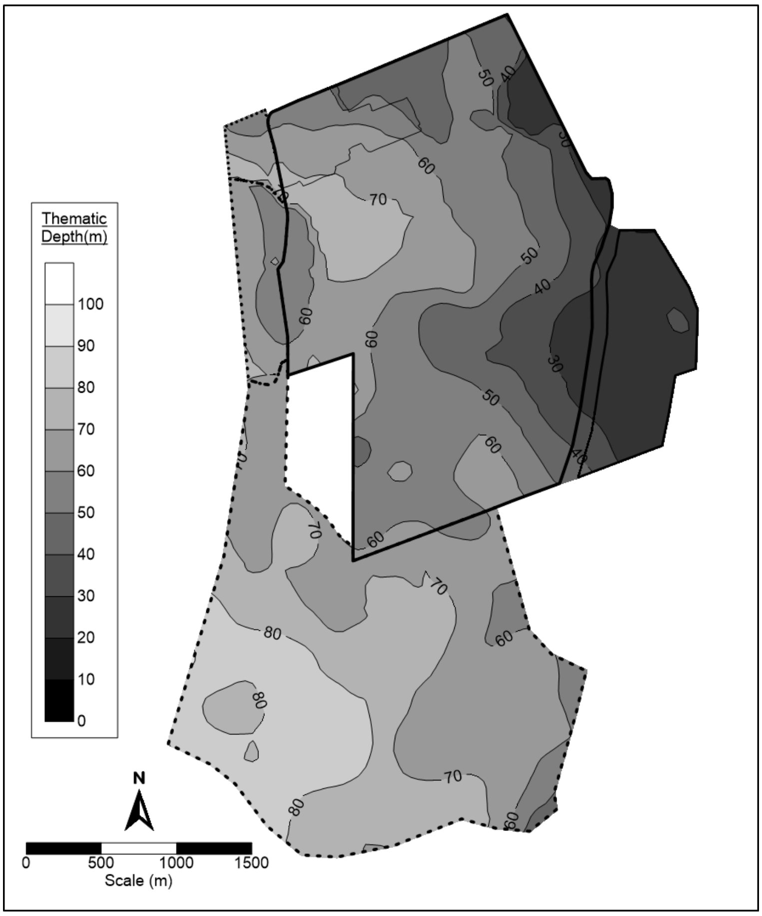


Figure 7.6 Thematic depiction of coal Seam-2 depths (m)

7.5. Groundwater Sources and Sinks

Rainfall is the only natural water source to the groundwater balance. No other/artificial water is generated otherwise (i.e. no irrigation or rivers draining over the area). Farmer dams in the eastern stream can contribute to a dewatered shallow weathered zone aquifer. The deepest aquifers below the Karoo Ecca probably benefits relatively slowly from these dams.

The only sinks to the groundwater resource are groundwater abstraction from boreholes, mine water pumping from the pit and natural evaporation from the pit. Groundwater is abstracted by both the mine (used for domestic all-purposes) and external users (used for agricultural & domestic use). Mine water that is pumped from the pit is used for dust suppression or storage in the pollution control dam.

7.6. Conceptual Model

The major groundwater flow units/aquifers, listed in Tables 7.1A-B and 7.2A-B, were identified and calibrated during the 2017 assessment for the Phase-1 mining period of 18years till 2033 which included numerical groundwater modelling required by the WUL. Numerical modelling for this study did not indicate that the parameters are substantially different.

Based on both the Phase-1 and Phase-2 field studies, the main aquifers identified from top-to-bottom, were:

- Karoo-Ecca (coal-bearing), Vryheid Formation, sandstone with dolerite sill intrusions above the coal Seam-2 in the Phase-1 pit area; which outcrops in regions south of the pit;
- Karoo-Dwyka, tillites with chert fractions, largely cementated to have low hydraulic conductivity below the Phase-1 pit area (see outcrops in Figure 5.1, indicated >1.2km north of Manungu pit);
- "Transition zone", wedged between Karoo rock and Black Reef (estimated 100m to 200m thick, below the Phase-1 pit), consisting of:
    - Dolerite intrusion zone on contact with Transvaal geology, average 15m thick, with the highest borehole yields in the area;
    - Low-yielding dolomite (not the same as the high-yielding Malmani Dolomites ±2.8km north);
    - Granite in places;

  - Tonalite in places;
- Black Reef (150m to 300m below surface beneath the Manungu Phase-1pit).

Based on slug-testing and pump testing of *DWS* monitoring boreholes, external users' survey and newly drilled monitoring boreholes for Manungu Colliery, all indications are that the reserve is not underlain by major leached dolomitic aquifers, which occur to the north (Malmani Dolomites), but instead by a fractured aquifer with a moderate yielding capacity. Higher yielding boreholes (DWS) G37018, 50L/s and G37017, 33L/s are respectively located north (2.5km) and west (2.5km) of Manungu.

On a local scale, the Dwyka is intact and forms a barrier, while on a regional scale interaction can be expected along geological structures or where sinkholes have occurred.

The aquifer with the highest hydraulic conductivity in the area, is an intrusion zone below the Karoo-Dwyka, which is on average 15m thick. Borehole yields range between 0m/d and >5L/s, with an estimated representative hydraulic conductivity of 0.1m/d. Interestingly, groundwater levels recovered very slowly (no full recovery, days after the pumping test), leading to the believe that these aquifers have very low storage capacity and have been partially dewatered.

The above statement on the dewatered state of the intrusion zone was further confirmed; i.e. deeper boreholes, in general, have deeper groundwater levels than shallower boreholes.

The dolerite sill in the Phase-1 pit is found above the Seam-2 and probably restricts rainfall recharge to deeper aquifers. In some boreholes, water-strikes were encountered on top of the sill, but the magnitude of these water-strikes could not be correlated to the depth of the sills. Consequently, the sill was not incorporated as a separate numerical model layer.

Descriptions and hydraulic characteristics of aquifer layers, incorporated in the numerical groundwater model, are presented in Tables 7.1(A-B) to 7.2(A-B). Karoo-Dwyka, dolomites and other geology types, not mentioned in these tables, were assigned the same hydraulic properties to the upper Karoo Ecca and Dwyka aquifers i.e. dependent on depth below surface.

The numerical groundwater flow model was calibrated for rainfall recharge of ±2% of MAP (=14mm/a =3.8x10 5m/d), which is in agreement with hydrogeological assessments in the surrounding coal fields.

Numerical groundwater modelling assumed that recharge to the rehabilitated opencast may be 12% of MAP.

Table 7.1A Aquifer layers – description – Karoo-Ecca

Aquifer	Average depth	Description	Comment
Aquifer-1A	5m to >30m (20m thick)	Soil-clay overburden profile forming part of the shallow weathered zone aquifer	Unconfined to semi-confined conditions. Groundwater levels are shallower after wet rainfall periods or in close proximity to drainage/rivers/streams. Deepest water strikes and depth of hydrogeological weathering used as indicator of zone bottom.
Aquifer-1B	20m to 35m (15m thick)	Highly weathered hard rock profile of the shallow weathered zone aquifer	
		Immediately below shallow weathered zone aquifer, with water-strikes contributing to borehole yields	
		Dolerite sill	
Aquifer-2	35m to 70m (35m thick)	Deep fractured aquifer	Observations have shown that the potential for the Karoo aquifer to transmit water is largely restricted at depths exceeding 60m to 80m below surface. This is assumed to be true for the Pre-Karoo aquifers in the area of investigation.
Aquifer-3	>80m	Deep non-fractured aquifer	Almost all fractures are believed closed.

Table 7.1B Aquifer layers – description – transition zone intrusive sills

Aquifer	Average depth	Description	Comment
Transition zone intrusions	- (average 15m thick)	Highest yielding aquifer. Yields vary substantially in boreholes. Very slow recovery after pump testing	Hydraulic properties assigned irrespective of depth.

Table 7.2A Aquifer layer – parameters – Karoo Ecca, Karoo-Dwyka, dolomite and other

Aquifer Layer	Thickness (m)	hydraulic conductivity (m/d) [m/s]	Storativity	Porosity	Rainfall Recharge (m/d) {mm/a} [%of MAP]
Aquifer-1A	20m	(0.04) [$4.6x10^{-7}$]	0.04	0.08	($3.8x10^{-5}$) {14} [2]
Aquifer-1B	15m	(0.04) [$4.6x10^{-7}$]	0.04	0.08	
Aquifer-2	35m	(0.005) [$5.8x10^{-8}$]	0.01	0.06	
Aquifer-3		(0.001) [$5.8x10^{-8}$]	0.01	0.06	

Table 7.2B Aquifer layer – parameters – transition zone intrusive sills

Aquifer Layer	Thickness (m)	Permeability (m/d) [m/s]	Storativity	Porosity	Rainfall Recharge (m/d) {mm/a} [%of MAP]
Transition zone intrusions	(average 15m thick))	(0.1) [$1.2x10^{-6}$]	0.01	0.02	Not applicable

7.7. Numerical Model

A complete description is provided in Section 7.2.

7.8. Results of the Model

7.8.1 Pre- Mining

Pre-mining groundwater level elevations and groundwater flow directions are depicted in Figure 7.1 (Section 7.3). Prior to mining, groundwater flow directions were primarily northeast across the pit, with a northwestern component in the northwestern region of the Pit. Two northward-draining non-perennial streams flank the Manungu Pit to the west and east. The western spruit is believed to have a smaller effect on groundwater flow direction than the eastern spruit, because groundwater flow from the west (except for the northwestern corner), was also toward this eastern spruit. The combined effect of both streams prior to mining was that the groundwater levels in the pit area were considered a relatively flat.

7.8.2 During Mining

Pertinent opencast water balance information during the operational phase is provided in Tables 7.3 and 7.4. The following main conclusions were reached with regard to the opencast mining:

- Mine water balance – opencast mining:
  - The main components of the opencast water balance were identified as groundwater inflow and direct rainfall recharge on various areas inside the opencast:
  - The groundwater volumes expected to flow into opencast, are summarised in Table 7.3:
    - Groundwater inflow volumes gradually increased over the first year, where after inflow increased at a slower rate; to be the case until the end of mining;
    - The minimum inflow volumes are estimated at 50% of the predicted average volumes during dry rainfall periods on an annual basis, and even lower during excessive droughts;
    - The maximum inflow volumes may be twice the average predictions during wet rainfall periods on an annual basis;
    - It is also possible that the maximum volumes may be exceeded for short periods (during the initial stages of mining, or during excessively wet rainfall periods);
  - The *Letsolo* (2017) estimates of ($600m^3/d$-$1000m^3/d$) compares favourably to the groundwater model predictions for the total first cut ($600m^3/d$);
  - Rainfall seasonality is therefore the main driver for variations in the mine water balance;
  - The calculated volumes served as input to the detailed operational water balance;
    - Although a rainfall deficit applies on an annual basis (MAP<MAE), summer rainfall will create a positive balance during certain months, especially during "wet" rainfall cycles;
    - On an annual basis, the groundwater inflow components will most likely be smaller than the contribution of rainfall to the total opencast water balance;
  - As indicated in Table 7.3, rainfall recharge to the opencast during the final stages of mining, calculates to $2500m^3/d$ and $350m^3/d$ for the main Pit and the OC-E:
    - Recharge at 12% of MAP on 70% rehabilitated areas; with much higher recharge on the remaining 30% which will not yet be rehabilitated;
    - The water balance will therefore be smaller once these pits are fully rehabilitated;
- In-pit storage of mine water:

- Although it is currently possible to store water in small localised depressions in the coal floor and mined zones, especially where the mine floor is deeper in the west, this may hamper mining progress;
- The blasting of in-pit sumps for water storage is not practical;
- All mine water is currently pumped out;

- The opencast is not expected to decant during the life-of-mine (LOM);
- Impact on groundwater levels (see projected maximum zone of influence in Figure 7.7A&B and summary in Table 7.5):
  - Groundwater levels in the immediate vicinity of the open pits will be influenced;
  - None of the monitoring boreholes are close enough to the pit to have been influenced to date;
  - The main contributing factors are the direction of groundwater flow, depth of mining below the groundwater level, mining schedule and hydraulic aquifer parameters;
  - Although the maximum extent of the dewatering cone should generally not exceed 350m from the Pit perimeter in the Karoo rock environment, various indicators (including numerical modelling) suggests a much wider impact zone (a larger impact zone is indicated in Figure 7.7 of generally 400m-500m wide, but up to 800m to the south – it is important that groundwater monitoring confirms this);
- Impact on groundwater quality:
  - Groundwater flow into the opencast workings is expected to be of similar quality than the background groundwater;
  - When groundwater and rainwater come into contact with loose material in the pits, mine water quality will deteriorate:
    - Currently, mine water quality SO_4 concentrations range between 150mg/L and 400mg/L;
    - If all in-pit water is pumped out within a relatively short period (<3months), the water will not acidify and SO_4 concentrations should not exceed 800mg/L;
    - If in-pit water is allowed to collect in the lowest regions for longer periods, it may eventually deteriorate, depending on the oxygen-water-rock (carbonaceous material) interaction;
    - Isolated "hot-spots" of higher concentrations and lower pH may exist;
  - Numerical geochemical modelling confirmed that in-pit storage of discard will have an insignificant effect on the long-term Pit mine water quality;
  - The surrounding aquifers are not expected to be impacted in terms of groundwater quality during the Operational Phase, due to groundwater flow being toward the dewatered mine;
- A summary of the Manungu impact on the local groundwater use, is provided in Table 7.5.

Table 7.3 Pertinent water balance information – operational phase

	Pit size (ha)	Elevations (mamsl)			Seam-2 average depth (m)	Post-mining material flooded (%)	Water volumes (m^3/d)				
							Water balance components average		Total water-make		
		Decant	Topo-graphy	Seam-2			Ground-water	Rainfall recharge to OC **	Long-term average	Typical dry season	Typical wet season
OC Main	561	1579	1592.37	1539.19	53.2	75%	760	2516	3276	304	6172
OC E	78	1573	1582.27	1555.42	26.8	65%	240	350	590	96	1060
UG NW	14		1579.3	1510.48	68.8		<40 *		<40	<40	<40
UG W	39		1581.42	1518.48	62.9		<40 *		<40	<40	<40
UG SW	495		1603.32	1531.27	72.1		140 *		142	85	200
							TOTAL FOR MINE		4050 #	<1000	±7 500

* Essentially rainfall recharge reaching the underground mining areas (passing through overlying dolerite sill).
** Estimate only (assuming 70% rehabilitation while mining final cut; water engineer will perform detailed work, inclusive of evaporation component.
# Used for post-closure WUL requires = 4050m^3/d (ranging between 1000m^3/d and ±7500m^3/d)

Table 7.4 Time till flooding

	If underground sealed from opencast (years)	If opencast interact freely with underground (years)	Elevation to flood (mamsl)	Estimated volume that can be stored (Million m^3)
OC Main	20-30	25-40	1579 = decant	2.7
OC E	15-20		1573 = decant	44.5
UG NW	Several decades	<2	1502 to 1527 *	0.3
UG W	Several decades	<5	1508 to 1534 *	0.8
UG SW	Several decades	<10	1510 to 1555 *	9.6

* Minimum floor till maximum roof (estimate) to flood underground

Table 7.5 Boreholes that may be impacted by mining activities

	Operational Phase		Post-mining Phase		Coordinate		Farm			Site status
	Impact on groundwater									
	Level	Quality **	Level	Quality	Latitude	Longitude	Owner	Name	No	
MBH01	X		X	X	-26.2248	28.6949	Manungu Coal Mine	Weilaagte	271/9	Manungu monitoring
MBH2					-26.2240	28.6950				
MBH3					-26.2288	28.6959				
MBH4					-26.2312	28.6972				
MBH5					-26.2331	28.7015				
MBH12					-26.2590	28.6977				
MBH12-Rep					-26.2599	28.6938				
MBH16					-26.2653	28.6876				
MBH19	X		X	X	-26.2286	28.6968	Kobus Oelofse	Weilaagte	271/8	Manungu monitoring
G37030					-26.2588	28.6927				
MWQ1 *					-26.2382	28.67664				
MWQ3 *					-26.2326	28.70714				
MWQ4 *					-26.2311	28.71144				
MWQ5 *					-26.2391	28.66237				
MWQ6 *					-26.208	28.68672				
PCD *					-26.2231	28.69862				
PCD Drainage *					-26.2225	28.6993				
MBH 01 Gate (Tap) *					-26.2248	28.69488				
MBH 17 JoJo Tank *					-26.2237	28.69889				
MBH Temp Tap (Trollop tap) *					-26.2312	28.69724				
MAN-BH2D	X		X	X	-26.2372	28.6790				New monitoring borehole group
MAN-BH2M					-26.2372	28.6790				
MAN-BH2S					-26.2371	28.6790				
MAN-BH3D	X			X	-26.2368	28.7038				New monitoring borehole group
MAN-BH3M					-26.2367	28.7038				
MAN-BH3S					-26.2367	28.7038				
MAN-BH4D	X		X	X	-26.2397	28.6944				New monitoring borehole group
MAN-BH4M					-26.2396	28.6945				
MAN-BH4S					-26.2396	28.6945				
MAN-BH5M	X		X	X	-26.2342	28.6834				New monitoring borehole
MAN-BH7M	X		X	X	-26.2431	28.6829				New monitoring borehole
MAN-BH8M	X			X	-26.2226	28.6995				
MAN-BH9D	X		X	X	-26.2483	28.6981				New monitoring borehole group
MAN-BH9M					-26.2483	28.6980				
MAN-BH9S					-26.2484	28.6980				
MAN-BH10M				X	-26.2408	28.7062				New monitoring borehole
MAN-BH11D	X		X	X	-26.2479	28.6878				New monitoring borehole group
MAN-BH11S					-26.2478	28.6878				
MAN-BH12D					-26.2568	28.67833				New monitoring borehole group
MAN-BH12M					-26.2568	28.67830				
MAN-BH12S					-26.2568	28.67827				
MAN-BH13D					-26.2656	28.67466				New monitoring borehole

* *Not a borehole (e.g. surface water or mine water)*

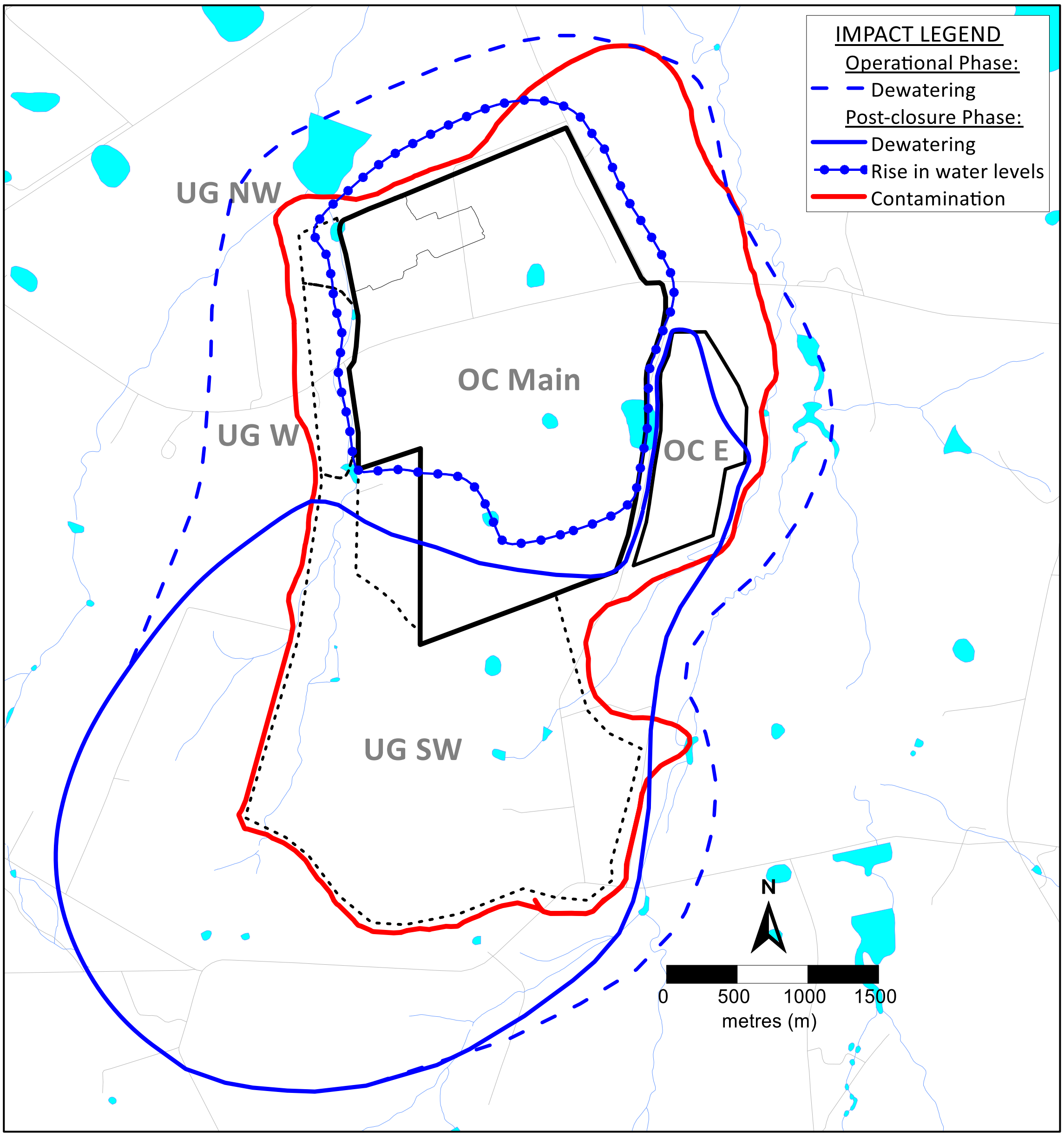


Figure 7.7A ***Groundwater level impact zone (operational and post-closure phases) and groundwater quality impact zone (post-closure phase)***

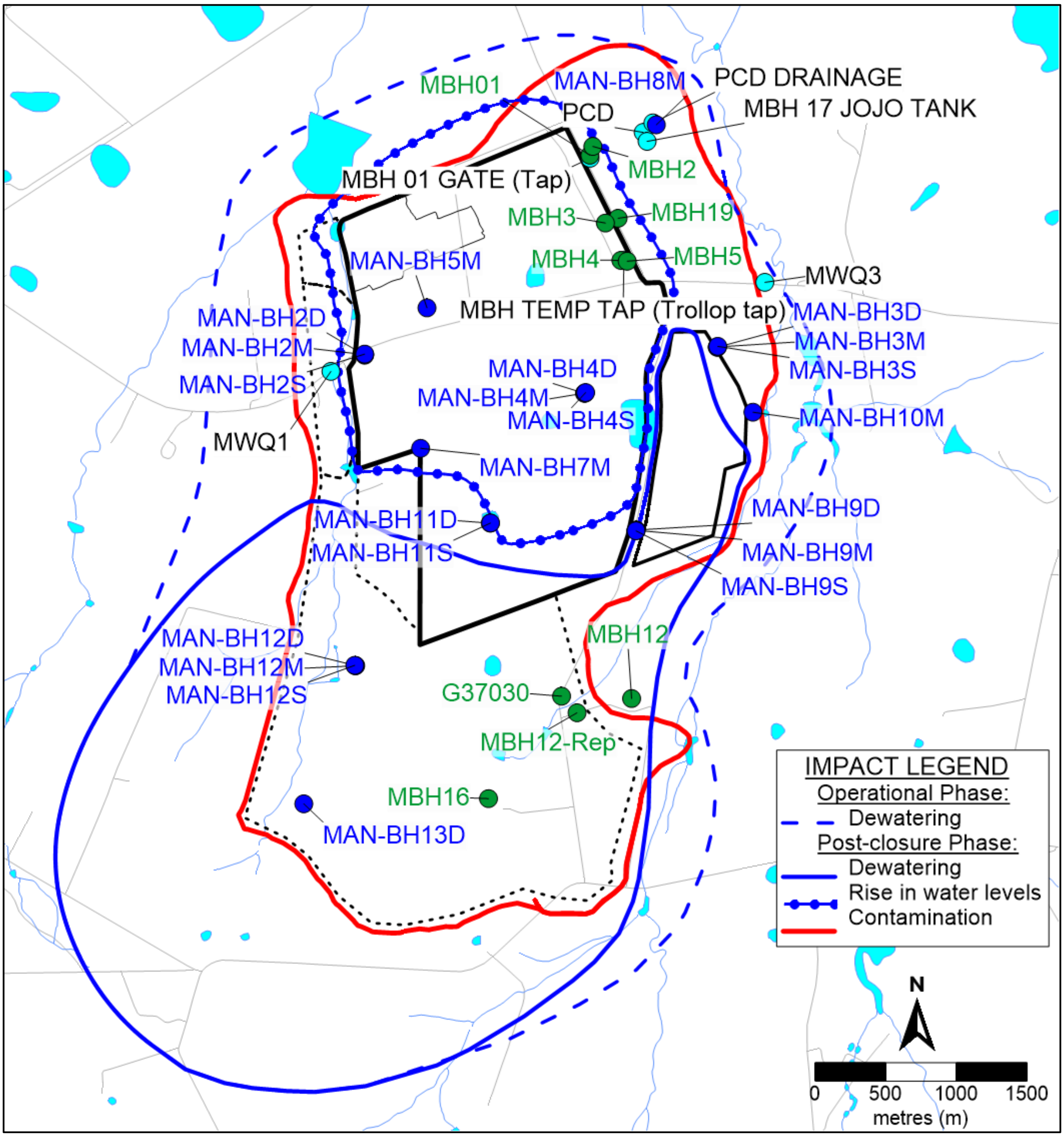


Figure 7.7B ***Groundwater level impact zone (operational and post-closure phases) and groundwater quality impact zone (post-closure phase) with boreholes that might be impacted***

7.8.3 Post-Mining

The following were concluded:

- Type of decant:
  - In addition to the decant at the opencast pit perimeter (i.e. decant that will flow to surface at the pit perimeter), a small volume of sub-surface decant will most-likely occur as contaminated base-flow to low-lying areas downstream/north of the pit perimeter (i.e. groundwater will flow below surface to a point further downstream where this water may decant to surface);
  - Sub-surface decant can be expected in the form of a contamination plume developing in the direction of groundwater flow;
- Time to decant (see summary in Table 7.4):
  - It is anticipated that decant will occur between 20years (earliest) and 30years after mining ceases for the main opencast if the underground is sealed off, and a few years longer if the underground is not sealed;

  - If the underground is sealed off from the main opencast pit area, it might take decades to flood; especially the UG SW, but will flood very quickly if the water that recharges to the pit can flow into the underground workings freely;
  - The time to decant has a bearing on the long-term water quality trends as geochemically modelled;
  - Stage curves are included as Figure 7.11 (i.e. indicating the volume of water that can be stored in opencast and underground sections below certain elevations);
  - Calculations took account of:
    - Depth to pit floor;
    - Moisture content of backfill material;
    - Soil subsidence/compaction;
    - In-pit water volume at the end of mining;
    - Natural rainfall recharge at 12% of MAP;
- Flooding status at time of decant (see Table 7.4):
  - The Manungu main Pit is expected to decant along the north-eastern and north-western pit perimeters at the locations indicated in Figure 7.10;
  - The decant elevation is estimated at 1579mamsl, which will result in 75% of the opencast being flooded eventually (see Tables 7.3 and 7.4); with small volumes of sub-surface decant potentially directly downstream/east of the pit perimeter;
- Impact on groundwater levels:
  - Pre-mining and post-mining groundwater levels are indicated in Figures 7.1 and 7.2A&B (Section 7.3);
  - Due to the flat groundwater table that can be expected inside the highly permeable backfill material inside the Pit, the post-mining situation will differ slightly from the pre-mining situation:
    - A slight rise in groundwater levels can be predicted in the vicinity of the decant point;
    - Groundwater levels in the rest of the opencast will be slightly deeper, but groundwater flow directions will essentially be in the same direction;
  - The post-mining dewatering cone will be smaller than the dewatering cone during the operational phase:
    - As the Mine continues to fill, the dewatering cone will retract from all directions;
    - The dewatering cone is not likely to expand further in any direction after the mining phase;
    - The difference between pre-mining and post-mining groundwater levels is expected to be less than 10m in the pit area;
  - Until such time as when the pit groundwater levels reach flooding elevations, groundwater flow will essentially be towards the pit. These flow conditions will continue from the south, and, to a limited extent, along the western pit boundaries (even after post-mining steady-state groundwater level elevations have been reached);
  - Groundwater flow will be away from the pit in the north-east and east; the driving force for contaminated movement;
  - Although the maximum extent of the dewatering cone should generally not exceed 350m from the Pit perimeter in the Karoo rock environment, various indicators (including numerical modelling and current observations in external user borehole which supplies the chicken farming) suggests a much wider impact zone of up to 800m to the south (it is important that groundwater monitoring confirms this);
  - All springs and hydrocensus boreholes potentially situated within the dewatering post-mining impacted groundwater level zones, are summarised Table 7.5;
- Impact on groundwater quality:
  - The time to flood was considered in the geochemical modelling as this will influence the long-term post-mining mine water quality;
  - The effect of placing discard from the proposed plant, into the Pit, was considered (see assessment in Appendix VI);
  - The anticipated average SO_4 concentrations within the opencast for a period of 100years after mining, was geochemically simulated (see Appendix VII and Figure 7.8 which serves as a summary of geochemical trends);
    - Within 10years after the cessation of mining, SO_4 concentrations are anticipated to increase to 3500mg/L, where after concentrations will gradually improve over many decades;
    - As can be seen, there is very little difference in the mine water quality if discard from the Wash Plant is added to the backfill;
  - Model results after 10/20/50/200years are included as Figures 7.9:
    - This would represent groundwater quality 10/20/50/200years after the cessation of mining;

        - A worst-case scenario is portrayed, which assumed that contamination plumes will form immediately, while in fact, the plume will only migrate after sufficient flooding;
        - The results are depicted in the shallow weathered zone aquifer as this is the highest yielding aquifer and an indication of the water qualities to be expected at decant areas;
    - The anticipated long-term groundwater quality impact zone on the local aquifers is depicted in Figure 7.7A. Provided that decant water is captured, the surrounding rivers/streams, wetlands and pans are not expected to be impacted in terms of groundwater quality;
- Mitigation of impact on groundwater quality (2017 assessment):
    - A modelling scenario was carried out where the pit level was artificially lowered 14m below the decant elevation to 1565mamsl;
    - Approximately 2000m^3/d will have to be removed from the pit on average (probably about 60% more during the summer rainfall season and 50% less during the dry winter months) to maintain this groundwater level elevation inside the pit:
        - This is ±500m^3/d more (±33% more) than the ±1500m^3/d that would have decanted naturally if no mitigation measures were introduced;
        - Further modelling is required to find an optimum management level to limit the water that has to be treated as well as limit the movement of groundwater contamination;
    - In pit manipulation can be achieved through evaporation or pumping, in which case this water will have to be treated before discharging to the surface water environment;
        - Natural decant at the pit perimeter
- Mine water balance and decant volumes/quality (see summary in Tables 7.3, 7.4 and 7.6):
    - Rainfall recharge to the opencast, at a rate of 12% of MAP over the long-term, calculates to 1500m^3/d which is equal to the long-term average decant volume at the north-eastern and western pit perimeter as numerically simulated:
        - This is because groundwater baseflow (subsurface outflow) away from the opencast areas will equal the groundwater inflow component (inclusive of the contribution from underground mining);
        - Some groundwater base-flow from the opencast (i.e. sub-surface groundwater flow to the northwest, east and northeast) may eventually manifest as surface seepage some distance from the opencast perimeter – the contaminated seepage volumes from all such areas were numerically simulated at 150m^3/d downstream of the opencast perimeter;
    - The changing hydro-chemical nature of the rehabilitated opencast will manifest in the groundwater decant and plume dynamics (i.e. varying over time, especially relevant to main impact zone at the pit perimeter – see Figure 7.8);
    - Decant volumes are summarised in Tables 7.6:
        - Decant volumes will gradually increase until the mine is flooded 20years to 30years after the cessation of mining, as the mine starts flooding, and the groundwater system establish pseudo steady-state flow patterns;
        - Decant volumes will vary on a seasonal basis and may potentially be 50% smaller or more during extreme dry seasons and be double during wet rainfall seasons.

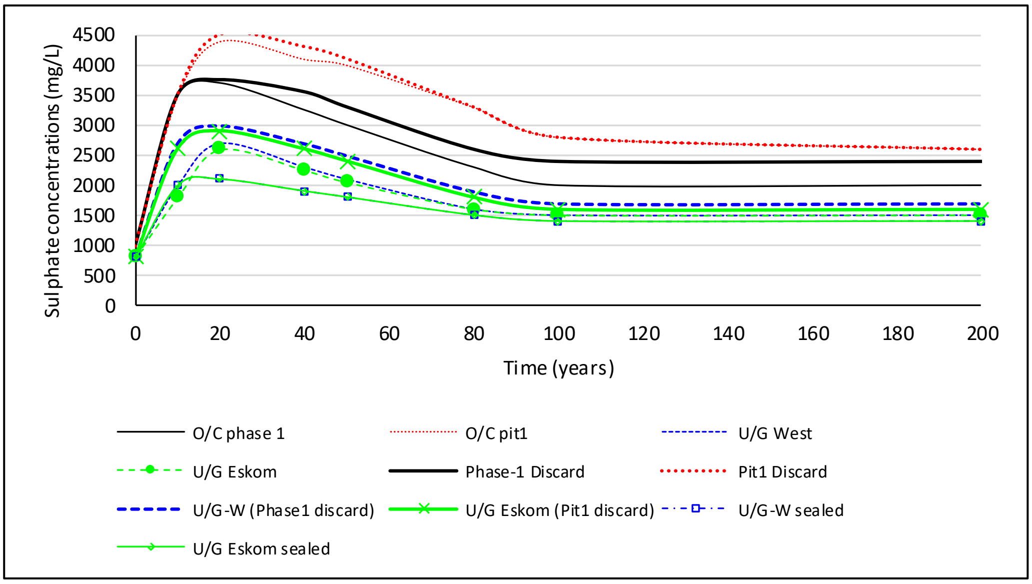
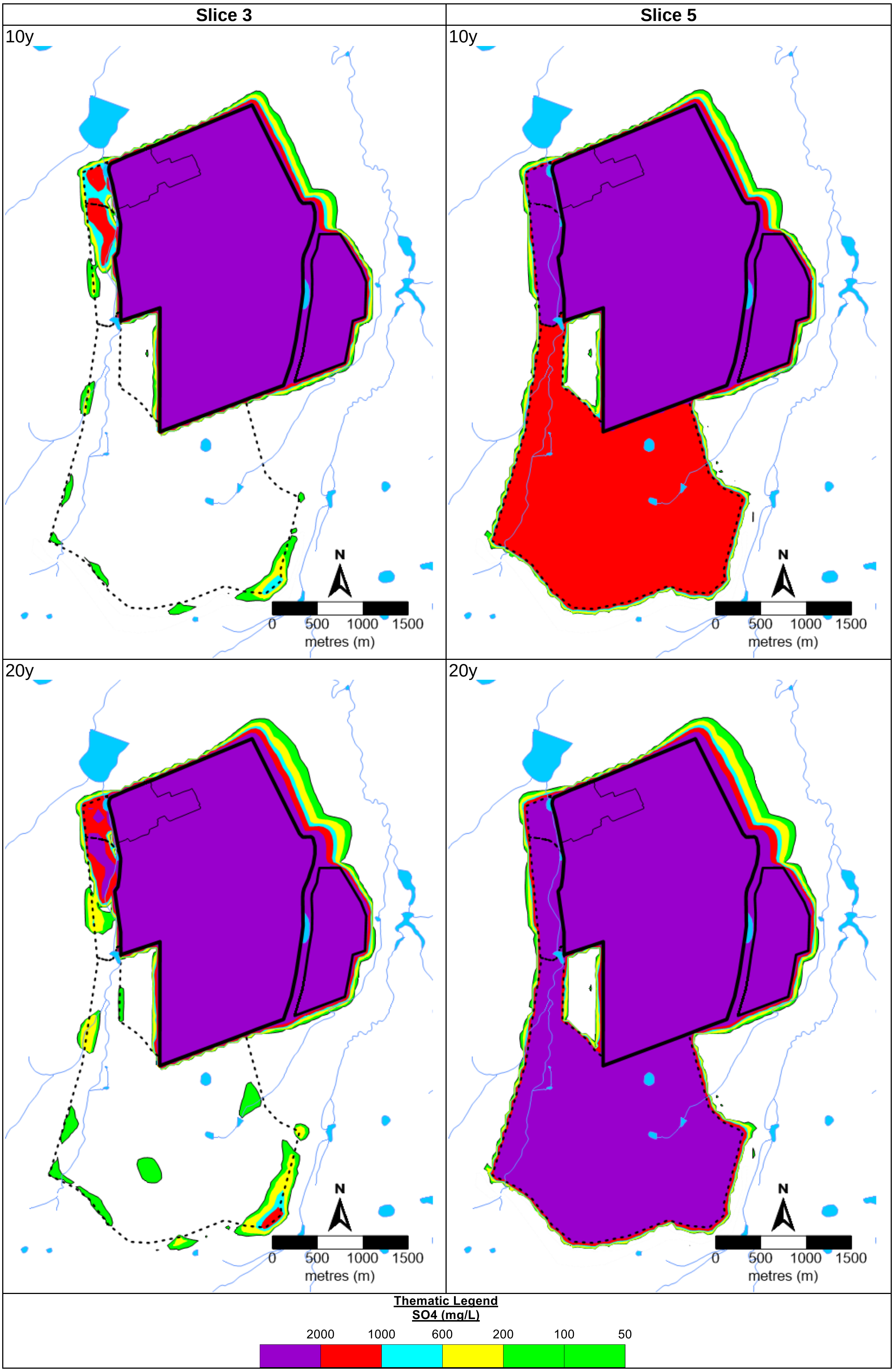


Figure 7.8 Summary of geochemical SO_4 (mg/L) trends for opencast and underground sections as geochemically modelled


Slice 3
Slice 5
10y
10y
20y
20y
N
0 500 1000 1500
metres (m)
Thematic Legend
SO4 (mg/L)
2000
1000
600
200
100
50

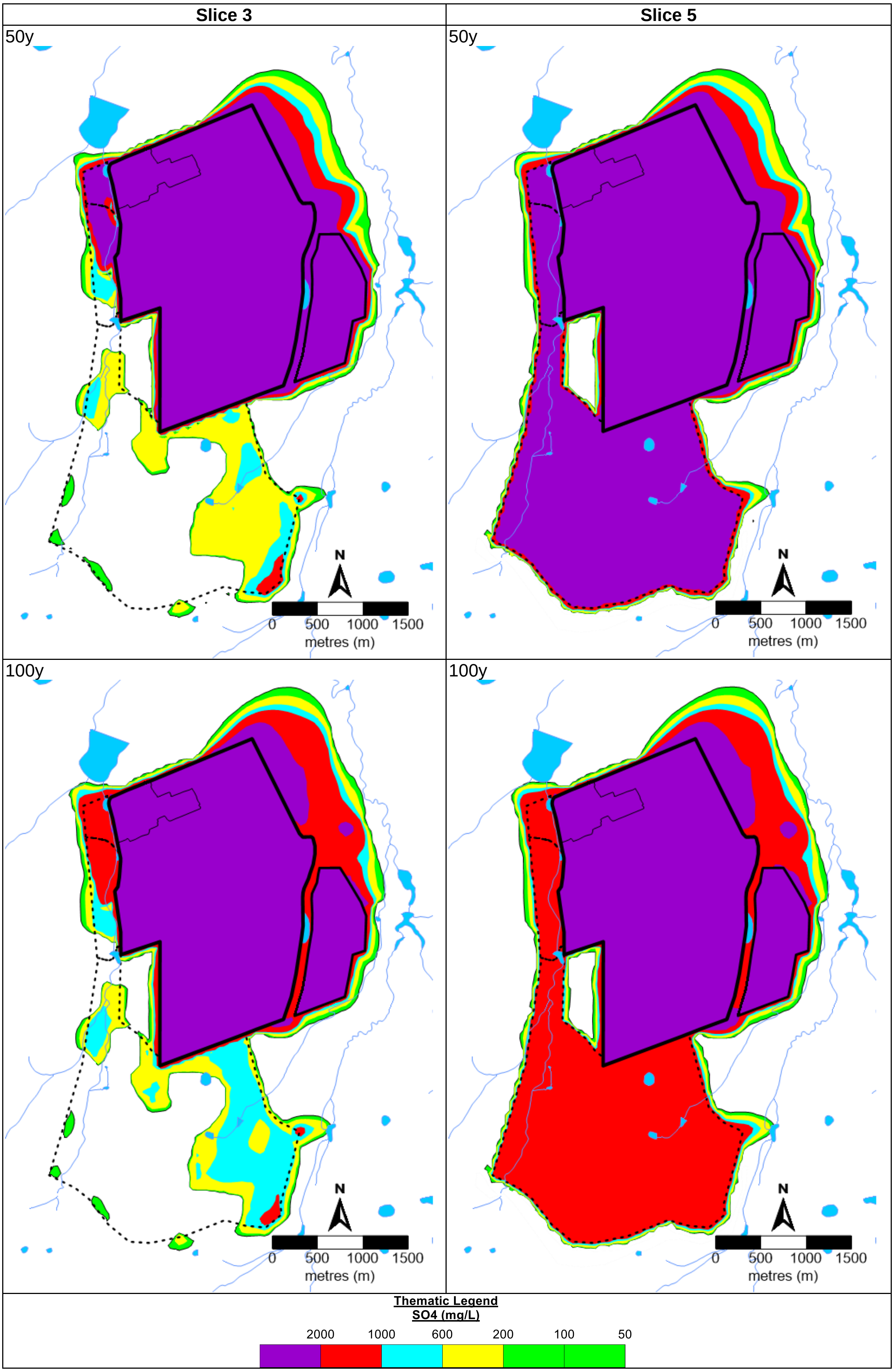


Figure 7.9 ***Numerically simulated SO_4 contamination plume (mg/L) after 10, 20 50 and 100years***

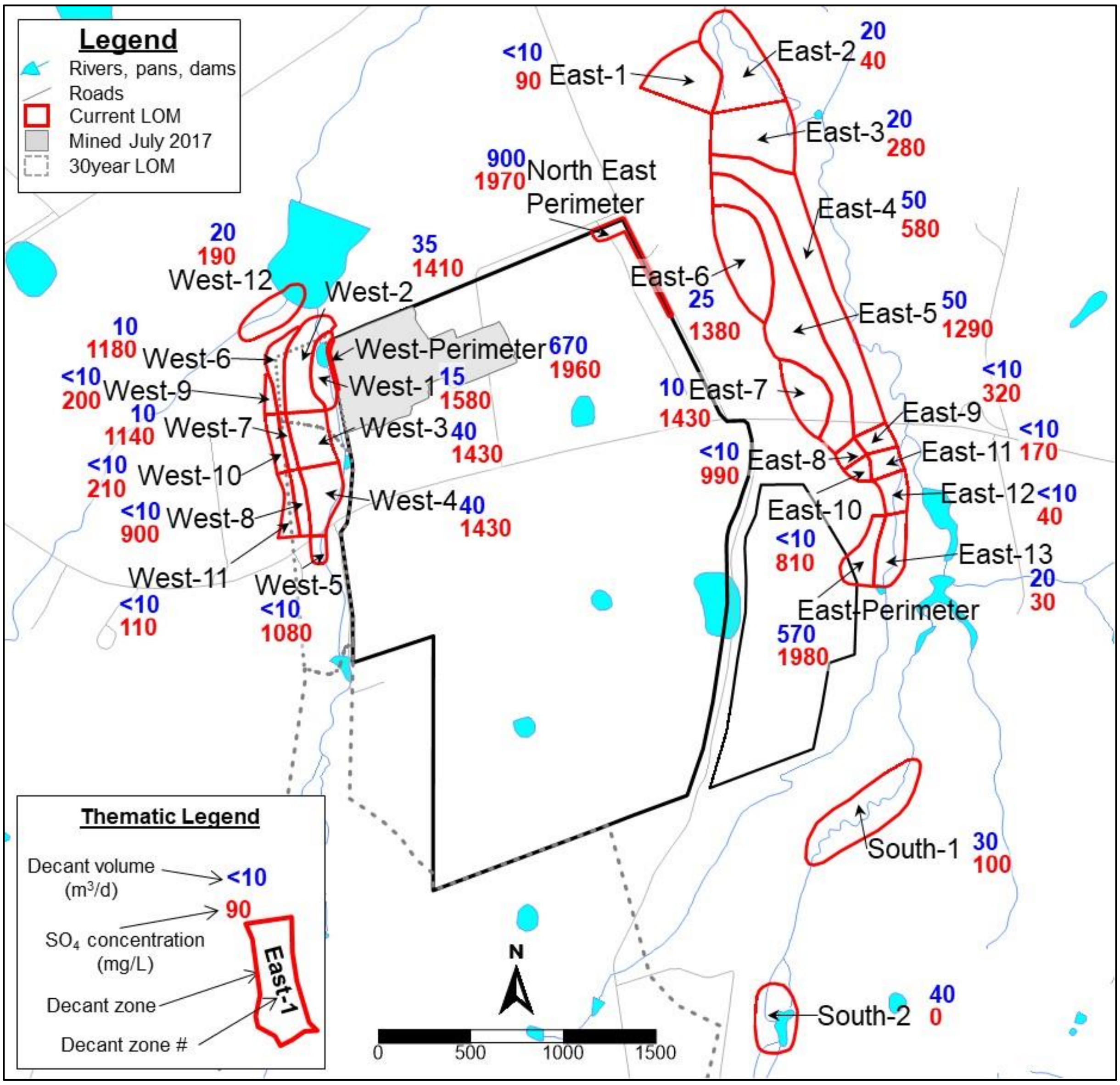


Figure 7.10 Decant zones after 100years

Table 7.6 Summary of anticipated decant volumes and quality after 100years

Decant Zone	Volume (m³/d)]	SO_4 concentration (mg/L)
East-1	<10	90
East-2	20	40
East-3	20	280
East-4	50	580
East-5	50	1290
East-6	25	1380
East-7	10	1430
East-8	<10	990
East-9	<10	320
East-10	<10	810
East-11	<10	170
East-12	<10	40
East-13	20	30
East-Perimeter	570	1980
NorthEast-Perimeter	900	1970
South-1	30	100
South-2	40	0
West-1	15	1580
West-2	35	1410
West-3	40	1430
West-4	40	1430
West-5	<10	1080
West-6	10	1180
West-7	10	1140
West-8	<10	900
West-9	<10	200
West-10	<10	210
West-11	<10	110
West-12	20	190
West-Perimeter	670	1960

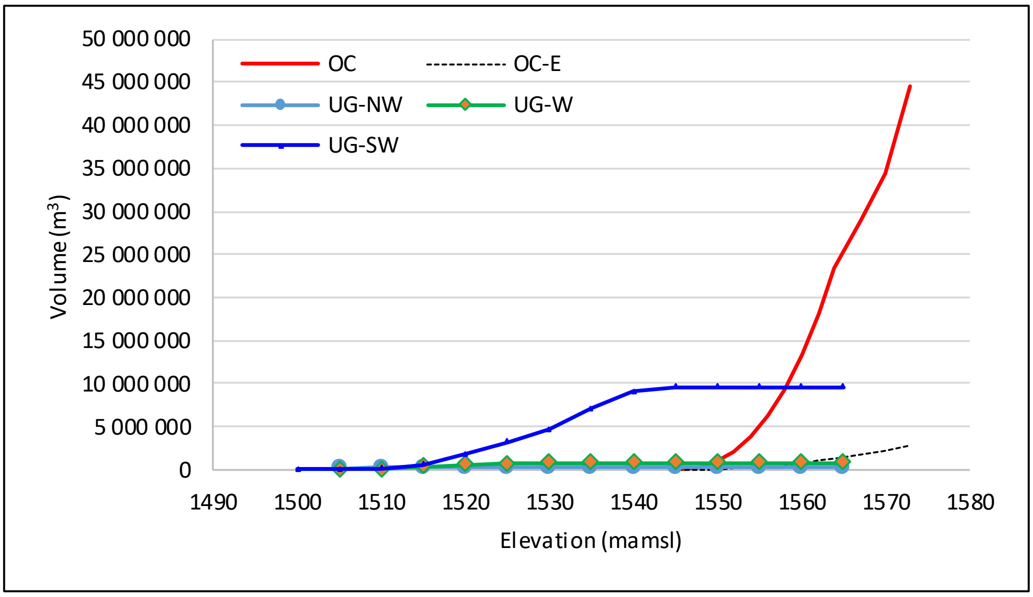


Figure 7.11 Water volume stage curves for opencast and underground sections

8. GEOHYDROLOGICAL IMPACTS

The headings in this section are contained in the risk assessment which are provided in Appendix VIII.

Manungu Colliery may potentially impact on the surrounding groundwater systems in terms of groundwater volumes, levels and quality. During the operational phase, groundwater is pumped from the mine, and the local groundwater levels are being impacted. During this operational phase period, groundwater contamination is primarily restricted to the pit. During the post-mining phase, groundwater levels may remain lower than the pre-mining situation in certain areas, while a rise in the groundwater table is expected near the decant zones. A groundwater contamination plume will also manifest during the post-mining phase.

The potential impacts on the local groundwater system, nearby rivers system, and external groundwater users, were investigated.

8.1 Construction Phase

The mine is currently operational. The following aspects are relevant for the 30year LOM extension:

- The upgrade of the Manungu sanitation facility(ies) at the office and changeroom ablutions;
- The relocation of the contactors yard and workshop;
- The establishment of a Coal Wash Plant facility;
- An additional Pollution Control Dam;
- Access and ventilation portals to the proposed underground workings.

8.1.1 Impacts on Groundwater Quantity

The 30year LOM extension in terms of access and ventilation portals to the proposed underground sections should have very limited localised, with insignificant changes to the larger groundwater regime. In close proximity to these mining activities, groundwater levels and boreholes yields may be impacted. Cumulative impacts will remain insignificant.

8.1.2 Impacts on Groundwater Quality

Apart from potential hydrocarbon contamination due lesser diesel and oil spills, as well as on-site sanitation there are no other activities that could impact on the regional groundwater quality.

8.1.3 Groundwater Management

Management measures that need to be put in place include the following:

- Procedures must be put in place for the storage, use & disposal of fuels, oils and grease.
  - Bunded impervious areas are to be created for the storage of all hazardous chemical substances;
- Emergency procedure to be put in place for the containment and clean-up of spillages of hazardous chemical substances.

8.2 Operational Phase

The discussion in Section 7.8.2 are condensed in this Section.

8.2.1 Impacts on Groundwater Quantity

The opencast is not expected to decant during the Life-of-Mine (LOM).

Although the maximum extent of the dewatering cone should generally not exceed 350m from the Pit perimeter in the Karoo rock environment, various indicators (including numerical modelling) suggests a much wider impact zone of generally 400m-500m wide, but up to 800m to the south (it is important that groundwater monitoring confirms this).

8.2.2 Impacts on Groundwater Quality

- Impact on groundwater quality:
  - Groundwater flow into the opencast workings is expected to be of similar quality than the background groundwater (to be evaluated for the final impact assessment report);

- Once in contact with the various materials within the Mine, the water quality will deteriorate over time:
  - Currently, mine water quality SO_4 concentrations range between 150mg/L and 400mg/L;
  - If all in-pit water is pumped out within a relatively short period (<3months), the water will not acidify and SO_4 concentrations should not exceed 800mg/L;
  - If in-pit water is allowed to collect in the lowest regions for longer periods, it may eventually deteriorate, depending on the oxygen-water-rock (carbonaceous material) interaction;
  - Isolated "hot-spots" of higher concentrations and lower pH may exist;
- The surrounding aquifers are not expected to be impacted in terms of groundwater quality during the Operational Phase. This is due to groundwater flow being toward the dewatered mining areas.

8.2.3 Impacts on Surface Water

The whole of the western flanking non-perennial stream falls within the expected cone of depression. Approximately two-thirds of the eastern flanking non-perennial stream falls within the expected cone of depression. A first order baseflow loss calculation (at 10.3mm/a) amounts to ±2.5l/s at the end-of-LOM or some 18.7% of the modelled groundwater inflows into the different mining sections.

Some manageable quality impact can be expected pertaining to the wash plant and associated stockpiles as far as the eastern flanking stream is concerned. All discharge water quality to rivers must comply with DWS standards.

8.2.4 Groundwater Management

Management measures and options in terms of the disposal of coal discard and residue from the wash plant are discussed in Section 10.4. Associated stockpiles are also addressed.

Operational Phase groundwater management measures include the following:

- Boreholes intersected by underground mining should be sealed to prevent drainage into the mine. Impacted external users' boreholes need to be replaced if impacted upon;
- Unstable geological conditions and problematic water makes (structural related) in the underground sections should be sealed off;
- Excess water in the mine must be used in the mine or pumped to pollution control facilities for re-use e.g. coal wash plant;
  - Water containment pollution control facilities must be lined;
  - All mine water pumpage and uses are to be metered and recorded;
  - Discharge water quality to rivers must comply with DWS standards;
- The mine water (monthly), groundwater, including external users' boreholes within a 1km radius (quarterly and selective monthly) and surface water (monthly) quality must be monitored on a regular basis;
- Water level measurements should be taken on a monthly basis in the monitoring boreholes, while the external users' boreholes within a 1km radius are to be monitored quarterly with some selected for monthly monitoring;
  - All groundwater abstractions are to be metered and recorded;
  - Selected surface water monitoring localities (rivers & streams) are to be monitored for stream flow on a monthly basis;
  - Monthly rainfall records should be kept in aid of the mine water balance as well as impact disputes.

8.3 Decommissioning Phase

It is anticipated that decant will occur between 20years (earliest) and 30years after mining ceases for the main opencast if the underground is sealed off, and a few years longer if the underground is not sealed Remediation of the Physical Activity, Storage Facilities, Environmental Impacts and Resources Impacts are discussed in Section 11.

8.4 Post-mining Phase

The discussion in Section 7.8.3 are condensed in this Section.

8.4.1 Groundwater Quantity

The following conclusions were reached:

- Type of decant:
  - In addition to the decant at the opencast pit perimeter (i.e. decant that will flow to surface at the pit perimeter), a small volume of sub-surface decant will most-likely occur as contaminated base-flow to low-lying areas downstream/north of the pit perimeter (i.e. groundwater will flow below surface to a point further downstream where this water may decant to surface);
  - Sub-surface decant can be expected in the form of a contamination plume developing in the direction of groundwater flow;
- Time to decant:
  - It is anticipated that decant will occur between 20years (earliest) and 30years after mining ceases;
  - The time to decant has a bearing on the long-term water quality trends as geochemically modelled;
  - Calculations took account of:
    - Depth to pit floor;
    - Moisture content of backfill material;
    - Soil subsidence/compaction;
    - In-pit water volume at the end of mining;
    - Natural rainfall recharge at 12% of MAP;
- Flooding status at time of decant are summarised in Table 7.4:
  - The Manungu Main Pit is expected to decant along the north-eastern and north-western pit perimeters at the location indicated in Figure 7.10;
  - The decant elevation is estimated at 1579mamsl, which will result in 75% of the opencast being flooded eventually; with small volumes of sub-surface decant potentially directly downstream/east of the pit perimeter;
- Impact on groundwater levels:
  - Pre-mining and post-mining groundwater levels are indicated in Figures 7.1 and 7.2A&B;
  - Due to the flat groundwater table that can be expected inside the highly permeable backfill material inside the Pit, the post-mining situation will differ slightly from the pre-mining situation:
    - A slight rise in groundwater levels can be predicted in the vicinity of the decant point;
    - Groundwater levels in the rest of the opencast will be slightly deeper, but groundwater flow directions will essentially be in the same direction;
  - The post-mining dewatering cone will be smaller than the operational phase dewatering cone:
    - As the Mine continues to fill, the dewatering cone will retract along the pit perimeter;
    - The dewatering cone is not likely to expand further in any direction after the mining phase;
    - The difference between pre-mining and post-mining groundwater levels is expected to be less than 5m in the pit area;
  - Until such time as when the pit groundwater levels reach flooding elevations, groundwater flow will essentially be towards the pit. These flow conditions will continue from the south, and, to a limited extent, along the western pit boundaries (even after post-mining steady-state groundwater level elevations have been reached);
  - Groundwater flow will be away from the pit in the north-east and east; the driving force for contaminated movement;
  - All springs and hydrocensus boreholes potentially situated within the dewatering post-mining impacted groundwater level zones, are summarised Table 7.5.

8.4.2 Groundwater Quality

- Impact on groundwater quality:
  - The anticipated average SO_4 concentrations within the opencast for a period of 100years after mining, was geochemically simulated as summarised in Figure 7.8:
    - Within 10years after the cessation of mining, SO_4 concentrations are likely to increase to 3500mg/L, where after concentrations will gradually improve over many decades;
  - Model results after 10/20/50/200years for the contamination plume are included as Figures 7.9:
    - This would represent groundwater quality 10/20/50/200years after the cessation of mining;
    - A worst-case scenario is portrayed, which assumed that contamination plumes will form immediately, while in fact, the pit will take between 20years to 30years to flood, after which the plumes can form beyond the pit perimeter;
    - The results are depicted in the shallow weathered zone aquifer as this is the highest yielding aquifer and an indication of the water qualities to be expected at decant areas;
  - The anticipated long-term groundwater quality impact zone on the local aquifers is depicted in Figures 7.7A-B. Provided that decant water is captured, the surrounding rivers/streams, wetlands and pans are not expected to be impacted in terms of groundwater quality;
- Mitigation of impact on groundwater quality:

  - During the 2017 Phase-1 (18years LOM) study, a modelling scenario was carried out where the pit level was artificially lowered 14m below the decant elevation to 1565mamsl;
  - On average, ±50% more will have to be removed to keep the in-pit level at this elevation;
  - In pit manipulation can be achieved through evaporation or pumping, in which case this water will have to be treated before discharging to the surface water environment;
- Mine water balance and decant volumes/quality (see summary in Tables 7.3, 7.4 and 7.6):
  - Rainfall recharge to the opencast, at a rate of 12% of MAP over the long-term, calculates to 1500m^3/d which is equal to the long-term average decant volume at the north-eastern and western pit perimeter as numerically simulated:
    - This is because groundwater baseflow (subsurface outflow) away from the opencast areas will equal the groundwater inflow component (inclusive of the contribution from underground mining);
    - Some groundwater base-flow from the opencast (i.e. sub-surface groundwater flow to the northwest, east and northeast) may eventually manifest as surface seepage some distance from the opencast perimeter – the contaminated seepage volumes from all such areas were numerically simulated at 150m^3/d downstream of the opencast perimeter;
  - The changing hydro-chemical nature of the rehabilitated opencast will manifest in the groundwater decant and plume dynamics (i.e. varying over time, especially relevant to main impact zone at the pit perimeter);
  - Decant volumes will vary on a seasonal basis and may potentially be 50% smaller or 60% higher than the average during extreme dry and wet rainfall seasons.

8.4.3 Cumulative Impacts

The main cumulative impact relates to the disposal of the discard. Groundwater contamination may occur through AMD toe seepages, if a discard dump is placed on surface. Given the almost identical mine water qualities for an opencast backfill with or without discard material, it is recommended that discard from the proposed Wash Plant be placed deep enough in the main Pit; thus, preventing the impacts associated with surface Discard Dumps.

Secondary, if the underground is sealed off from the main opencast pit area, it might take decades to flood; especially the UG SW but will flood very quickly if the water that recharges to the pit can flow into the underground workings freely. The time to decant has a bearing on the long-term water quality trends as geochemically modelled.

8.4.4 Groundwater Management

This report evaluated one management measure to reduce the mine water quality impact on the local groundwater setting. During the Phase-1 assessment, a modelling scenario was carried out to evaluate the effect of artificially lowering the in-pit level by 14m below the decant elevation to 1565mamsl. On average, ±50% more that the natural decant volume will have to be removed to keep the in-pit level at this elevation. In pit manipulation can be achieved through evaporation or pumping, in which case this water will have to be treated before discharging to the surface water environment. Further modelling is required to find an optimum management level to limit the water that has to be treated as well as limit the movement of groundwater contamination.

9. GROUNDWATER MONITORING SYSTEM

The following aspects/information were considered:

- A review of current monitoring localities;
- Potential groundwater level and groundwater quality impacts of Manungu mining on the local groundwater system;
- Potential impacts from neighbouring mining activities on Manungu Colliery;
- Location of external groundwater users;
- The complex geological environment;
- Groundwater drilling by *Groundwater Square*.

Manungu is currently monitoring the surface water environment (surface water and mine water) and groundwater localities as summarised in Tables 9.1 to 9.3, indicated in Figure 9.1 (also see Figures 4.1 and 5.6. Sampling and water level (flow measurement frequencies) are indicated in Tables 9.1 and 9.2.

The following water quality parameters are analysed by an accredited water laboratory at least biannually: pH, EC, TDS, Ca, Mg, Na, K, Cl, SO_4, NO_3, Tot.Alk., P, F, Fe, Mn, Al, Si, N, SS, NTU.

9.1 Groundwater Monitoring Network

9.1.1 Source, Plume, Impact and Background Monitoring

The monitoring system must be designed to distinguish between the following types of monitoring boreholes:

- Source = nearest to potential contamination sources;
- Plume = monitoring the progression/break-through water quality trend curves;
- Background = upstream to serve as reference.

As mining progresses, and more information is gathered, these subdivisions will be emphasized. The dewatering effect during mining will have to be monitored with the existing groundwater monitoring system; potentially expanding the monitoring system to provide additional/relevant monitoring.

9.1.2 System Response Monitoring Network

The plume monitoring boreholes serve as an early warning system to take remedial action if contamination occurs. These holes, together with the source monitoring boreholes will indicate drastic changes in the groundwater levels; especially important with regard to the village drinking water supplies.

Due to the slow changes that normally occur in groundwater quality and natural groundwater level fluctuations, quarterly groundwater monitoring should be sufficient to identify any changes which may require action. Boreholes that supply drinking water may, however, become unusable more abruptly, if such holes are reliant on single water fractures, which may become dewatered during droughts, or excessive pumping. Fortunately, the groundwater supply to the local village is utilised continuously, which will prompt an immediate complain to the mine.

Investigations should be conducted to determine the reasons for sudden changes in groundwater quality and groundwater levels.

9.1.3 Monitoring Frequency

Table 9.1 Surface water sampling points

Borehole No.	Coordinates		Current monitoring frequency		Sampling depth (m)
	Latitude	Longitude	Water volume	Water quality	
MWQ1	26.2382	28.6766	Monthly	Monthly	Below water surface
MWQ3	26.2326	28.7071	Monthly	Monthly	
MWQ4	26.2310	28.7114	Monthly	Monthly	
MWQ5	26.2391	28.6623	Monthly	Monthly	
MWQ6	26.2080	28.6867	Monthly	Monthly	
PCD	26.2231	28.6986	Monthly	Monthly	
PCD Drainage	26.2225	28.6993	Monthly	Monthly	
Pit area	Changes monthly		Monthly	Monthly	

Table 9.2 Groundwater sampling points

Borehole No.	Coordinates		Current monitoring frequency		Sampling depth (m)
	Latitude	Longitude	Water level	Water quality	
MBH01	26.2247	28.6948	Monthly	Monthly	To be verified
MBH4	26.2312	28.6972	Monthly	Monthly	
MBH5	26.2331	28.7015	Quarterly	Quarterly	
MBH6 **	26.2388	28.7305	Quarterly	Quarterly	
MBH7	26.2369	28.6612	Quarterly	Quarterly	
MBH12-Replace	26.2599	28.6938	Monthly	Monthly	
MBH17	26.2236	28.6988	Monthly	Monthly	
MBH19	26.2286	28.6968	Quarterly	Quarterly	
MBH22* **	26.2055	28.7237	Quarterly	Quarterly	
MBH32	26.2369	28.6612	Quarterly	Quarterly	

*Coordinates for MBH22 (-26.8948/28.66129) according to Philo Environmental Management Report.
**It is recommended that boreholes MBH6 and MBH22 be removed from the current monitoring system (located >3km from the Pit LOM).

Table 9.3 Additional sampling points to be added to Manungu groundwater monitoring system

Site Name	WGS84 LO29			Monitoring frequency		Sampling Horizon (m)
	Latitude	Longitude	Elevation (mamsl)	Water level	Water quality	
MAN-BH2D	26.237200	28.679010	1592	Monthly	Quarterly	88
MAN-BH2M	26.237160	28.679010	1590	Monthly	Quarterly	23
MAN-BH2S	26.237130	28.679020	1590	Monthly	Quarterly	5
MAN-BH3D	26.236750	28.703780	1580	Monthly	Quarterly	71
MAN-BH3M	26.236730	28.703790	1580	Monthly	Quarterly	15
MAN-BH3S	26.236690	28.703820	1580	Monthly	Quarterly	7
MAN-BH4D	26.239650	28.694450	1595	Monthly	Quarterly	67
MAN-BH4M	26.239630	28.694490	1595	Monthly	Quarterly	25
MAN-BH4S	26.239600	28.694530	1596	Monthly	Quarterly	8
MAN-BH5M	26.234210	28.683400	1597	Monthly	Quarterly	32
MAN-BH6D	26.216920	28.683900	1572	Monthly	Quarterly	75
MAN-BH6M	26.216880	28.683880	1572	Monthly	Quarterly	30
MAN-BH7M	26.243110	28.682930	1597	Monthly	Quarterly	25
MAN-BH8M	26.222640	28.699540	1570	Monthly	Quarterly	15
MAN-BH9D	26.248280	28.698050	1593	Monthly	Quarterly	66
MAN-BH9M	26.248340	28.698050	1593	Monthly	Quarterly	30
MAN-BH9S	26.248370	28.698050	1593	Monthly	Quarterly	8.5
MAN-BH10M	26.240870	28.706280	1577	Monthly	Quarterly	17
MAN-BH11D	26.247860	28.687810	1606	Monthly	Quarterly	71
MAN-BH11S	26.247850	28.687830	1606	Monthly	Quarterly	5.5
MAN-BH12D	26.256870	28.678330	1596	Monthly	Quarterly	59
MAN-BH12M	26.256880	28.678300	1596	Monthly	Quarterly	28
MAN-BH12S	26.256850	28.678270	1596	Monthly	Quarterly	5
MAN-BH13D	26.265620	28.674660	1602	Monthly	Quarterly	78

It is assumed that monitoring recommendations do exist for the local surface water environment. Mine water quality in Dams and the Pits, should be monitored at least monthly.

It is recommended that groundwater levels in the regular boreholes be initially measured on a monthly basis. Water quality samples should be collected quarterly, except for drinking water supply to the mine and local village, which require monthly monitoring.

Drinking water supply boreholes and external users' boreholes which may be affected should also be monitored monthly. Elsewhere, external users' boreholes should be monitored annually.

9.2 Monitoring Parameters

Water quality monitoring parameters are summarised in Table 9.2 for the mining phase and post-mining phases respectively. Note, as explained in Section 9.1, there is a distinction between the monitoring of regular mining boreholes and monitoring intervals for external users (originally identified during the 2009 hydrocensus), consisting of village boreholes and holes further away.

Groundwater monitoring of the boreholes listed in Table 9.2 and Table 9.3, should be conducted as follows (as minimum for a period of two years, when less frequent groundwater quality monitoring may be recommended by an expert):

Table 9.2 Monitoring parameters and frequency

Groundwater levels	Groundwater quality
Quarterly	Quarterly: pH, EC, TDS, Ca, Mg, Na, K, Cl, SO_4, NO_3, Tot.Alk. [NOTE: all drinking water to be analysed monthly]
	Annually: Si, Fe, Mn, Al & ICP-Scan, additional recommendations by geochemist
	Annually: hydrocarbon-type analyses (e.g. TPH, DRO and GRO) and bacteriological.

9.3 Monitoring Boreholes

Groundwater monitoring points are summarised in Tables 9.4. See Figure 9.1 for monitoring localities. External user's boreholes are depicted in Figure 9.2.

Mine water quality in Dams and the Pits are important. Surface water monitoring, as recommended by the surface water expert should be reported/interpreted together with groundwater monitoring.

Table 9.4 Monitoring boreholes – regular monitoring

Site Name	WGS84 LO29			End of hole (m)	Collar Height (m)	Water Level (m)	Sampling Horizon (m)
	Latitude	Longitude	Elevation (mamsl)				
MAN-BH2D	26.237200	28.679010	1592	175	0.50	34.40	88
MAN-BH2M	26.237160	28.679010	1590	41	0.55	3.54	23
MAN-BH2S	26.237130	28.679020	1590	10	0.57	3.03	5
MAN-BH3D	26.236750	28.703780	1580	100	0.27	26.01	71
MAN-BH3M	26.236730	28.703790	1580	30	0.32	4.18	15
MAN-BH3S	26.236690	28.703820	1580	10	0.3	3.99	7
MAN-BH4D	26.239650	28.694450	1595	90	0.32	28.1	67
MAN-BH4M	26.239630	28.694490	1595	41	0.28	7.23	25
MAN-BH4S	26.239600	28.694530	1596	10	0.24	6.4	8
MAN-BH5M	26.234210	28.683400	1597	40	0.36	4.43	32
MAN-BH6D	26.216920	28.683900	1572	91	0.3	32.6	75
MAN-BH6M	26.216880	28.683880	1572	40	0.42	5.15	30
MAN-BH7M	26.243110	28.682930	1597	36	0.27	6.53	25
MAN-BH8M	26.222640	28.699540	1570	31	0.61	2.77	15
MAN-BH9D	26.248280	28.698050	1593	96	0.43	43.84	66
MAN-BH9M	26.248340	28.698050	1593	46	0.58	8.23	30
MAN-BH9S	26.248370	28.698050	1593	10	0.53	7.82	8.5
MAN-BH10M	26.240870	28.706280	1577	26	0.47	5.23	17
MAN-BH11D	26.247860	28.687810	1606	86	0.46	36	71
MAN-BH11S	26.247850	28.687830	1606	7	0.52	4.18	5.5
MAN-BH12D	26.256870	28.678330	1596	86	0.73	41.17	59
MAN-BH12M	26.256880	28.678300	1596	40	0.75	4.11	28
MAN-BH12S	26.256850	28.678270	1596	7	0.74	3.5	5
MAN-BH13D	26.265620	28.674660	1602	86	0.70	52.22	78

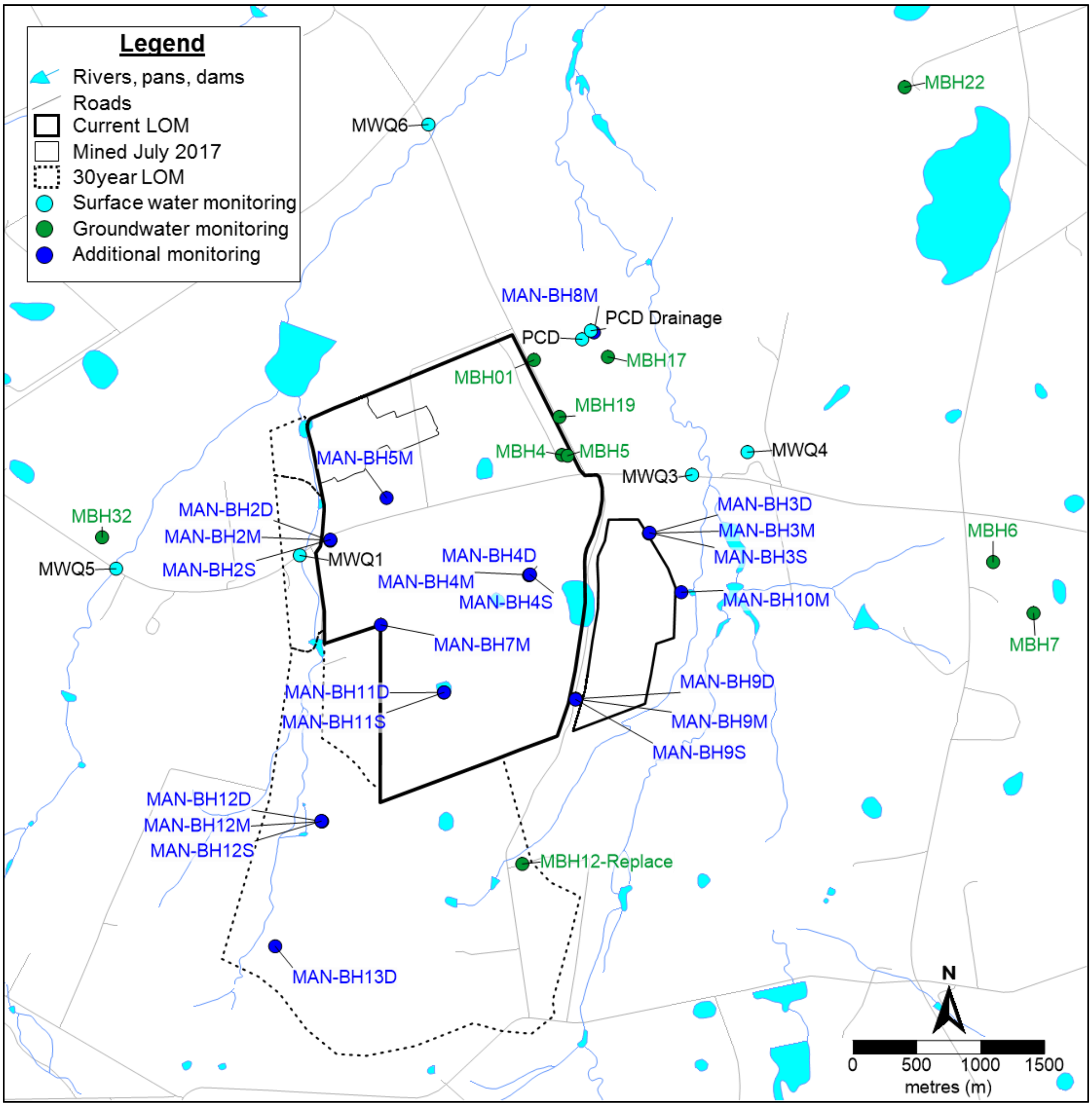


Figure 9.1 Recommended groundwater monitoring boreholes

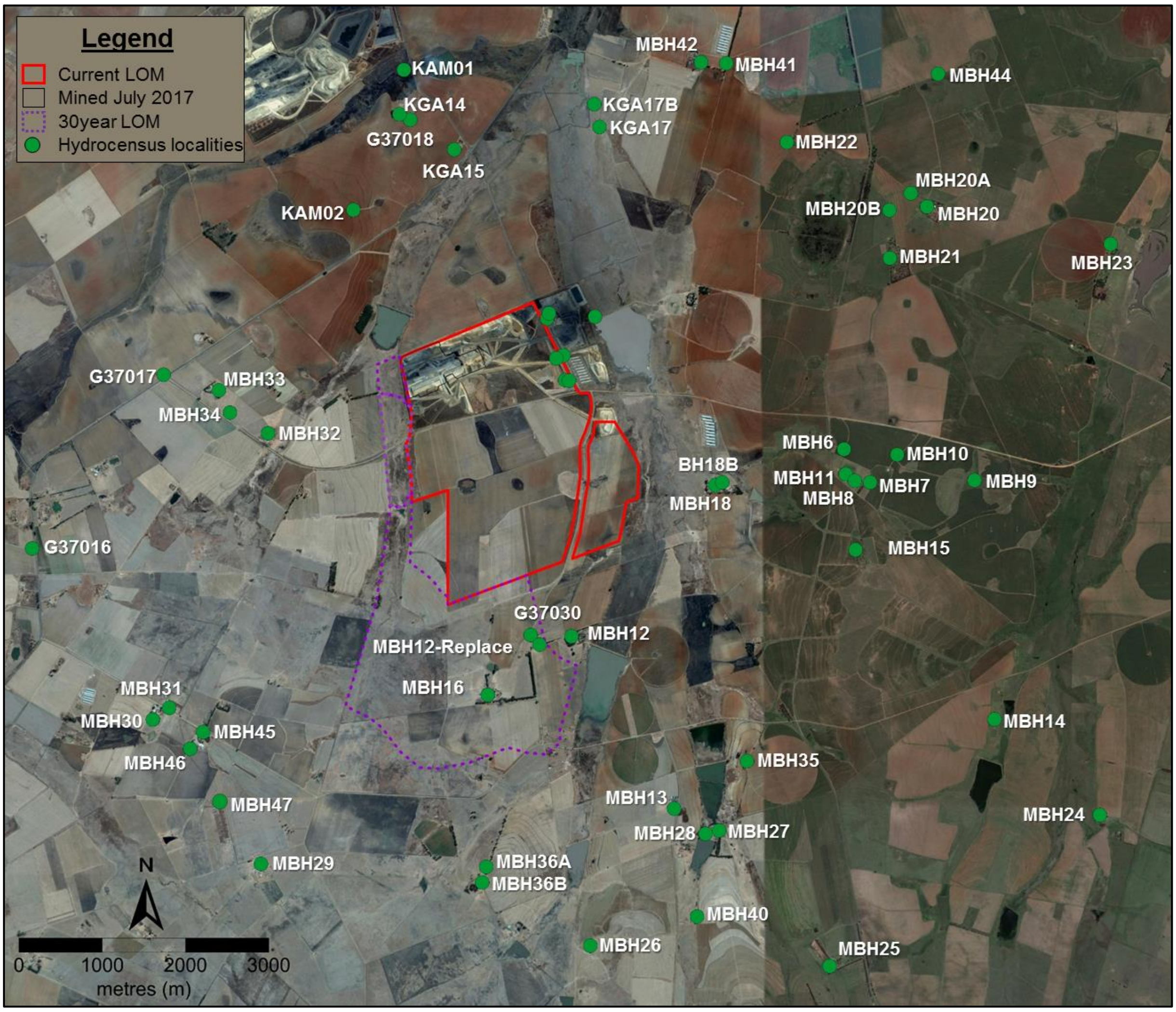


Figure 9.2 ***External users identified by Groundwater Square (Ref: GW2_069, 2009), depicted against an August 2016 Google Earth aerial photograph***

10 GROUNDWATER ENVIRONMENTAL MANAGEMENT PROGRAMME

10.2 Current Groundwater Conditions

Prior to the commencement of mining in 2014, the area represented an unimpacted groundwater environment with no mining, only agricultural impacts.

Currently, the main impacts relate to the dewatering of the local aquifer surrounding the current Pit.

10.3 Predicted Impacts of Mining

Dewatering of the local aquifers will expand. Mining will impact on the local groundwater supply through dewatering of the local aquifers. Groundwater contamination from the opencast pit should not impact on the local groundwater supply.

Groundwater contamination may occur through AMD toe seepages, if a discard dump is placed on surface. Given the almost identical mine water qualities for an opencast backfill with or without discard material, it is recommended that discard from the proposed Wash Plant be placed deep enough in the main Pit; thus preventing the impacts associated with surface Discard Dumps.

10.4 Mitigation Measures

During the operational phase the most-important mitigation measures relate to:

- Groundwater monitoring recommendations in Section 9 are important.
- The placement of discard material:
  - If discard is placed on undisturbed/uncontaminated ground, a liner system will be required to prevent the contamination of the local groundwater system, and toe seepages should be collected:
    - Any seepages and rainfall runoff originating from stockpiles should be identified and captured/diverted to the dirty water system;
    - Dirty water should be removed as quickly as possible to reduce the driving mechanism for contaminant migration;
  - If the dump is placed on rehabilitated mining areas without a liner system, the discard seepage water will mix with pit water and pumped out if necessary;
  - If the discard is paced in mined-out areas – the preferred option – it should be placed sufficiently deep below the long-term decant elevation (e.g. 10m);
- In line with pollution prevention and minimisation strategies, the following principles should apply if filter cake material is stored on-site as non-select product:
  - Source reduction through general site maintenance:
    - Product should be moved off-site as quickly to prevent continuous seepages from occurring;
    - The site should be maintained to be free draining. Where relevant, areas should be compacted/shaped;
    - Rainfall runoff should be separated into clean and dirty water (rainfall falling on the site should be allowed to drain quickly/freely, and contaminated water should then be captured in the mine dirty water system and re-used where possible);
    - Clean upstream rainfall water runoff should be diverted around the site;
  - Treatment:
    - If too much water has to be manged, treatment may need to be considered;
  - Secure disposal:
    - All dirty water collected on the site should be re-used or stored during operation;
- The storage of contaminated operational mine water:
  - This water will be pumped to surface water dams where it can be reused;
  - In-pit water storage in low-lying areas may also be pursued.

<u>AMD Prevention</u>

One option that may be pursued, is the placement of coal-fire station fly ash on top of the backfilled opencast. However, detailed research is required to investigate, especially, the geochemistry and water balance of such a scenario. Due to the long-term benefits of flushing acid-generating minerals from backfill material, this option should be carefully evaluated in terms of the potential impact on the local surface water environment and ecosystem. One aspect to consider is that water should first flow through the ash (e.g. rainfall recharge) before entering acid generating material, such as backfill. If decant water is treated in this way, it is advisable not to use ash, unless properly researched, but rather add calcitic lime.

A combination of ash and cement can potentially be utilised to limit rainfall recharge into rehabilitated areas.

SA National Development Plan

Water will remain a critical component of the National Development Plan initiative of the South African Government, as it can stimulate economic growth. Local farmers have been utilising the local surface water environment for decades to irrigate crops. The irrigation infrastructure consists of the river system, purpose build canals and -dams, as well as pump stations.

The Manungu opencast (and surrounding mining environment) can potentially be incorporated into this system to store water for long periods, from where it can be utilised for irrigation; obviously ensuring that the water is of acceptable quality. It can potentially be beneficial for future generations, thus stimulating job creation in the local surroundings.

Detailed planning and research are required.

Decant Prevention Measures

In-pit evaporation from a final void or large enough in-pit-shaped evaporation can minimise the opencast water balance. Such a design is not currently planned. If such a design is pursued, it should account for rainfall that would fall directly on the evaporation area and the rainfall deficit that occurs on an annual basis.

A fundamental design criteria of in-pit evaporation areas, relates to the slopes above- and below the anticipated in-pit groundwater level. The slopes would be steeper above the groundwater level to minimise rainfall run-off. The slopes below the anticipated groundwater would be more gradual to optimise evaporation and evapotranspiration by plants, to account for the fluctuating in-pit groundwater levels on a seasonal basis. In practice, it will be very difficult to construct a large in-pit evaporation area.

10.4.1 Lowering of Groundwater Levels during Mining Operation

It is not possible to prevent the dewatering of the aquifers surrounding the proposed opencast mining (see anticipated zone of dewatering in Figure 7.7A-B, Section 7.8.2). As soon as groundwater monitoring indicates a dewatered state of boreholes which supply external groundwater users, an alternative water sources should be provided.

10.4.2 Rise of Groundwater Levels Post-Mining Operation

As discussed in Section 11, groundwater levels around the decant zones are anticipated to be higher than prior to mining. Decant will be contaminated, resulting an overland run-off towards the local surface water drainage lines.

Because this decant cannot be prevented (unless water is evaporated somewhere in the pit, or water is pumped from the pit), and in line with best practice guidelines, water management measures should be introduced to reduce the impact of the source (i.e. specifically addressing water quality).

With reference to comments made on the South African National Development Plan, consideration should be given to utilise this water for irrigation projects in the area.

10.4.3 Spread of Groundwater Pollution Post-Mining Operation

The anticipated spread of groundwater contamination is discussed in Section 7.8.2 (see anticipated migration of groundwater in Figures 7.9, and maximum groundwater contamination impact zones in Figure 7.7A-B).

The spread of groundwater contamination can be restricted through active manipulation of the groundwater flow directions in the decant areas; e.g. pumping from boreholes or installation of a trench. However, this will require a huge rehabilitation fund.

The spread of groundwater contamination can also be restricted through the manipulation of groundwater gradients through lowering the in-pit levels. The added water that will have to be removed from the pit should be considered. Pumped water should be managed, but a tree plantation may have benefits in terms of water management and creating an income.

11 POST CLOSURE MANAGEMENT PLAN

The impact assessments and management of the impacts contained in this report (Sections 5 and 6), adhere to the DWAF series of Best Practice Guidelines (BPGs), which was developed for mines in line with International Principles and Approaches towards sustainability. The series of BPGs were grouped as outlined below (directly quoted from the documents):

- BEST PRACTICE GUIDELINES dealing with aspects of DWAF's water management HIERARCHY:
  - H1. Integrated Mine Water Management;
  - H2. Pollution Prevention and Minimisation of Impacts;
  - H3. Water Reuse and Reclamation;
  - H4. Water Treatment;
- BEST PRACTICE GUIDELINES dealing with GENERAL water management strategies, techniques and tools, which could be applied cross-sectoral:
  - G1. Storm Water Management;
  - G2. Water and Salt Balances;
  - G3. Water Monitoring Systems;
  - G4. Impact Prediction;
  - G5. Water Management Aspects for Mine Closure;
- BEST PRACTICE GUIDELINES dealing with specific mining ACTIVITIES or ASPECTS, which address the prevention and management of impacts from:
  - A1. Small-scale Mining;
  - A2. Water Management for Mine Residue Deposits;
  - A3. Water Management in Hydrometallurgical Plants;
  - A4. Pollution Control Dams;
  - A5. Water Management for Surface Mines;
  - A6. Water Management for Underground Mines.

One of the functions performed within the hierarchy of decision making is to inform interested and affected parties on good practice at mines.

11.2 Remediation of Physical Activity

Groundwater monitoring recommendations in Section 9 are important.

The following recommendations are noteworthy in terms of adhering to the principle of pollution prevention and source reduction:

- All remaining material of the coal Wash Plant area should be removed, and placed into the bottom of a mining area below the final post-mining groundwater level;
- The expertise of a soil scientist should be called upon to assess the base/foundation layer and underlying soils in terms of the degree of contamination (in the context of the general soil contamination of surrounding soils):
  - In the event that salts are identified, a decision should be taken on the need (and best method) to rehabilitate the footprint areas (e.g. placement of foundation layer into the bottom of the pit);
  - Topsoil should be placed back to restore the site to its original status/soil-condition.

11.3 Remediation of Storage Facilities

It is recommended that discard material be placed in mined-out areas, sufficiently deep below the long-term decant elevation. However, if permission is not granted for this, contaminated toe seepages of sulphate concentrations exceeding 5000 mg/L should be prevented, through covering the Discard Dump with an engineered capping system to prevent rainfall infiltration. This approach adheres to the principle of source reduction. Groundwater monitoring recommendations in Section 9 are important.

In line with pollution prevention and minimisation strategies, the following principles should apply if filter cake material and discard remain on site as a discard dump:

- Groundwater monitoring recommendations in Section 9 are important;
- Source reduction through:
  - Capping of the dump;
  - General site maintenance, allowing free draining, and capturing of dirty water (runoff and seepages originating from the dump);

- Storage, treatment and/or reuse of contaminated water (e.g. such as the irrigation projects mentioned in Section 11.5).

Similarly, remaining contaminated footprint materials and soils in the coal handling areas, ROM stockpiles and Pollution Control Dams, should be removed according to the guidelines of a soil scientist, and placed in the bottom of the Pit.

11.4 Remediation of Environmental Impacts

It is recommended that optimal surface rehabilitation be performed, such as the placing of a thin topsoil layer and ensuring that the area is covered by indigenous plants (i.e. also removal of invading plant species). It is important that a free draining post-mining topography be established. This will prevent contaminated rainfall runoff over the contaminated soils.

11.5 Remediation of Water Resources Impacts

The Manungu Mine does not impact directly on the local surface water resources. When decant eventually occur at the Pit perimeters, these will be managed. Options include, capturing, reuse through projects (e.g. irrigation if possible) or treatment. Insufficient storage will be available.

Sub-surface decant, will affect the groundwater system, gradually expanding over decades. Remediation options include:

- Quick flooding of the underground will result in an improved water quality; especially if this water can be replenished from surface water sources, similar to a water reservoir, to be utilised for irrigation on an ongoing basis;
- It is preferable that the underground be sealed from the opencast workings;
- Manipulating the in-pit mine water levels, with obvious increased treatment costs (unless the water quality proves to be of good enough quality to use directly for irrigation);
- Artificially treating the backfill material at high cost to improve the long-term post-mining water quality.

11.6 Backfilling of the Pits

All post-mining rehabilitated areas need to be free draining where possible unless stated differently in the EMP. This will limit groundwater recharge and maximise clean surface water runoff from the rehabilitated areas.

If the discard is placed in mined-out areas – the preferred option – it should be placed sufficiently deep below the long-term decant elevation (e.g. 10m). In all likelihood, sufficient space will be available to store this material.

12 CONCLUSIONS AND RECOMMENDATIONS

See executive summary

13 ASSUMPTIONS AND LIMITATIONS

The numerical groundwater flow and transport model is believed to be sufficiently representative of the local aquifers and groundwater conditions, to predict the post-mining decant situation to a sufficient level of accuracy.

The following main assumptions applied to this study:

- Data and information were presumed sufficiently accurate:
  - Where relevant, datasets (e.g. hydraulic testing, water monitoring, surface topography and aquifer geometry);
  - The basis of the impact assessments, were field studies (e.g. hydrocensus, hydrogeological drilling, geophysical surveys, pump testing and groundwater monitoring) by *Groundwater Square* over the past 5years, and the collection of various water/geochemical samples;
  - Project consultants ECMA, GeoSoilWater, GEMECS, CCIC, and EIMS supplied the following information (through discussions, spreadsheets, presentations and electronic CAD drawings):
    - Latest mining scheduling and life-of-mine plans;
    - Infrastructure layout and design;
    - Geological model of coal seams;
    - Groundwater monitoring database;
    - Bulking factor of rehabilitated backfill material;
  - During several visits to the Manungu Colliery, the current water situation was discussed with Mine Personal and mentioned project consultants; providing valuable insight into the future mine water balance;
- Inter-mine flow calculations are not relevant to the project;
- Aquifer parameters of geological units:
  - Although aquifer parameters vary over orders of magnitude over short distances (e.g. fracture flow compared to flow through the solid portions of the rock matrix), the values utilised in the groundwater model for similar geological units of similar depths, will be representative of groundwater flow over distances applicable to typical mining impacts;
  - Where aquifer information was not to the same level of detail as the Karoo aquifers (i.e. hydraulic aquifer parameters of geological units within the numerical groundwater model domain, other than Karoo Ecca rock, within which coal mining is taking place), pumping test information, and anecdotal information on farmers' boreholes and knowledge of these rock type aquifers were considered;
  - The dolerite sills in the area probably has a major impact of groundwater recharge to the deeper aquifers;
- The existing and proposed pit areas are devoid of major vertical geological structures, which can create preferential flow zones, but horizontal aquifer zones and are believed relevant to the deeper aquifers below coal bearing rocks;
- Conceptually, the groundwater flow field is well understood;
- The current interaction of mining with the surrounding aquifers will continue as the opencast mine expands to the south and underground areas;
- Geochemical evaluation:
  - Geochemical samples were representative of the backfilled spoils, mined coal seams and the complete litho-stratigraphical profile;
  - Discard samples were created from coal, based on the Plant design criteria to perform geochemical testing;
  - Given the scientific integrity of the geochemical modelling considerations and technique, geochemical trend predictions are therefore within an acceptable range of accuracy.

The following limitations applied to the study:

- Rainfall seasonality will influence the mine water balance, and the compounding effect of sequential wet or dry rainfall periods may result in much larger than average decant for such extreme wet periods, and zero decant during extreme droughts. An indication of "relatively" wet and dry cycles was provided in the report, but it is not possible to provide for extreme events, such as 100/1000year extremes†;

† The National Water Act requires operators to be able to handle a 1:50 rainfall event, i.e. a risk of spillage <2%. Unfortunately, there is insufficient meteorological data to estimate a 1:1000 year event.

- The sequence of mining will affect the mine water balance; especially relevant with regard to the storage of mine water from the historical underground workings;
- It is very important to perform groundwater level and groundwater quality monitoring, to verify modelling predictions, and timeously correct assumptions in the unlikely event that the groundwater system behaves differently to expectations.

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for *GROUNDWATER SQUARE*

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Appendix I – Photographic Record of External Users

Appendix II – Geophysical Survey

Appendix III – Borehole Logs

Appendix IV – Pumping Test Reports

Appendix V – Groundwater Level Data

Site name	Date	Water Level (m)
BH1	01-08-2014	6.42
KAM01	20-03-2017	11.48
KGA14	20-03-2017	11.80
KGA15	20-03-2017	10.41
MAN-BH1	01-08-2014	15.91
MAN-BH2D	23-05-2017	28.29
MAN-BH2D	01-07-2018	47.30
MAN-BH2D	31-07-2018	32.49
MAN-BH2D	01-10-2018	40.40
MAN-BH2M	23-05-2017	3.54
MAN-BH2M	01-07-2018	8.13
MAN-BH2M	31-07-2018	8.38
MAN-BH2M	01-10-2018	8.70
MAN-BH2S	23-05-2017	3.03
MAN-BH2S	01-07-2018	6.85
MAN-BH2S	31-07-2018	6.03
MAN-BH2S	01-10-2018	6.40
MAN-BH3D	23-05-2017	26.01
MAN-BH3D	01-07-2018	35.00
MAN-BH3D	31-07-2018	32.39
MAN-BH3D	01-10-2018	31.35
MAN-BH3M	23-05-2017	4.18
MAN-BH3M	01-07-2018	11.00
MAN-BH3M	31-07-2018	5.89
MAN-BH3M	01-10-2018	5.80
MAN-BH3S	23-05-2017	3.99
MAN-BH3S	01-07-2018	5.81
MAN-BH3S	31-07-2018	4.97
MAN-BH3S	01-10-2018	4.80
MAN-BH4D	23-05-2017	28.10
MAN-BH4D	01-07-2018	9.00
MAN-BH4D	31-07-2018	27.79
MAN-BH4D	01-10-2018	43.90
MAN-BH4M	23-05-2017	7.23
MAN-BH4M	01-07-2018	8.67
MAN-BH4M	31-07-2018	8.34
MAN-BH4M	01-10-2018	8.50
MAN-BH4S	23-05-2017	6.40
MAN-BH4S	01-07-2018	8.60
MAN-BH4S	31-07-2018	8.44
MAN-BH4S	01-10-2018	8.50
MAN-BH5M	23-05-2017	4.43
MAN-BH6D	23-05-2017	32.60
MAN-BH6D	01-07-2018	30.00
MAN-BH6D	01-10-2018	31.20
MAN-BH6M	23-05-2017	5.15
MAN-BH6M	01-07-2018	5.50
MAN-BH6M	01-10-2018	5.60
MAN-BH7M	22-08-2017	6.53
MAN-BH7M	31-07-2018	7.67
MAN-BH8	01-07-2018	2.87
MAN-BH8	01-10-2018	2.90

Site name	Date	Water Level (m)
MAN-BH8M	22-08-2017	2.77
MAN-BH9D	22-08-2017	8.99
MAN-BH9D	31-07-2018	44.11
MAN-BH9M	22-08-2017	8.23
MAN-BH9M	31-07-2018	8.56
MAN-BH9S	22-08-2017	7.82
MAN-BH9S	31-07-2018	8.36
MAN-BH10M	22-08-2017	5.23
MAN-BH10M	31-07-2018	3.62
MAN-BH11D	15-08-2017	32.10
MAN-BH11D	22-08-2017	36.00
MAN-BH11D	31-07-2018	30.12
MAN-BH11S	22-08-2017	4.18
MAN-BH11S	31-07-2018	5.21
MAN-BH12D	22-08-2017	41.17
MAN-BH12D	31-07-2018	40.42
MAN-BH12M	22-08-2017	4.11
MAN-BH12M	31-07-2018	4.55
MAN-BH12S	22-08-2017	3.50
MAN-BH12S	31-07-2018	4.32
MAN-BH13D	22-08-2017	52.22
MAN-BH13D	31-07-2018	52.08
MBH01	01-08-2014	6.42
MBH01	20-03-2017	7.52
MBH2	01-08-2014	6.33
MBH2	20-03-2017	5.23
MBH4	20-03-2017	8.68
MBH5	08-06-2016	0.50
MBH5	08-09-2016	0.50
MBH5	06-12-2016	0.50
MBH5	16-03-2017	0.50
MBH6	20-03-2017	11.55
MBH10	20-03-2017	80.56
MBH12	20-03-2017	56.80
MBH12	31-07-2018	67.40
MBH13	20-03-2017	3.88
MBH15	20-03-2017	31.43
MBH17	20-03-2017	5.85
MBH18B	20-03-2017	28.48
MBH22	20-03-2017	39.10
MBH23	20-03-2017	71.74
MBH27	20-03-2017	6.56
MBH28	20-03-2017	1.14
MBH29	20-03-2017	11.26
MBH35	20-03-2017	27.21
MBH36B	20-03-2017	15.41
MBH40	20-03-2017	3.33
MBH41	20-03-2017	11.20
MBH45	20-03-2017	9.91
MBH46	20-03-2017	75.75
MBH47	20-03-2017	12.63

Appendix VI – Groundwater Quality Data

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		5.5														
2 - Target Level (>)		9.5	150	1000	150	70	200	50	200	400		10.0	1.0	0.20	0.10	0.30
3 - Critical Level (<)		4														
4 - Critical Level (>)		11	370	2400	300	100	400	100	600	600		20.0	1.5	2.00	1.00	0.50
B2N073	13-03-2017	9.4	33	176	3	12	47	1	13	12	120	3.4	0.2	<0.01	<0.01	<0.01
KAM01	13-03-2017	7.2	73	374	37	21	74	3	56	43	235	<0.35	0.3	<0.01	0.04	<0.01
KGA14	13-03-2017	7.8	55	301	53	25	13	4	15	5	211	13.4	<0.09	<0.01	<0.01	<0.01
KGA15	13-03-2017	7.8	63	347	58	33	12	3	18	8	230	17.2	<0.09	<0.01	<0.01	<0.01
MAN-BH1	16-07-2014	8.2	48	255	28	20	40	6	11	2	244	<0.01	0.5	0.54	0.14	0.12
MAN-BH2D	23-05-2017	9.3	70	389	0	0	163	4	23	5	318	<0.35	1.4	0.04	<0.01	0.05
MAN-BH2D	01-06-2018	9.1	48	389	1	1	161	1	20	1	314	0.3	1.3	<0.004	<0.001	<0.002
MAN-BH2D	01-09-2018	9.0	69	376	1	0	160	1	24	<0.141	304	<0.194	1.4	0.01	<0.001	1.09
MAN-BH2D-Pumptest	03-07-2017	7.2	69	362	44	15	77	3	17	3	326	1.7	0.4	0.03	<0.01	0.04
MAN-BH2M	23-05-2017	8.2	34	175	31	11	15	5	12	8	140	1.6	0.1	0.01	0.02	<0.01
MAN-BH2M	01-06-2018	8.7	8	32	3	2	4	1	3	5	15	0.5	0.4	<0.004	<0.001	<0.002
MAN-BH2M	01-09-2018	8.3	31	207	39	10	14	4	14	4	127	3.2	<0.263	0.01	0.04	0.24
MAN-BH2S	23-05-2017	9.2	21	109	12	7	13	5	14	12	67	0.5	0.2	0.02	<0.01	<0.01
MAN-BH2S	01-06-2018	7.9	19	117	20	7	12	4	12	5	87	0.4	<0.263	<0.004	0.18	<0.002
MAN-BH2S	01-09-2018	8.3	22	120	22	7	12	4	14	0	99	<0.194	<0.263	<0.004	0.17	1.37
MAN-BH3D	23-05-2017	8.4	55	301	15	16	78	5	20	31	225	<0.35	0.8	<0.01	<0.01	0.01
MAN-BH3D	01-06-2018	8.2	38	263	24	18	44	5	6	6	209	0.4	0.5	<0.004	0.03	<0.002
MAN-BH3D	01-09-2018	8.4	43	261	24	19	45	5	8	6	208	0.4	0.4	<0.004	0.01	0.13
MAN-BH3M	23-05-2017	7.2	36	189	27	16	25	7	7	6	169	<0.35	0.2	<0.01	0.13	<0.01
MAN-BH3M	01-06-2018	7.1	39	259	27	16	27	5	5	2	187	0.4	0.8	3.88	0.16	<0.002
MAN-BH3M	01-09-2018	7.5	34	259	28	17	27	6	7	<0.141	192	0.2	0.3	3.68	0.17	0.56
MAN-BH3S	23-05-2017	7.9	24	125	16	10	15	3	17	23	68	<0.35	0.3	0.01	0.08	<0.01
MAN-BH3S	01-06-2018	6.9	14	85	9	6	10	2	13	2	51	0.3	0.5	2.32	0.38	<0.002
MAN-BH3S	01-09-2018	6.9	13	80	8	6	10	2	17	<0.141	53	0.2	<0.263	1.81	0.44	0.51
MAN-BH4D	23-05-2017	8.0	37	196	30	18	18	8	5	9	168	1.5	<0.09	0.07	0.02	<0.01
MAN-BH4D	01-06-2018	9.1	26	143	7	12	11	7	17	4	96	2.6	<0.263	<0.004	0.00	<0.002
MAN-BH4D	01-09-2018	8.5	33	193	23	20	20	6	12	3	149	2.2	0.6	<0.004	0.04	0.24
MAN-BH4M	23-05-2017	7.2	34	167	27	15	15	10	4	4	154	<0.35	0.1	<0.01	0.20	<0.01
MAN-BH4M	01-06-2018	8.3	27	168	18	18	16	9	3	2	161	0.3	<0.263	<0.004	0.02	<0.002
MAN-BH4M	01-09-2018	8.3	39	232	35	20	17	10	4	<0.141	199	0.2	<0.263	<0.004	0.09	0.46
MAN-BH4S	23-05-2017	8.1	27	135	18	12	8	10	6	8	115	<0.35	0.2	<0.01	0.15	<0.01
MAN-BH4S	01-06-2018	8.0	34	190	30	18	9	8	18	19	127	0.4	<0.263	<0.004	0.64	<0.002
MAN-BH4S	01-09-2018	8.3	30	159	27	16	9	8	21	0	122	0.4	<0.263	<0.004	0.64	0.14
MAN-BH5M	23-05-2017	8.8	31	174	17	11	19	9	13	20	108	3.3	0.2	<0.01	0.01	<0.01
MAN-BH6D	23-05-2017	7.9	42	228	22	12	45	3	14	14	152	5.7	0.5	0.06	0.03	<0.01
MAN-BH6D	01-06-2018	7.7	37	276	22	10	62	3	19	9	180	1.9	0.8	<0.004	0.02	<0.002
MAN-BH6D	01-09-2018	8.3	45	279	22	10	61	3	23	13	170	2.9	0.9	<0.004	0.01	0.41
MAN-BH6D-Pumptest	29-06-2017	7.2	68	351	49	17	63	3	16	<0.5	323	1.9	0.3	0.02	<0.01	0.03
MAN-BH6M	23-05-2017	7.5	38	231	33	17	15	5	9	37	108	11.4	<0.09	0.03	<0.01	<0.01
MAN-BH6M	01-06-2018	7.7	34	263	33	16	16	5	7	16	114	8.5	0.6	<0.004	0.01	<0.002
MAN-BH6M	01-09-2018	8.1	39	292	36	17	16	5	9	24	116	9.6	<0.263	<0.004	0.01	1.26
MAN-BH7M	22-08-2017	8.1	40	204	29	14	24	10	9	6	181	0.8	<0.09	0.24	0.04	0.03
MAN-BH8M	22-08-2017	7.6	56	300	34	22	43	6	8	13	279	0.4	0.1	<0.01	0.16	<0.01
MAN-BH8M	01-06-2018	9.2	25	170	3	15	39	6	10	8	141	0.3	0.6	<0.004	<0.001	<0.002
MAN-BH8M	01-09-2018	8.9	30	173	6	16	40	6	13	<0.141	148	0.2	0.6	<0.004	0.01	0.56
MAN-BH9D	15-09-2017	7.3	44	223	27	26	18	5	18	4	186	2.5	0.7	0.08	0.04	0.01
MAN-BH9D-Pumptest	16-09-2017	8.1	46	246	39	21	28	2	12	5	221	1.4	0.6	0.02	0.02	<0.01
MAN-BH9M	23-08-2017	7.9	40	235	34	17	12	9	24	4	132	11.2	<0.09	1.04	0.03	0.01
MAN-BH9S	23-08-2017	8.1	36	213	28	14	9	9	22	6	69	18.5	0.3	0.51	0.03	0.15
MAN-BH10M	22-08-2017	7.3	53	289	53	23	15	3	11	29	181	9.8	<0.09	<0.01	0.17	<0.01
MAN-BH11D	23-08-2017	8.8	116	617	2	1	249	4	54	1	509	<0.35	<0.09	0.75	<0.01	0.05
MAN-BH11D -Pumptest	15-08-2017	8.5	116	679	4	2	277	3	53	<0.5	560	<0.35	1.9	0.04	<0.01	0.02
MAN-BH11S	23-08-2017	7.2	96	527	143	26	14	7	156	14	270	0.4	<0.09	0.64	1.00	<0.01
MAN-BH12D	22-08-2017	8.7	124	652	2	1	271	3	25	21	538	0.9	0.2	<0.01	<0.01	0.01
MAN-BH12M	22-08-2017	8.0	66	355	31	20	75	5	23	20	288	1.0	<0.09	2.08	0.06	0.07
MAN-BH12S	22-08-2017	7.9	103	538	46	37	99	4	77	93	297	<0.35	<0.09	<0.01	0.14	<0.01
MAN-BH13D	22-08-2017	8.8	125	685	3	2	260	7	43	9	562	<0.35	7.4	0.99	<0.01	14.46
MAN-PCD	23-05-2017	8.6	154	942	28	12	260	7	13	265	245	46.4	1.4	0.02	<0.01	0.05
MBH01	08-06-2016	7.4	37	208	30	14	13	7	21	36	77	9.5	0.0	<0.01	<0.01	<0.01
MBH01	14-10-2016	7.6	36	212	30	15	13	6	19	39	83	9.0	<0.09	<0.01	<0.01	0.05
MBH01	14-11-2016	7.7	43	243	37	19	15	8	25	26	119	9.5	<0.09	<0.01	<0.01	0.02
MBH01	06-12-2016	7.7	43	235	37	18	15	7	26	16	122	9.6	<0.09	<0.01	<0.01	0.04
MBH01	19-01-2017	7.4	37	202	35	14	8	6	21	25	80	9.7	<0.01	<0.63	0.08	<0.01
MBH01	20-02-2017	7.4	42	247	40	19	15	7	26	19	118	11.2	<0.09	<0.01	<0.01	<0.01
MBH01	16-03-2017	7.7	42	231	37	18	14	7	24	16	114	10.8	<0.09	<0.01	<0.01	<0.01

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		5.5														
2 - Target Level (>)		9.5	150	1000	150	70	200	50	200	400		10.0	1.0	0.20	0.10	0.30
3 - Critical Level (<)		4														
4 - Critical Level (>)		11	370	2400	300	100	400	100	600	600		20.0	1.5	2.00	1.00	0.50
MBH01	22-03-2017	7.0	35	198	26	14	13	7	17	30	79	10.1	<0.09	<0.01	<0.01	<0.01
MBH01	11-07-2017	7.5	43	244	100	83	15	7	26	16	124	10.3	<0.09	<0.01	<0.01	<0.01
MBH01	21-08-2017	7.9	40	210	31	15	13	6	21	21	98	9.9	<0.09	<0.01	<0.01	<0.01
MBH01	21-09-2017	7.7	42	239	38	17	13	6	25	18	119	11.5	<0.09	<0.01	<0.01	<0.01
MBH01-Office Tap 1	16-07-2017	7.5	43	244	100	83	15	7	26	16	124	10.3	<0.09	<0.01	<0.01	<0.01
MBH01-Office Tap 1	16-08-2017	7.9	40	210	31	15	13	6	21	21	98	9.9	<0.09	<0.01	<0.01	<0.01
MBH01-Office Tap 1	16-09-2017	7.7	42	239	38	17	13	6	25	18	119	11.5	<0.09	<0.01	<0.01	<0.01
MBH01-Office Tap 1	16-10-2017	7.8	42	238	36	18	14	6	26	20	118	11.0	<0.09	<0.01	<0.01	<0.01
MBH01-Office Tap 1	16-11-2017	7.6	42	242	38	18	13	5	25	19	119	11.9	<0.09	<0.01	<0.01	<0.01
MBH01-Office Tap 1	16-12-2017	7.4	42	230	36	17	13	5	23	15	<0.01	11.3	<0.09	<0.01	<0.01	<0.01
MBH01-Office Tap 1	16-01-2018	7.4	42	248	38	21	14	6	28	17	121	11.9	<0.09	<0.01	<0.01	<0.01
MBH01-Office Tap 1	16-02-2018	7.7	40	300	37	18	16	7	23	16	121	8.1	<0,063	<0,004	<0,001	
MBH01-Office Tap 1	16-03-2018	7.5	46	312	41	19	16	7	24	17	132	8.6	<0.263	<0.004	<0.001	<0.002
MBH01-Office Tap 1	01-05-2018	7.8	42	330	40	19	15	7	23	19	138	8.9	<0.263	<0.004	0.00	<0.002
MBH01-Office Tap 1	01-06-2018	7.7	49	312	34	16	15	7	31	24	102	8.7	<0.263	<0.004	<0.001	<0.002
MBH01-Office Tap 1	01-07-2018	7.6	44	296	34	16	15	7	19	25	105	7.1	<0.263	<0.004	<0.001	<0.002
MBH01-Office Tap 1	01-08-2018	7.6	34	283	30	14	14	7	15	29	109	6.5	<0.263	<0.004	<0.001	<0.002
MBH01-Office Tap 1	01-09-2018	7.7	42	344	42	19	15	7	21	21	153	8.7	0.3	<0.004	<0.001	<0.002
MBH01-Office Tap 1	01-10-2018	8.0	39	314	36	18	15	7	22	31	105	7.6	<0.263	<0.004	0.00	0.03
MBH01-Office Tap 1	Q1	7.7	45	313	36	17	15	7	24	22	115	8.2	<0.263	<0.004	0.00	<0.002
MBH01-Office Tap 1	Q2	7.7	38	314	36	17	15	7	19	27	122	7.6	0.3	<0.004	0.00	0.03
MBH01-Office Tap 2	16-03-2017	7.4	40	234	20	8	33	5	6	78	22	16.0	0.2	0.01	0.01	0.01
MBH01-Office Tap 2	16-06-2017	7.7	47	246	37	19	25	6	10	33	181	1.7	<0.09	0.02	0.06	0.05
MBH01-Office Tap 2	16-09-2017	7.7	70	386	62	37	24	6	25	49	304	<0.35	0.1	<0.01	0.06	<0.01
MBH01-Office Tap 2	16-12-2017	7.5	52	281	41	23	26	4	14	34	<0.01	2.0	0.3	0.43	0.38	0.75
MBH01-Office Tap 2	16-02-2018	7.7	40	275	35	17	15	6	23	15	124	7.9	<0,263	<0,004	<0,001	<0,002
MBH01-Office Tap 2	16-03-2018	7.6	46	306	40	19	15	7	24	17	121	8.6	<0.263	<0.004	<0.001	<0.002
MBH01-Office Tap 2	01-05-2018	7.7	42	332	39	18	15	7	22	21	135	8.9	<0.263	<0.004	<0.001	<0.002
MBH01-Office Tap 2	01-06-2018	7.6	44	313	34	16	15	7	23	23	114	8.9	<0.263	<0.004	<0.001	<0.002
MBH01-Office Tap 2	01-07-2018	7.5	44	298	34	16	15	7	19	23	107	7.2	<0.263	<0.004	<0.001	<0.002
MBH01-Office Tap 2	01-08-2018	7.6	33	282	30	14	14	7	15	29	105	6.7	<0.263	<0.004	<0.001	<0.002
MBH01-Office Tap 2	01-09-2018	7.6	40	332	42	19	15	7	21	14	149	8.6	<0.263	<0.004	<0.001	<0.002
MBH01-Office Tap 2	01-10-2018	8.0	38	296	32	17	15	7	21	32	84	7.2	<0.263	<0.004	<0.001	0.11
MBH01-Office Tap 2	Q1	7.6	43	314	36	17	15	7	21	22	119	8.3	<0.263	<0.004	<0.001	<0.002
MBH01-Office Tap 2	Q2	7.7	37	303	35	17	15	7	19	25	113	7.5	<0.263	<0.004	<0.001	0.11
MBH05	14-09-2017	7.7	70	386	62	37	24	6	25	49	304	<0.35	0.1	<0.01	0.06	<0.01
MBH4	08-06-2016	6.9	38	212	30	16	13	7	15	9	97	14.3	<0.09	<0.01	<0.01	0.03
MBH4	14-10-2016	7.0	37	204	32	16	11	7	17	9	100	11.8	<0.09	0.02	<0.01	0.10
MBH4	14-11-2016	7.5	39	214	32	18	12	8	19	10	108	11.3	<0.09	<0.01	<0.01	0.05
MBH4	06-12-2016	7.2	41	218	34	18	14	7	18	10	112	11.3	<0.09	<0.01	<0.01	0.06
MBH4	20-02-2017	7.1	39	231	35	19	13	7	18	10	114	13.6	<0.09	<0.01	<0.01	<0.01
MBH4	16-03-2017	7.6	39	221	33	17	13	7	17	13	101	13.7	0.2	<0.01	<0.01	<0.01
MBH4	16-04-2017	7.1	39	217	30	17	12	6	17	9	101	14.6	0.1	0.01	0.01	0.01
MBH4	16-05-2017	7.1	42	233	33	18	13	9	18	16	122	12.2	<0.09	<0.01	<0.01	<0.01
MBH4	16-06-2017	7.2	42	233	34	18	13	8	18	17	118	12.2	0.1	0.02	<0.01	<0.01
MBH4	17-07-2017	7.1			40	<0.01	14	7	18	18	113	15.9	<0.09	<0.01	<0.01	<0.01

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		5.5														
2 - Target Level (>)		9.5	150	1000	150	70	200	50	200	400		10.0	1.0	0.20	0.10	0.30
3 - Critical Level (<)		4														
4 - Critical Level (>)		11	370	2400	300	100	400	100	600	600		20.0	1.5	2.00	1.00	0.50
MBH4	21-08-2017		39	217	30	17	12	6	17	9	101	14.6	<0.09	<0.01	<0.01	<0.01
MBH4	21-09-2017	7.3	42	241	38	17	13	7	18	18	120	13.0	<0.09	0.01	<0.01	<0.01
MBH4	16-10-2017	7.4	42	241	36	72	13	5	19	15	112	15.4	<0.09	0.01	<0.01	<0.01
MBH4	16-11-2017	7.2	43	240	38	19	13	6	19	17	122	12.6	<0.09	0.01	<0.01	<0.01
MBH4	16-12-2017	7.1	44	249	38	19	13	6	21	20		12.9	<0.09	0.01	<0.01	<0.01
MBH4	16-01-2018	7.8	48	258	40	24	26	3	19	12	205	2.1	0.6	0.02	<0.01	0.03
MBH4	16-02-2018	8.0	46	258	34	26	37	2	17	16	216	0.6	0.6	<0,004	0.00	<0,04
MBH4	16-03-2018	8.0	41	284	35	26	34	3	18	11	219	0.6	0.5	<0.004	<0.001	<0.002
MBH4	01-05-2018	8.1	45	302	34	25	33	3	17	12	239	0.8	0.6	<0.004	0.02	<0.002
MBH4	01-06-2018	8.0	45	281	33	24	35	2	19	12	203	0.8	0.7	<0.004	<0.001	<0.002
MBH4	01-07-2018	8.0	46	290	34	25	36	3	17	10	219	0.7	0.6	<0.004	<0.001	<0.002
MBH4	01-08-2018	7.9	49	294	33	24	35	2	15	11	244	0.5	0.7	<0.004	<0.001	<0.002
MBH4	01-09-2018	7.8	47	306	38	27	34	3	15	10	247	0.6	0.7	<0.004	<0.001	<0.002
MBH4	01-10-2018	8.2	48	299	38	26	30	5	20	22	200	1.3	0.5	<0.004	0.01	0.08
MBH4	Q1	8.0	45	291	34	25	35	3	18	11	220	0.8	0.6	<0.004	0.02	<0.002
MBH4	Q2	8.0	48	300	36	25	33	3	17	14	230	0.8	0.6	<0.004	0.01	0.08
MBH5	08-06-2016	6.9	30	153	24	12	6	8	11	44	74	0.8	0.1	0.15	0.20	0.59
MBH5	06-12-2016	7.7	40	220	34	18	16	7	17	64	97	1.5	<0.09	<0.01	0.02	0.05
MBH5	16-03-2017	7.4	40	234	20	8	33	5	6	78	22	16.0	0.2	<0.01	<0.01	<0.01
MBH6	13-03-2017	7.5	61	312	62	17	20	10	48	10	198	6.0	<0.09	<0.01	<0.01	<0.01
MBH12	14-03-2017	7.9	67	356	16	14	104	3	21	11	308	0.4	0.5	<0.01	<0.01	<0.01
MBH12	31-07-2018	7.7	67	362	20	16	101	2	26	11	305	0.4	0.7	0.08	<0.01	<0.01
MBH13	14-03-2017	7.7	75	421	100	20	15	5	38	21	251	15.9	<0.09	<0.01	<0.01	<0.01
MBH15	14-03-2017	7.8	72	389	59	23	49	9	14	21	330	3.6	0.1	<0.01	<0.01	<0.01
MBH17	08-06-2016	8.6	43	208	20	22	27	6	18	6	174	1.1	0.3	<0.01	<0.01	0.03
MBH17	22-03-2017	7.8	131	725	47	30	197	5	83	33	542	1.0	0.3	<0.01	<0.01	<0.01
MBH18B	14-03-2017	7.8	38	188	32	16	16	4	13	9	161	<0.35	0.1	<0.01	<0.01	<0.01
MBH20	15-03-2017	7.4	32	171	22	11	19	6	10	4	119	6.3	0.1	<0.01	<0.01	<0.01
MBH25	20-03-2017	7.5	94	494	60	37	78	4	56	23	370	3.2	0.2	<0.01	<0.01	<0.01
MBH27	22-03-2017	7.0	40	207	40	13	22	2	5	11	191	<0.35	<0.09	<0.01	0.01	<0.01
MBH29	20-03-2017	7.8	325	2166	302	259	76	2	546	517	435	46.1	<0.09	<0.01	<0.01	<0.01
MBH31	20-03-2017	7.8	74	378	52	33	39	3	72	8	239	6.1	<0.09	<0.01	<0.01	<0.01
MBH32	08-06-2016	7.2	66	340	64	22	25	8	39	25	217	6.1	<0.09	<0.01	<0.01	0.02
MBH32	06-12-2016	7.3	68	360	71	23	27	8	39	32	223	5.8	<0.09	0.10	<0.01	0.03
MBH32	14-03-2017	7.5	63	333	59	21	26	7	34	24	232	5.0	<0.09	<0.01	<0.01	<0.01
MBH32	16-03-2017	7.3	63	338	65	21	24	7	33	28	227	5.3	<0.09	<0.01	<0.01	<0.01
MBH32	16-06-2017	7.9	66	348	66	23	26	9	37	29	<0.01	4.6	<0.09	<0.01	<0.01	<0.01
MBH32	16-09-2017	7.4	63	344	65	21	23	7	35	29		5.7	<0.09	<0.01	<0.01	<0.01
MBH32	17-09-2017	7.4	63	344	65	21	23	7	35	29		5.7	<0.09	<0.01	<0.01	<0.01
MBH32	16-12-2017	7.3	65	352	67	22	24	6	37	29	<0.01	6.3	<0.09	<0.01	<0.01	<0.01
MBH35	20-03-2017	7.2	45	236	35	17	19	5	24	16	146	7.1	<0.09	<0.01	<0.01	<0.01
MBH36A	20-03-2017	7.6	88	449	37	26	98	5	54	21	346	<0.35	0.3	0.01	<0.01	<0.01
MBH40	14-03-2017	7.7	76	405	70	26	44	2	46	24	301	2.5	0.1	<0.01	<0.01	<0.01
MBH41	15-03-2017	7.3	23	124	16	12	9	3	4	4	90	5.4	0.1	<0.01	<0.01	<0.01
MBH45	20-03-2017	7.4	123	660	140	43	38	1	153	35	357	8.0	<0.09	<0.01	<0.01	<0.01
MBH46	20-03-2017	7.9	67	336	44	29	39	3	64	8	218	4.0	<0.09	<0.01	<0.01	<0.01
MBH47	20-03-2017	7.8	116	676	99	66	33	3	88	127	316	16.0	<0.09	<0.01	<0.01	<0.01
MWQ1	08-06-2016	7.5	24	122	11	9	18	6	4	15	91	0.7	0.3	0.09	0.02	0.10
MWQ1	14-11-2016	6.9	27	152	11	10	22	11	12	31	88	<0.35	0.2	0.36	0.78	0.78
MWQ1	06-12-2016	7.9	36	194	22	16	30	7	14	16	147	<0.35	0.2	0.12	<0.01	0.10
MWQ1	19-01-2017	7.2	31	167	15	13	30	4	11	24	115	<0.35	0.3	0.32	0.08	0.27
MWQ1	20-02-2017	8.3	33	182	18	13	36	4	10	11	151	<0.35	0.3	0.11	<0.01	0.02
MWQ1	16-03-2017	7.6	39	209	19	14	28	9	13	21	152	0.8	0.2	0.04	<0.01	0.02
MWQ1	16-04-2017	7.2	39	188	16	14	34	4	25	13	137	<0.35	0.2	0.16	<0.01	<0.01
MWQ1	17-05-2017	7.8	30	150	18	13	18	5	14	16	110	<0.35	0.1	0.05	0.01	0.05
MWQ1	17-06-2017	7.3	37	202	25	16	27	6	20	20	144	<0.35	0.2	0.09	0.33	0.07
MWQ1	11-07-2017	7.1	45	251	30	23	31	7	29	19	183	<0.35	0.3	0.02	1.47	<0.01
MWQ1	17-08-2017	8.0	52	274	27	23	44	11	47	11	180	0.8	0.1	0.01	<0.01	<0.01
MWQ1	17-09-2017	7.3	106	577	49	37	96	21	128	8	374	<0.35	0.4	4.52	4.83	<0.01
MWQ1	16-11-2017	7.0	17	299	38	22	26	17	28	65	162	0.5	0.3	0.32	0.61	0.06
MWQ1	16-12-2017	7.2	56	306	19	19	61	8	31	71	158	0.4	0.3	0.21	0.01	0.08
MWQ1	16-01-2018	7.5	68	374	26	29	73	12	47	21	267	0.5	0.5	0.26	0.53	0.31
MWQ1	16-02-2018	8.4	58	382	20	68	16	<0,002	36	13	246	0.2	28.8	2.11	0.02	0.11
MWQ1	16-03-2018	7.4	45	300	31	22	37	18	26	<0.141	240	0.2	0.5	0.92	1.48	<0.002
MWQ1	01-05-2018	8.1	46	283	23	17	57	7	21	14	220	0.5	0.4	<0.004	0.28	<0.002
MWQ1	01-06-2018	7.9	51	326	31	22	65	7	30	12	242	0.3	0.5	<0.004	2.15	0.05
MWQ1	01-07-2018	7.9	45	349	36	25	67	11	33	5	271	0.3	0.4	<0.004	1.96	<0.002
MWQ1	01-08-2018	8.1	82	462	38	29	101	12	48	1	378	<0.194	0.6	<0.004	1.16	<0.002
MWQ1	Q1	8.0	47	319	30	21	63	9	28	10	244	0.3	0.4	<0.004	1.46	0.05
MWQ3	08-06-2016	7.4	32	165	14	11	24	7	16	27	95	1.3	0.4	0.80	<0.01	1.77
MWQ3	14-10-2016	7.7	48	276	21	17	43	13	30	57	141	1.6	0.7	1.32	<0.01	1.45
MWQ3	14-11-2016	7.1	19	99	7	6	12	11	10	21	52	<0.35	0.3	0.08	0.01	0.16
MWQ3	06-12-2016	7.6	31	175	16	12	26	12	15	35	90	0.7	0.5	0.09	<0.01	0.16
MWQ3	19-01-2017	7.4	25	129	14	8	17	7	12	24	75	<0.35	0.6	<0.01	0.01	<0.01

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		5.5														
2 - Target Level (>)		9.5	150	1000	150	70	200	50	200	400		10.0	1.0	0.20	0.10	0.30
3 - Critical Level (<)		4														
4 - Critical Level (>)		11	370	2400	300	100	400	100	600	600		20.0	1.5	2.00	1.00	0.50
MWQ3	20-02-2017	7.5	31	176	16	11	28	10	17	35	93	0.9	0.6	<0.01	<0.01	<0.01
MWQ3	16-03-2017	7.5	24	127	12	9	17	10	9	18	85	<0.35	0.4	0.06	<0.01	0.08
MWQ3	16-04-2017	7.2	32	161	13	11	24	9	14	32	93	0.4	0.5	0.01	<0.01	<0.01
MWQ3	17-05-2017	7.6	32	172	14	12	25	10	16	34	96	<0.35	0.5	1.34	0.02	2.22
MWQ3	17-06-2017	7.6	34	183	15	12	28	11	16	35	104	0.5	0.5	0.23	<0.01	0.45
MWQ3	11-07-2017	7.4	36	212	18	14	32	11	19	45	113	0.8	0.6	0.09	0.01	0.18
MWQ3	11-08-2017	7.9	41	223	20	14	34	11	23	47	117	0.9	0.3	0.13	<0.01	0.25
MWQ3	11-09-2017	7.4	44	241	22	15	35	11	23	56	123	1.1	0.7	<0.01	<0.01	<0.01
MWQ3	16-10-2017	7.8	48	277	25	17	47	14	26	60	141	0.6	0.9	0.04	<0.01	0.06
MWQ3	16-11-2017	7.7	15	296	27	19	48	11	30	70	148	0.5	1.1	<0.01	<0.01	<0.01
MWQ3	16-12-2017	7.2	28	306	12	9	21	10	13	42	70	<0.35	0.4	0.11	0.05	0.15
MWQ3	16-01-2018	7.5	60	374	32	26	56	11	36	84	156	<0.35	1.3	,0	<0.01	<0.01
MWQ3	16-02-2018	7.8	20	138	6	15	8	0	7	26	63	0.3	9.8	0.04	0.01	<0,004
MWQ3	16-03-2018	7.6	22	171	22	13	18	9	8	23	126	<0.194	0.3	<0.004	0.02	0.07
MWQ3	01-06-2018	8.0	57	368	36	26	59	14	42	66	196	0.8	0.7	<0.004	0.90	<0.002
MWQ3	01-07-2018	8.2	63	458	45	28	85	16	52	78	248	0.3	0.8	<0.004	<0.001	<0.002
MWQ3	Q1	8.1	60	413	40	27	72	15	47	72	222	0.6	0.7	<0.004	0.90	<0.002
MWQ3	Q2															
MWQ4	08-06-2016	7.5	97	485	41	28	98	11	95	28	300	0.4	0.3	0.09	0.11	0.04
MWQ4	14-10-2016	7.2	207	1218	63	62	294	26	233	13	836	<0.35	1.4	2.03	6.49	0.03
MWQ4	14-11-2016	8.2	115	721	90	32	88	9	64	375	103	<0.35	<0.09	0.03	<0.01	0.05
MWQ4	16-03-2017	7.4	114	625	53	35	130	14	117	64	354	<0.35	0.2	0.39	<0.01	<0.01
MWQ4	17-05-2017	7.4	144	786	52	38	184	13	152	76	448	<0.35	<0.09	0.11	1.05	<0.01
MWQ4	17-06-2017	7.4	181	943	70	50	200	25	148	5	719	<0.35	0.3	3.27	5.29	0.22
MWQ4	11-07-2017	7.4	36	212	18	14	32	11	19	45	113	0.8	0.6	0.09	0.01	0.18
MWQ4	11-08-2017	7.9	41	223	20	14	34	11	23	47	117	0.9	0.3	0.13	<0.01	0.25
MWQ4	11-09-2017	7.4	44	241	22	15	35	11	23	56	123	1.1	0.7	<0.01	<0.01	<0.01
MWQ4	16-09-2017	7.8	172	888	60	48	216	12	127	11	687	<0.35	0.2	1.28	<0.01	<0.01
MWQ5	08-06-2016	7.5	36	177	22	17	19	8	16	19	123	0.5	0.2	0.08	<0.01	0.17
MWQ5	14-10-2016	7.9	50	277	19	26	40	10	36	35	184	<0.35	0.4	0.03	0.02	0.05
MWQ5	14-11-2016	7.3	34	176	14	14	24	11	25	35	86	<0.35	0.1	0.35	<0.01	0.65
MWQ5	06-12-2016	8.1	57	297	30	24	40	13	33	35	201	<0.35	0.1	0.01	<0.01	0.06
MWQ5	19-01-2017	7.6	48	226	2	17	36	7	54	24	110	<0.35	0.2	0.27	0.08	0.28
MWQ5	20-02-2017	8.7	40	208	16	17	35	7	51	15	111	<0.35	0.3	0.07	0.04	0.03
MWQ5	16-03-2017	7.5	42	213	16	18	35	10	46	25	106	<0.35	0.1	0.13	0.01	0.12
MWQ5	16-04-2017	8.2	43	214	17	17	34	9	47	19	118	<0.35	0.2	0.05	<0.01	0.04
MWQ5	17-05-2017	7.9	32	161	16	14	19	9	26	12	103	<0.35	0.1	1.17	0.13	1.58
MWQ5	17-06-2017	6.9	36	166	17	14	20	9	31	5	109	<0.35	0.2	0.17	1.65	<0.01
MWQ5	11-07-2017	7.1	45	251	30	23	31	7	29	19	183	<0.35	0.3	0.02	1.47	<0.01
MWQ5	11-08-2017	8.0	52	251	23	23	33	12	51	9	169	<0.35	0.1	<0.01	0.06	<0.01
MWQ5	11-09-2017	7.6	60	281	22	98	38	12	56	6	188	<0.35	0.5	1.97	2.19	<0.01
MWQ5	16-10-2017	7.7	64	327	27	29	47	13	75	6	206	0.4	0.5	<0.01	<0.01	0.03
MWQ5	16-11-2017	7.5	21	276	28	24	33	13	54	19	168	0.5	0.5	0.02	0.08	<0.01
MWQ5	16-12-2017	7.1	58	310	21	21	52	13	43	62	160	<0.35	0.3	0.37	0.26	0.16
MWQ5	16-01-2018	8.9	67	353	26	25	65	15	60	17	190	0.4	0.4	0.27	0.04	0.37
MWQ5	16-02-2018	8.3	78	538	34	89	26	<0,002	66	<0,141	329	0.9	35.0	2.72	0.02	0.27
MWQ5	16-03-2018	7.5	39	260	32	20	33	12	29	6	196	<0.194	0.3	<0.004	0.04	<0.002
MWQ5	01-05-2018	8.1	34	279	30	20	39	12	30	20	196	0.4	0.3	0.01	0.32	0.14
MWQ5	01-06-2018	8.2	32	252	25	19	39	11	33	16	162	0.3	0.4	<0.004	0.74	<0.002
MWQ5	01-07-2018	8.4	37	252	24	15	42	13	35	17	160	2.0	0.3	<0.004	<0.001	<0.002
MWQ5	01-08-2018	8.2	57	324	29	22	50	14	39	18	236	0.4	0.5	0.01	0.25	0.10
MWQ5	01-09-2018	7.9	58	349	29	27	61	14	51	13	248	0.2	0.5	<0.004	0.40	0.03
MWQ5	01-10-2018	8.5	68	359	22	25	76	16	81	6	213	<0.194	0.5	<0.004	<0.001	<0.002
MWQ5	Q1	8.2	34	261	26	18	40	12	33	18	173	0.9	0.3	0.01	0.53	0.14
MWQ5	Q2	8.2	61	344	26	25	62	15	57	12	232	0.3	0.5	0.01	0.33	0.06
MWQ6	08-06-2016	8.0	27	137	16	11	15	7	9	27	83	0.5	0.3	0.13	<0.01	0.36
MWQ6	06-12-2016	7.6	40	215	33	14	25	8	3	51	135	<0.35	0.2	<0.01	<0.01	0.04
MWQ6	19-01-2017	7.7	30	151	24	13	8	9	8	23	108	<0.35	0.4	0.03	0.04	0.04
MWQ6	20-02-2017	7.1	27	155	23	6	11	13	8	56	49	1.3	0.2	0.03	<0.01	0.02
MWQ6	16-04-2017	7.7	33	176	18	12	21	11	16	40	94	0.4	0.1	0.09	0.02	0.14
MWQ6	16-05-2017	7.6	44	229	24	17	27	13	21	49	129	<0.35	0.2	0.05	<0.01	0.13
MWQ6	17-05-2017	7.7	33	176	18	12	21	11	16	40	94	0.4	0.1	0.09	0.02	0.14
MWQ6	17-06-2017	7.6	44	229	24	17	27	13	21	49	129	<0.35	0.2	0.05	<0.01	0.13
MWQ6	16-10-2017	7.6	40	207	30	15	19	12	11	28	145	0.4	0.9	0.05	0.61	0.05
MWQ6	16-11-2017	7.3	32	160	14	14	23	9	12	10	130	<0.35	0.3	0.15	<0.01	0.11
MWQ6	16-12-2017	8.0	25	138	20	10	12	8	5	19	101	0.4	0.5	0.04	<0.01	0.08
MWQ6	16-02-2018	8.0	26	178	8	11	10	<0,002	5	44	76	0.2	21.6	0.10	0.02	<0,004
MWQ6	16-03-2018	7.6	24	184	26	12	14	10	6	29	121	0.4	0.4	<0.004	<0.001	<0.002
MWQ6	01-05-2018	8.1	28	194	21	12	17	11	13	23	127	0.4	0.3	<0.004	0.00	0.17
MWQ6	01-06-2018	8.2	31	246	36	18	24	12	19	47	140	0.3	0.3	<0.004	0.01	0.01
MWQ6	Q1	8.1	29	220	28	15	21	11	16	35	134	0.3	0.3	<0.004	0.00	0.09
OB2	01-06-2018	8.4	130	1004	95	51	128	9	28	478	124	30.6	0.3	<0.004	<0.001	<0.002
OB2	01-07-2018	8.3	127	986	111	56	132	9	27	508	117	16.3	0.3	<0.004	<0.001	<0.002
OB2	01-08-2018	8.3	152	1144	112	62	138	11	44	519	143	38.3	0.4	<0.004	<0.001	<0.002

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		5.5														
2 - Target Level (>)		9.5	150	1000	150	70	200	50	200	400		10.0	1.0	0.20	0.10	0.30
3 - Critical Level (<)		4														
4 - Critical Level (>)		11	370	2400	300	100	400	100	600	600		20.0	1.5	2.00	1.00	0.50
OB2	01-09-2018	8.4	143	1035	104	62	144	9	36	465	118	31.8	0.3	<0.004	<0.001	<0.002
OB2	01-10-2018	9.2	147	1099	93	62	136	10	44	601	68	25.0	0.4	<0.004	<0.001	<0.002
OB2	Q1	8.4	129	995	103	53	130	9	27	493	121	23.5	0.3	<0.004	<0.001	<0.002
OB2	Q2	8.6	147	1093	103	62	139	10	41	528	110	31.7	0.4	<0.004	<0.001	<0.002
PCD	08-06-2016	8.3	66	388	31	12	72	5	4	143	89	15.3	0.8	<0.01	<0.01	0.09
PCD	14-10-2016	8.2	75	484	36	15	91	6	7	191	111	15.8	1.0	0.01	<0.01	0.06
PCD	14-11-2016	8.4	67	379	27	11	78	5	6	138	91	13.2	0.7	<0.01	<0.01	<0.01
PCD	06-12-2016	8.3	68	396	31	14	74	6	6	137	96	16.0	0.9	0.03	<0.01	0.15
PCD	20-02-2017	8.5	76	493	37	15	97	6	7	189	105	17.5	0.9	<0.01	<0.01	<0.01
PCD	16-03-2017	8.6	105	631	32	14	143	6	7	212	132	30.5	1.0	0.03	<0.01	0.14
PCD	16-04-2017	8.1	296	442	34	22	104	3	34	58	296	1.7	0.5	0.08	0.05	0.19
PCD	17-05-2017	8.5	146	937	22	15	249	8	12	232	243	56.2	1.4	0.04	<0.01	0.10
PCD	07-06-2017	8.5	156	960	29	17	251	8	13	237	258	55.8	1.4	<0.01	<0.01	<0.01
PCD	11-07-2017	8.3	159	994	23	12	280	8	15	239	263	57.8	1.7	0.03	<0.01	0.09
PCD	17-08-2017	8.6	184	1181	20	12	337	7	17	278	287	73.3	1.1	<0.01	<0.01	0.02
PCD	17-09-2017	8.4	224	1383	22	16	393	7	20	436	339	63.9	2.0	0.19	0.02	0.70
PCD	16-10-2017	8.6	233	1535	23	20	452	7	23	529	353	60.2	2.2	0.05	<0.01	0.11
PCD	16-11-2017	8.9	224	1536	14	12	450	7	21	559	329	60.4	2.2	1.57	0.02	4.98
PCD	16-12-2017	8.3	175	1101	22	12	315	5	12	409	256	38.7	1.6	0.02	<0.01	<0.01
PCD	16-01-2018	8.7	196	1286	16	14	384	6	17	504	235	41.2	1.6	<0.01	<0.01	,0.01
PCD	16-02-2018	8.9	176	1352	7	483	5	<0,002	15	517	375	46.7	11.7	<0,001	0.01	<0,004
PCD	16-03-2018	8.7	166	1171	14	8	360	9	15	393	0	41.6	1.2	<0.004	<0.001	0.00
PCD	01-05-2018	8.7	136	1054	20	10	337	4	10	380	253	28.3	1.1	<0.004	<0.001	0.11
PCD	01-06-2018	8.5	197	1677	44	21	460	6	14	764	271	42.8	1.0	<0.004	<0.001	<0.002
PCD	01-07-2018	8.6	227	1786	37	21	511	7	14	875	346	22.8	0.9	<0.004	<0.001	<0.002
PCD	01-08-2018	8.8	242	1453	29	19	423	7	14	639	245	36.1	1.1	<0.004	<0.001	0.07
PCD	01-09-2018	8.7	242	1799	25	19	582	7	16	732	428	32.3	1.0	<0.004	<0.001	0.01
PCD	01-10-2018	8.8	267	1805	20	20	574	7	21	785	383	30.2	1.1	<0.004	<0.001	0.16
PCD	Q1	8.6	187	1506	34	17	436	6	12	673	290	31.3	1.0	<0.004	<0.001	0.11
PCD	Q2	8.8	250	1686	25	19	526	7	17	719	352	32.9	1.1	<0.004	<0.001	0.08
PCD Drainage	08-06-2016	8.0	88	471	26	17	122	5	41	68	302	2.3	0.8	<0.01	0.01	0.03
PCD Drainage	14-10-2016	7.9	78	446	27	19	113	3	40	62	286	2.0	0.7	0.01	<0.01	0.05
PCD Drainage	14-11-2016	7.9	79	439	28	20	114	4	42	65	262	1.9	0.4	0.04	0.01	0.13
PCD Drainage	06-12-2016	7.9	81	420	26	18	104	4	39	56	273	1.8	0.6	0.06	0.01	0.21
PCD Drainage	20-02-2017	7.8	81	467	29	21	121	5	43	61	300	1.5	0.6	0.05	0.04	0.10
PCD Drainage	16-03-2017	7.8	80	443	28	20	118	3	39	55	291	1.3	0.5	0.04	0.03	0.10
PCD Drainage	16-04-2017	8.5	116	698	27	13	172	6	12	222	161	33.3	1.2	0.05	<0.01	0.17
PCD Drainage	17-05-2017	7.7	84	451	27	22	110	<0.03	35	58	315	1.1	0.5	0.26	0.11	0.52
PCD Drainage	17-06-2017	7.8	86	461	28	23	114	4	37	59	318	1.2	0.4	0.06	0.04	0.14
PCD Drainage	11-07-2017	7.7	86	489	33	25	112	3	39	78	317	1.8	0.5	0.13	0.03	0.26
PCD Drainage	17-08-2017	7.7	81	452	29	24	105	3	39	68	287	2.7	0.2	0.11	0.05	0.20
PCD Drainage	17-09-2017	7.4	80	426	32	21	99	3	39	50	280	3.3	0.6	0.02	0.02	0.03
PCD Drainage	16-10-2017	7.9	80	459	38	22	107	3	44	56	291	3.2	0.7	<0.01	21.70	<0.01
PCD Drainage	16-11-2017	8.1	76	424	31	20	99	2	37	51	279	3.6	0.6	0.08	0.02	0.18
PCD Drainage	16-12-2017	7.5	75	416	30	20	94	3	33	55	275	3.2	0.8	0.08	0.02	0.15
PCD Drainage	16-01-2018	8.0	77	454	41	25	14	3	34	70	278	3.2	0.8	0.78	<0.01	0.01
PCD Drainage	16-02-2018	8.9	96	592	21	181	4	<0,002	28	145	303	5.9	29.1	<0,001	0.01	<0,004
PCD Drainage	16-03-2018	8.4	67	519	34	25	118	4	32	87	<0.002	1.3	0.7	<0,004	<0,001	<0.002
PCD Drainage	01-05-2018	8.5	105	859	27	16	257	4	17	264	278	17.8	1.0	<0.004	<0.001	<0.002
PCD Drainage	01-06-2018	8.5	86	629	36	24	158	4	31	144	287	5.2	0.9	<0.004	<0.001	0.25
PCD Drainage	01-07-2018	8.6	75	564	37	26	135	4	29	116	296	1.8	0.7	<0.004	<0.001	<0.002
PCD Drainage	01-08-2018	8.7	90	640	33	25	155	3	26	118	408	1.1	0.8	<0.004	<0.001	<0.002
PCD Drainage	01-09-2018	8.4	85	636	43	30	145	4	29	124	362	1.1	0.9	<0.004	<0.001	<0.002

Site Name	Date	pH	EC (mS/m)	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Cl (mg/L)	SO4 (mg/L)	TALK (mg/L)	NO3 (as N) (mg/L)	F (mg/L)	Fe (mg/L)	Mn (mg/L)	Al (mg/L)
1 - Target Level (<)		**5.5**														
2 - Target Level (>)		**9.5**	**150**	**1000**	**150**	**70**	**200**	**50**	**200**	**400**		**10.0**	**1.0**	**0.20**	**0.10**	**0.30**
3 - Critical Level (<)		**4**														
4 - Critical Level (>)		**11**	**370**	**2400**	**300**	**100**	**400**	**100**	**600**	**600**		**20.0**	**1.5**	**2.00**	**1.00**	**0.50**
PCD Drainage	01-10-2018	8.4	91	571	37	29	138	4	36	74	351	0.7	0.8	<0.004	<0.001	**0.90**
PCD Drainage	Q1	8.6	89	684	33	22	183	4	26	175	287	8.3	0.9	<0.004	<0.001	0.25
PCD Drainage	Q2	8.5	88	616	38	28	146	3	30	105	374	1.0	0.8	<0.004	<0.001	**0.90**
Pit Area	08-06-2016	8.1	**199**	**1255**	24	14	**319**	9	14	235	198	**116.0**	1.0	**0.21**	<0.01	**1.23**
Pit Area	14-10-2016	8.4	**187**	**1165**	2	2	**353**	5	21	130	279	**108.0**	**2.7**	**0.56**	<0.01	0.08
Pit Area	14-11-2016	8.3	102	666	9	5	189	4	16	88	180	**53.9**	**1.6**	**2.12**	<0.01	**5.12**
Pit Area	06-12-2016	8.5	**246**	**1717**	20	9	**453**	11	11	266	219	**181.0**	**1.9**	**1.05**	0.03	**5.80**
Pit Area	20-02-2017	8.5	**272**	**1887**	38	26	**534**	10	19	**727**	332	**73.7**	**1.6**	0.06	0.01	**0.31**
Pit Area	16-03-2017	8.8	**162**	**1075**	5	5	**318**	9	10	273	251	**64.4**	**3.3**	**3.95**	<0.01	**6.08**
Pit Area	16-04-2017	8.7	**211**	**1487**	21	21	**427**	9	13	**460**	237	**88.4**	**1.6**	0.04	<0.01	0.11
Pit Area	17-06-2017	8.5	**235**	**1523**	10	10	**412**	9	15	110	256	**178.0**	**2.6**	0.15	<0.01	**1.27**
Pit Area	11-07-2017	8.6	**164**	**1107**	6	3	**337**	5	17	145	308	**90.9**	**3.1**	0.04	<0.01	0.12
Pit Area	16-08-2017	8.3	**331**	**2236**	94	**73**	**688**	10	21	**1042**	331	**48.8**	0.6	**0.39**	<0.01	**0.75**
Pit Area	17-08-2017	8.3	**331**	**2236**	94	**73**	**688**	10	21	**1042**	331	**48.8**	0.6	**0.39**	<0.01	**0.75**
Pit Area	17-09-2017	8.5	**218**	**1403**	22	16	**426**	9	22	**521**	442	**26.2**	**1.5**	**0.38**	<0.01	**1.13**
Pit Area	16-11-2017	8.3	**221**	**1449**	5	3	**480**	4	21	**517**	451	**32.6**	**1.9**	0.02	<0.01	0.06
Pit Area	16-12-2017	8.2	**179**	**1155**	17	5	**348**	5	9	341	61	**90.2**	**2.1**	0.05	<0.01	0.07
Pit Area	16-01-2018	6.9	34	226	25	10	19	<0.03	7	82	16	**14.7**	0.2	0.16	**0.10**	0.18
Pit Area	16-02-2018	8.8	124	800	2	**274**	2	<0,002	16	79	293	**49.8**	**3.9**	<0,001	0.00	<0,004
Pit Area	16-03-2018	8.2	136	**1040**	37	22	**250**	10	16	215	<0.004	**68.1**	**1.1**	<0,004	<0.001	<0.002
Pit Area	01-05-2018	8.5	74	598	40	26	109	8	16	69	223	**37.7**	**1.3**	<0.004	0.04	0.04
Pit Area	01-06-2018	8.4	105	808	51	30	149	9	17	95	180	**73.8**	**1.5**	<0.004	0.03	<0.002
Pit Area	01-09-2018	8.6	**184**	**1293**	8	5	**441**	5	18	324	554	**29.8**	**1.5**	<0.004	<0.001	0.29
Pit Area	01-10-2018	8.3	119	795	74	44	114	11	18	168	182	**53.9**	**1.1**	<0.004	0.01	**0.32**
Pit Area	Q1	8.5	90	703	45	28	129	8	16	82	202	**55.8**	**1.4**	<0.004	0.03	0.04
Pit Area	Q2	8.4	**152**	**1044**	41	25	**278**	8	18	246	368	**41.9**	**1.3**	<0.004	0.01	**0.31**
WRD-1	26-03-2018	7.8	145	984	134	48	108	9	23	**491**	109	**23.5**	0.3	0.03	<0.01	0.05

Site Name	Date	As (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Cd (mg/L)	CN (mg/L)	Co (mg/L)	Cr (mg/L)	Cr6+ (mg/L)	Cu (mg/L)	Hg (mg/L)
B2N073	13-03-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
KAM01	13-03-2017	0.010					<0.01	<0.01	<0.01		<0.01	
KGA14	13-03-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
KGA15	13-03-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH1	16-07-2014	<0.005				<0.003	<0.01	<0.01	<0.01		<0.01	
MAN-BH2D	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH2D-Pumptest	03-07-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH2M	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH2S	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH3D	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH3M	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH3S	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH4D	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH4M	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH4S	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH5M	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH6D	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH6D-Pumptest	29-06-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH6M	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH7M	22-08-2017	<0.005						<0.01	<0.01		<0.01	
MAN-BH8M	22-08-2017	<0.005						<0.01	<0.01		<0.01	
MAN-BH9D	15-09-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH9D-Pumptest	16-09-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MAN-BH9M	23-08-2017	<0.005						<0.01	<0.01		<0.01	
MAN-BH9S	23-08-2017	<0.005						<0.01	<0.01		<0.01	
MAN-BH10M	22-08-2017	<0.005						<0.01	<0.01		<0.01	
MAN-BH11D	23-08-2017	<0.005						<0.01	<0.01		<0.01	
MAN-BH11D-Pumptest	15-08-2017	0.010					<0.01	<0.01	<0.01		<0.01	
MAN-BH11S	23-08-2017	<0.005						<0.01	<0.01		<0.01	
MAN-BH12D	22-08-2017	<0.005						<0.01	<0.01		<0.01	
MAN-BH12M	22-08-2017	<0.005						<0.01	<0.01		<0.01	
MAN-BH12S	22-08-2017	<0.005						<0.01	<0.01		<0.01	
MAN-BH13D	22-08-2017	<0.005						<0.01	<0.01		<0.01	
MAN-PCD	23-05-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MBH01	08-06-2016					<0.002			<0.01			0.02
MBH01	06-12-2016					<0.002			<0.01	<0.02		0.01
MBH01	19-01-2017					<0.09			<0.01			
MBH01	20-02-2017											
MBH01	16-03-2017					<0.002			<0.01	<0.02		0.01
MBH01	22-03-2017	<0.005					0.01	<0.01	<0.01		<0.01	
MBH01	21-09-2017								<0.01			
MBH01-Office Tap 1	16-08-2017											27.20
MBH01-Office Tap 1	16-09-2017								<0.01			28.80
MBH01-Office Tap 1	16-10-2017					<0.002			<0.01			0.01
MBH01-Office Tap 1	16-11-2017					0.01			<0.01			28.90
MBH01-Office Tap 1	16-12-2017					<0.003			<0.01			27.50
MBH01-Office Tap 1	16-03-2018								<0.003			
MBH01-Office Tap 2	16-03-2017					0.00			0.01			0.00
MBH01-Office Tap 2	16-06-2017					<0.002			<0.01			<0.003
MBH01-Office Tap 2	16-09-2017					<0.002			<0.01			<0.003
MBH01-Office Tap 2	16-12-2017					<0.002			<0.01			<0.003
MBH01-Office Tap 2	16-03-2018								<0.003			
MBH05	14-09-2017					<0.002			<0.01			<0.003
MBH4	08-06-2016					<0.002			<0.01			0.02

Site Name	Date	As (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Cd (mg/L)	CN (mg/L)	Co (mg/L)	Cr (mg/L)	Cr6+ (mg/L)	Cu (mg/L)	Hg (mg/L)
MBH4	06-12-2016					<0.002			<0.01	<0.02		<0.003
MBH4	16-03-2017					<0.002			<0.01	<0.02		0.01
MBH4	16-06-2017					<0.002			<0.01			<0.003
MBH4	17-07-2017											<0.003
MBH4	21-09-2017					<0.002			<0.01			<0.003
MBH4	16-10-2017					<0.002			<0.01			<0.003
MBH4	16-11-2017					<0.002			<0.01			<0.003
MBH4	16-12-2017					<0.002			<0.01			<0.003
MBH4	16-03-2018								<0.003			
MBH5	08-06-2016					<0.002			<0.01			<0.003
MBH5	06-12-2016					<0.002			<0.01	<0.02		<0.003
MBH5	16-03-2017					<0.002			<0.01	<0.02		<0.003
MBH6	13-03-2017	<0.005					0.01	<0.01	<0.01		<0.01	
MBH12	14-03-2017	0.010					0.01	<0.01	<0.01		<0.01	
MBH12	31-07-2018	<0.005					<0.01	<0.01	<0.01		<0.01	
MBH13	14-03-2017	0.010					0.01	<0.01	<0.01		<0.01	
MBH15	14-03-2017	0.010					0.01	<0.01	<0.01		<0.01	
MBH17	08-06-2016					<0.002			<0.01			<0.003
MBH17	22-03-2017	0.020					0.01	<0.01	<0.01		<0.01	
MBH18B	14-03-2017	0.010					0.01	<0.01	<0.01		<0.01	
MBH20	15-03-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MBH25	20-03-2017	0.010					<0.01	<0.01	<0.01		<0.01	
MBH27	22-03-2017	0.010					0.01	<0.01	<0.01		<0.01	
MBH29	20-03-2017	0.010					0.01	<0.01	<0.01		<0.01	
MBH31	20-03-2017	0.010					<0.01	<0.01	<0.01		<0.01	
MBH32	08-06-2016					<0.002			<0.01			0.01
MBH32	06-12-2016					<0.002			<0.01	<0.02		<0.003
MBH32	14-03-2017	0.010					0.02	<0.01	<0.01		<0.01	
MBH32	16-03-2017					<0.002			<0.01	<0.02		0.01
MBH32	16-06-2017					<0.002			<0.01			<0.003
MBH32	16-09-2017					<0.002			<0.01			<0.003
MBH32	17-09-2017					<0.002			<0.01			<0.003
MBH32	16-12-2017								<0.01			<0.003
MBH35	20-03-2017	0.010					0.01	<0.01	<0.01		<0.01	
MBH36A	20-03-2017	0.010					0.05	<0.01	<0.01		<0.01	
MBH40	14-03-2017	0.010					0.01	<0.01	<0.01		<0.01	
MBH41	15-03-2017	<0.005					<0.01	<0.01	<0.01		<0.01	
MBH45	20-03-2017	0.010					<0.01	<0.01	<0.01		<0.01	
MBH46	20-03-2017	0.010					<0.01	<0.01	<0.01		<0.01	
MBH47	20-03-2017	0.010					<0.01	<0.01	<0.01		0.05	
MWQ1	16-02-2018					2.54						
MWQ3	16-02-2018					0.31						
MWQ5	16-02-2018					2.35						
MWQ6	16-02-2018					0.23						
PCD	16-02-2018					0.58						
PCD Drainage	16-02-2018					0.12						
Pit Area	16-02-2018					0.51						
WRD-1	26-03-2018	<0.005	0.110	0.030	<0.01	<0.002	<0.01	<0.01	<0.01		<0.01	<0.003

Site Name	Date	Li (mg/L)	Ni (mg/L)	Pb (mg/L)	Sb (mg/L)	Si (mg/L)	Sn (mg/L)	Sr (mg/L)	U (mg/L)	V (mg/L)	ZN (mg/L)
1 - Target Level (<)											
2 - Target Level (>)									**0.07**		
3 - Critical Level (<)											
4 - Critical Level (>)									**0.28**		
B2N073	13-03-2017		<0.01	<0.01		4.56			<0.01		<0.01
KAM01	13-03-2017		<0.01	<0.01		13.70			<0.01		<0.01
KGA14	13-03-2017		<0.01	<0.01		19.20			<0.01		<0.01
KGA15	13-03-2017		<0.01	<0.01		19.30			<0.01		0.02
MAN-BH1	16-07-2014		<0.01	<0.01		15.29			<0.01		<0.01
MAN-BH2M	23-05-2017		<0.01	<0.01		5.38			<0.01		<0.01
MAN-BH2S	23-05-2017		<0.01	<0.01		0.14			<0.01		<0.01
MAN-BH3D	23-05-2017		<0.01	<0.01		4.92			<0.01		<0.01
MAN-BH3M	23-05-2017		<0.01	<0.01		14.60			<0.01		<0.01
MAN-BH3S	23-05-2017		<0.01	<0.01		1.21			<0.01		<0.01
MAN-BH4D	23-05-2017		<0.01	<0.01		10.80			<0.01		<0.01
MAN-BH4M	23-05-2017		<0.01	<0.01		15.90			<0.01		<0.01
MAN-BH4S	23-05-2017		<0.01	<0.01		1.24			<0.01		<0.01
MAN-BH5M	23-05-2017		<0.01	<0.01		1.44			<0.01		<0.01
MAN-BH6D	23-05-2017		<0.01	<0.01		14.30			<0.01		<0.01
MAN-BH6D-Pumptest	29-06-2017		<0.01	<0.01		10.40			<0.01		<0.01
MAN-BH6M	23-05-2017		<0.01	<0.01		23.40			<0.01		<0.01
MAN-BH7M	22-08-2017		<0.01	<0.01		1.19			<0.01		<0.01
MAN-BH8M	22-08-2017		<0.01	<0.01		6.01			<0.01		<0.01
MAN-BH9D	15-09-2017		<0.01	<0.01		6.50			<0.01		<0.01
MAN-BH9D-Pumptest	16-09-2017		<0.01	<0.01		0.23			<0.01		<0.01
MAN-BH9M	23-08-2017		<0.01	<0.01		10.66			<0.01		<0.01
MAN-BH9S	23-08-2017		<0.01	<0.01		2.81			<0.01		<0.01
MAN-BH10M	22-08-2017		<0.01	<0.01		10.30			<0.01		<0.01
MAN-BH11D	23-08-2017		<0.01	<0.01		1.95			<0.01		<0.01
MAN-BH11D-Pumptest	15-08-2017		<0.01	<0.01		3.52			<0.01		<0.01
MAN-BH11S	23-08-2017		<0.01	<0.01		6.02			<0.01		<0.01
MAN-BH12D	22-08-2017		<0.01	<0.01		4.35			<0.01		<0.01
MAN-BH12M	22-08-2017		<0.01	<0.01		2.69			<0.01		<0.01
MAN-BH12S	22-08-2017		<0.01	<0.01		2.90			<0.01		<0.01
MAN-BH13D	22-08-2017		<0.01	<0.01		26.18			<0.01		<0.01
MAN-BH2D	23-05-2017		<0.01	<0.01		0.34			<0.01		<0.01
MAN-BH2D-Pumptest	03-07-2017		<0.01	<0.01		9.60			<0.01		<0.01
MAN-PCD	23-05-2017		<0.01	<0.01		3.26			<0.01		<0.01
MBH01	08-06-2016					24.80				<0.01	<0.01
MBH01	14-10-2016					31.70					
MBH01	14-11-2016					30.90					
MBH01	06-12-2016					30.60				<0.01	<0.01
MBH01	19-01-2017					29.90					
MBH01	20-02-2017					30.20					
MBH01	16-03-2017					25.10				<0.01	<0.01
MBH01	22-03-2017		<0.01	<0.01		31.10			<0.01		<0.01
MBH01	11-07-2017		<0.4								
MBH01	21-08-2017					27.20					
MBH01	21-09-2017					28.80				<0.01	<0.01
MBH01-Office Tap 1	16-07-2017					15.70					
MBH01-Office Tap 1	16-08-2017					<0.4					
MBH01-Office Tap 1	16-09-2017					<0.4				<0.01	<0.01
MBH01-Office Tap 1	16-10-2017					29.00				<0.01	<0.01
MBH01-Office Tap 1	16-11-2017					6.00				<0.01	<0.01
MBH01-Office Tap 1	16-12-2017					<0.4				490.00	<0.01
MBH01-Office Tap 1	16-01-2018					25.70					
MBH01-Office Tap 1	16-02-2018										0.21

Site Name	Date	Li (mg/L)	Ni (mg/L)	Pb (mg/L)	Sb (mg/L)	Si (mg/L)	Sn (mg/L)	Sr (mg/L)	U (mg/L)	V (mg/L)	ZN (mg/L)
1 - Target Level (<)											
2 - Target Level (>)									0.07		
3 - Critical Level (<)											
4 - Critical Level (>)									0.28		
MBH01-Office Tap 1	16-03-2018					25.90					0.31
MBH01-Office Tap 2	16-03-2017					4.81				0.01	0.01
MBH01-Office Tap 2	16-06-2017					5.73				<0.01	<0.01
MBH01-Office Tap 2	16-09-2017					1.59				<0.01	<0.01
MBH01-Office Tap 2	16-12-2017					8.84				<382	<0.01
MBH01-Office Tap 2	16-02-2018										0.02
MBH01-Office Tap 2	16-03-2018					26.40					0.01
MBH05	14-09-2017					1.59				<0.01	<0.01
MBH4	08-06-2016					20.10				<0.01	<0.01
MBH4	14-10-2016					26.40					
MBH4	14-11-2016					26.80					
MBH4	06-12-2016					25.20				<0.01	<0.01
MBH4	20-02-2017					26.00					
MBH4	16-03-2017					24.10				<0.01	0.08
MBH4	16-04-2017					23.60					
MBH4	16-05-2017					24.10					
MBH4	16-06-2017					26.30				<0.01	0.39
MBH4	17-07-2017					<0.4					
MBH4	21-08-2017					23.60					
MBH4	21-09-2017					24.60				<0.01	0.72
MBH4	16-10-2017					24.60				<0.01	0.40
MBH4	16-11-2017					23.20				<0.01	0.19
MBH4	16-12-2017					23.00				<0.01	0.15
MBH4	16-01-2018					9.57					
MBH4	16-02-2018										0.02
MBH4	16-03-2018					7.48					0.06
MBH5	08-06-2016					9.07				<0.01	<0.01
MBH5	06-12-2016					9.76				<0.01	<0.01
MBH5	16-03-2017					4.81				<0.01	<0.01
MBH6	13-03-2017		<0.01	<0.01		22.00			<0.01		0.01
MBH12	14-03-2017		<0.01	<0.01		5.19			<0.01		0.02
MBH12	31-07-2018		<0.01	<0.01		5.21			<0.01		<0.01
MBH13	14-03-2017		<0.01	<0.01		22.30			<0.01		<0.01
MBH15	14-03-2017		<0.01	<0.01		15.80			<0.01		<0.01
MBH17	08-06-2016					11.90				<0.01	<0.01
MBH17	22-03-2017		<0.01	<0.01		7.58			<0.01		<0.01
MBH18B	14-03-2017		<0.01	<0.01		6.61			<0.01		<0.01
MBH20	15-03-2017		<0.01	<0.01		29.10			<0.01		0.02
MBH25	20-03-2017		<0.01	<0.01		11.50			<0.01		0.01
MBH27	22-03-2017		<0.01	<0.01		16.40			<0.01		<0.01
MBH29	20-03-2017		<0.01	<0.01		23.30			0.01		0.01
MBH31	20-03-2017		<0.01	<0.01		15.90			<0.01		0.01
MBH32	08-06-2016					21.40				<0.01	<0.01
MBH32	06-12-2016					23.60				<0.01	0.03
MBH32	14-03-2017		<0.01	<0.01		21.40			<0.01		<0.01
MBH32	16-03-2017					19.40				<0.01	<0.01
MBH32	16-06-2017					21.90				<382	<0.01
MBH32	16-09-2017					22.90				<382	<0.01
MBH32	17-09-2017					22.90				<0.01	<0.01
MBH32	16-12-2017					21.40				<382	<0.01
MBH35	20-03-2017		<0.01	<0.01		21.60			<0.01		<0.01
MBH36A	20-03-2017		<0.01	<0.01		9.53			<0.01		<0.01
MBH40	14-03-2017		<0.01	<0.01		12.30			<0.01		0.18
MBH41	15-03-2017		<0.01	<0.01		25.10			<0.01		<0.01
MBH45	20-03-2017		<0.01	<0.01		20.60			<0.01		<0.01
MBH46	20-03-2017		<0.01	<0.01		13.70			<0.01		<0.01
MBH47	20-03-2017		<0.01	<0.01		24.70			<0.01		0.01
MWQ1	08-06-2016					3.53					
MWQ1	14-11-2016					10.70					

Site Name	Date	Li (mg/L)	Ni (mg/L)	Pb (mg/L)	Sb (mg/L)	Si (mg/L)	Sn (mg/L)	Sr (mg/L)	U (mg/L)	V (mg/L)	ZN (mg/L)
1 - Target Level (<)											
2 - Target Level (>)									0.07		
3 - Critical Level (<)											
4 - Critical Level (>)									0.28		
MWQ1	06-12-2016					10.00					
MWQ1	19-01-2017					6.79					
MWQ1	20-02-2017					5.75					
MWQ1	16-03-2017					6.91					
MWQ1	16-04-2017					5.65					
MWQ1	17-05-2017					1.95					
MWQ1	17-06-2017					0.74					
MWQ1	11-07-2017					1.40					
MWQ1	17-08-2017					<0.1					
MWQ1	17-09-2017					1.63					
MWQ1	16-11-2017					3.81					
MWQ1	16-12-2017					13.40					
MWQ1	16-01-2018					6.72					
MWQ1	16-03-2018					5.17					
MWQ3	08-06-2016					6.81					
MWQ3	14-10-2016					7.03					
MWQ3	14-11-2016					5.09					
MWQ3	06-12-2016					4.71					
MWQ3	19-01-2017					4.70					
MWQ3	20-02-2017					4.27					
MWQ3	16-03-2017					3.94					
MWQ3	16-04-2017					4.06					
MWQ3	17-05-2017					8.27					
MWQ3	17-06-2017					3.91					
MWQ3	11-07-2017					3.47					
MWQ3	11-08-2017					2.93					
MWQ3	11-09-2017					2.75					
MWQ3	16-10-2017					2.73					
MWQ3	16-11-2017					1.61					
MWQ3	16-12-2017					9.23					
MWQ3	16-01-2018					1.48					
MWQ3	16-03-2018					0.22					
MWQ4	08-06-2016					10.30					
MWQ4	14-10-2016					16.10					
MWQ4	14-11-2016					6.92					
MWQ4	16-03-2017					17.90					
MWQ4	17-05-2017					14.35					
MWQ4	17-06-2017					11.30					
MWQ4	11-07-2017					3.47					
MWQ4	11-08-2017					2.93					
MWQ4	11-09-2017					2.75					
MWQ4	16-09-2017					11.60					
MWQ5	08-06-2016					0.55					
MWQ5	14-10-2016					<0.1					
MWQ5	14-11-2016					13.20					
MWQ5	06-12-2016					8.52					
MWQ5	19-01-2017					5.98					
MWQ5	20-02-2017					1.95					
MWQ5	16-03-2017					5.91					
MWQ5	16-04-2017					2.87					
MWQ5	17-05-2017					4.14					
MWQ5	17-06-2017					<0.1					
MWQ5	11-07-2017					1.40					
MWQ5	11-08-2017					0.34					
MWQ5	11-09-2017					0.52					
MWQ5	16-10-2017					1.59					
MWQ5	16-11-2017					2.63					
MWQ5	16-12-2017					13.40					
MWQ5	16-01-2018					3.61					
MWQ5	16-03-2018					2.32					
MWQ6	08-06-2016					1.31					
MWQ6	06-12-2016					4.02					
MWQ6	19-01-2017					4.71					
MWQ6	20-02-2017					3.37					
MWQ6	16-04-2017					4.77					
MWQ6	16-05-2017					2.88					

Site Name	Date	Li (mg/L)	Ni (mg/L)	Pb (mg/L)	Sb (mg/L)	Si (mg/L)	Sn (mg/L)	Sr (mg/L)	U (mg/L)	V (mg/L)	ZN (mg/L)
1 - Target Level (<)											
2 - Target Level (>)									0.07		
3 - Critical Level (<)											
4 - Critical Level (>)									0.28		
MWQ6	17-05-2017					4.77					
MWQ6	17-06-2017					2.88					
MWQ6	16-10-2017					4.96					
MWQ6	16-11-2017					13.50					
MWQ6	16-12-2017					1.06					
MWQ6	16-03-2018					3.77					
PCD	08-06-2016					1.12					
PCD	14-10-2016					2.00					
PCD	14-11-2016					1.43					
PCD	06-12-2016					1.71					
PCD	20-02-2017					1.52					
PCD	16-03-2017					1.53					
PCD	16-04-2017					11.70					
PCD	17-05-2017					6.99					
PCD	07-06-2017					3.45					
PCD	11-07-2017					3.40					
PCD	17-08-2017					3.22					
PCD	17-09-2017					4.93					
PCD	16-10-2017					12.70					
PCD	16-11-2017					12.70					
PCD	16-12-2017					5.19					
PCD	16-01-2018					3.74					
PCD	16-03-2018					2.18					
PCD Drainage	08-06-2016					7.79					
PCD Drainage	14-10-2016					11.30					
PCD Drainage	14-11-2016					9.72					
PCD Drainage	06-12-2016					12.00					
PCD Drainage	20-02-2017					13.10					
PCD Drainage	16-03-2017					11.00					
PCD Drainage	16-04-2017					2.23					
PCD Drainage	17-05-2017					13.60					
PCD Drainage	17-06-2017					12.80					
PCD Drainage	11-07-2017					12.40					
PCD Drainage	17-08-2017					11.70					
PCD Drainage	17-09-2017					13.00					
PCD Drainage	16-10-2017					<0.1					
PCD Drainage	16-11-2017					12.80					
PCD Drainage	16-12-2017					14.10					
PCD Drainage	16-01-2018					13.70					
PCD Drainage	16-03-2018					11.10					
Pit Area	08-06-2016					5.92					
Pit Area	14-10-2016					16.10					
Pit Area	14-11-2016					5.02					
Pit Area	06-12-2016					12.50					
Pit Area	20-02-2017					4.86					
Pit Area	16-03-2017					6.66					
Pit Area	16-04-2017					3.11					
Pit Area	17-06-2017					4.81					
Pit Area	11-07-2017					3.62					
Pit Area	16-08-2017					4.54					
Pit Area	17-08-2017					4.54					
Pit Area	17-09-2017					7.83					
Pit Area	16-11-2017					4.56					
Pit Area	16-12-2017					4.38					
Pit Area	16-01-2018					30.60					
Pit Area	16-03-2018					2.02					
WRD-1	26-03-2018	0.03	<0.01	<0.01	0.05	6.06	0.04	0.59	<0.01	<0.01	<0.01

Site Name	Date	Chemical Oxygen Demand O2 (mg/L)	Oxygen Absorbed O2 (mg/L)	Oxygen Dissolved O2 (mg/L)	Ortho Phosphate (P mg/L)	N_Ammonia (mg/L)	Suspended Solids (mg/L)	TPH (mg/L)
B2N073	13-03-2017	4.00		6.88	<0.03	<0.45	2.00	
KAM01	13-03-2017	4.00		6.77	<0.03	<0.45	19.60	
KGA14	13-03-2017	<1		6.73	<0.03	<0.45	<0.4	
KGA15	13-03-2017	3.00		6.76	<0.03	<0.45	<0.4	
MAN-BH1	16-07-2014	8.00	<0.2	8.21	0.02	0.27	29.20	
MAN-BH2D	23-05-2017	4.00	1.36	5.82	<0.03	0.67	90.40	
MAN-BH2D	01-06-2018				0.05		45.00	
MAN-BH2D	01-09-2018				0.03		49.00	
MAN-BH2D-Pumptest	03-07-2017	1.00	<0.02	6.88	<0.03	<0.45	<0.4	
MAN-BH2M	23-05-2017	4.00	3.06	6.78	<0.03	2.30	85.20	
MAN-BH2M	01-06-2018				0.03		30.00	
MAN-BH2M	01-09-2018				0.01		39.00	
MAN-BH2S	23-05-2017	4.00	0.30	6.84	0.18	3.19	36.00	
MAN-BH2S	01-06-2018				0.03		189.00	
MAN-BH2S	01-09-2018				0.01		329.00	
MAN-BH3D	23-05-2017	2.00	1.40	5.91	<0.03	0.49	65.60	
MAN-BH3D	01-06-2018				0.27		233.00	
MAN-BH3D	01-09-2018				0.02		33.00	
MAN-BH3M	23-05-2017	<1	<0.1	7.25	<0.03	<0.45	119.00	
MAN-BH3M	01-06-2018				<0.005		67.00	
MAN-BH3M	01-09-2018				<0.005		54.00	
MAN-BH3S	23-05-2017	2.00	0.98	5.64	<0.03	0.67	106.40	
MAN-BH3S	01-06-2018				<0.005		48.00	
MAN-BH3S	01-09-2018				<0.005		1294.00	
MAN-BH4D	23-05-2017	3.00	1.04	5.88	<0.03	<0.45	28.40	
MAN-BH4D	01-06-2018				0.05		29.00	
MAN-BH4D	01-09-2018				0.02		22.00	
MAN-BH4M	23-05-2017	<1	0.08	5.24	<0.03	0.64	114.00	
MAN-BH4M	01-06-2018				0.03		24.00	
MAN-BH4M	01-09-2018				0.02		38.00	
MAN-BH4S	23-05-2017	<1	<0.02	5.28	<0.03	2.52	62.00	
MAN-BH4S	01-06-2018				0.03		41.00	
MAN-BH4S	01-09-2018				0.02		27.00	
MAN-BH5M	23-05-2017	<1	0.40	6.31	<0.03	4.45	72.00	
MAN-BH6D	23-05-2017	<1	0.66	7.11	0.05	<0.45	85.60	
MAN-BH6D	01-06-2018				0.03		732.00	
MAN-BH6D	01-09-2018				0.02		9.00	
MAN-BH6D-Pumptest	29-06-2017	<1	<0.02	6.94	<0.03	<0.45	<0.4	
MAN-BH6M	23-05-2017	<1	1.58	6.99	<0.03	<0.45	65.20	
MAN-BH6M	01-06-2018				0.04		8.00	
MAN-BH6M	01-09-2018				0.02		62.00	
MAN-BH7M	22-08-2017	34.00		6.10	<0.03	<0.45	65.20	
MAN-BH8M	22-08-2017	3.00		6.02	<0.03	2.87	82.80	
MAN-BH8M	01-06-2018				0.03		9.00	
MAN-BH8M	01-09-2018				0.01		17.00	
MAN-BH9D	15-09-2017	2.00	1.30	7.85	0.06	0.63	54.40	
MAN-BH9D-Pumptest	16-09-2017	<1	<0.02	6.97	0.04		<0.4	
MAN-BH9M	23-08-2017	4.00		6.41	<0.03	3.41	51.20	
MAN-BH9S	23-08-2017	7.00		5.70	<0.03	<0.45	111.00	
MAN-BH10M	22-08-2017	6.00		6.38	<0.03	1.67	346.00	
MAN-BH11D	23-08-2017	0.00		6.02	<0.03	<0.45	<0.4	
MAN-BH11D-Pumptest	15-08-2017	13.00	0.30	6.62	0.03	0.83	<0.4	
MAN-BH11S	23-08-2017	85.00		4.74	<0.03	<0.45	293.00	
MAN-BH12D	22-08-2017	8.00		6.68	<0.03	1.61	185.00	
MAN-BH12M	22-08-2017	0.00		6.38	<0.03	1.62	52.40	
MAN-BH12S	22-08-2017	11.00		6.15	<0.03	2.68	191.00	
MAN-BH13D	22-08-2017	32.00		6.59	0.04	0.75	792.00	
MAN-PCD	23-05-2017	171.00	29.84	7.44	<0.03	1.69	160.00	
MBH01	08-06-2016				0.03	<0.45	<0.4	0.00
MBH01	14-10-2016				<0.03	<0.45	2.00	
MBH01	14-11-2016				<0.03	<0.45	<0.4	
MBH01	06-12-2016				<0.03	<0.45	<0.4	0.00

Site Name	Date	Chemical Oxygen Demand O2 (mg/L)	Oxygen Absorbed O2 (mg/L)	Oxygen Dissolved O2 (mg/L)	Ortho Phosphate (P mg/L)	N_Ammonia (mg/L)	Suspended Solids (mg/L)	TPH (mg/L)
MBH01	19-01-2017				<0.03	<0.45	<0.4	
MBH01	20-02-2017				<0.03	<0.45	<0.4	
MBH01	16-03-2017				0.04	<0.45	<0.4	<1
MBH01	22-03-2017	<1		6.49	<0.03	<0.45	<0.4	
MBH01	11-07-2017						15.70	
MBH01	21-08-2017						<0.4	
MBH01	21-09-2017						<0.4	<382
MBH01-Office Tap 1	16-09-2017							<382
MBH01-Office Tap 1	16-12-2017							<0.002
MBH01-Office Tap 1	01-05-2018				0.01		<4.5	
MBH01-Office Tap 1	01-06-2018				0.06		<4.5	
MBH01-Office Tap 1	01-07-2018				0.04		<4.5	
MBH01-Office Tap 1	01-08-2018				<0.005		<4.5	
MBH01-Office Tap 1	01-09-2018				0.02		<4.5	
MBH01-Office Tap 1	01-10-2018				0.02		6.00	
MBH01-Office Tap 1	Q1				0.03		<4.5	
MBH01-Office Tap 1	Q2				0.02		<4.5	
MBH01-Office Tap 2	16-06-2017							<382
MBH01-Office Tap 2	16-09-2017							<382
MBH01-Office Tap 2	01-05-2018				0.01		<4.5	
MBH01-Office Tap 2	01-06-2018				0.05		<4.5	
MBH01-Office Tap 2	01-07-2018				0.04		<4.5	
MBH01-Office Tap 2	01-08-2018				<0.005		<4.5	
MBH01-Office Tap 2	01-09-2018				0.02		<4.5	
MBH01-Office Tap 2	01-10-2018				0.02		<4.5	
MBH01-Office Tap 2	Q1				0.03		<4.5	
MBH01-Office Tap 2	Q2				0.02		<4.5	
MBH05	14-09-2017						35.00	<382
MBH4	08-06-2016				<0.03	<0.45	<0.4	0.00
MBH4	14-10-2016				<0.03	<0.45	<0.4	
MBH4	14-11-2016				<0.03	<0.45	<0.4	
MBH4	06-12-2016				<0.03	<0.45	<0.4	
MBH4	20-02-2017				<0.03	<0.45	<0.4	
MBH4	16-03-2017				0.03	<0.45	<0.4	<1
MBH4	16-06-2017							<382
MBH4	17-07-2017						<0.4	
MBH4	21-08-2017						<0.4	
MBH4	21-09-2017						<0.4	<382
MBH4	16-12-2017							<382
MBH4	01-05-2018				<0.005		<4.5	
MBH4	01-06-2018				0.04		<4.5	
MBH4	01-07-2018				0.03		<4.5	
MBH4	01-08-2018				<0.005		<4.5	
MBH4	01-09-2018				0.01		<4.5	
MBH4	01-10-2018				0.01		<4.5	1026.00
MBH4	Q1				0.03		<4.5	
MBH4	Q2				0.01		<4.5	1026.00
MBH5	08-06-2016				<0.03	<0.45	20.40	0.00
MBH5	06-12-2016				<0.03	<0.45	62.40	0.00
MBH5	16-03-2017				0.06	<0.45	97.60	<1

Site Name	Date	Chemical Oxygen Demand O2 (mg/L)	Oxygen Absorbed O2 (mg/L)	Oxygen Dissolved O2 (mg/L)	Ortho Phosphate (P mg/L)	N_Ammonia (mg/L)	Suspended Solids (mg/L)	TPH (mg/L)
MBH6	13-03-2017	3.00		6.62	<0.03	<0.45	<0.4	
MBH12	14-03-2017	3.00		6.64	<0.03	<0.45	<0.4	
MBH12	31-07-2018	15.00	1.42	6.73	0.07	<0.45	41.20	
MBH13	14-03-2017	<1		6.71	<0.03	<0.45	<0.4	
MBH15	14-03-2017	6.00		6.83	<0.03	<0.45	<0.4	
MBH17	08-06-2016				0.04	<0.45	<0.4	0.00
MBH17	22-03-2017	6.00		6.78	<0.03	<0.45	<0.4	
MBH18B	14-03-2017	1.00		6.68	<0.03	<0.45	<0.4	
MBH20	15-03-2017	<1		6.81	0.05	<0.45	<0.4	
MBH25	20-03-2017	4.00		6.82	<0.03	<0.45	<0.4	
MBH27	22-03-2017	<1		6.77	<0.03	<0.45	108.00	
MBH29	20-03-2017	14.00		6.80	<0.03	<0.45	1.20	
MBH31	20-03-2017	<1		6.81	<0.03	<0.45	<0.4	
MBH32	08-06-2016				0.04	<0.45	<0.4	0.00
MBH32	06-12-2016				0.03	<0.45	<0.4	0.00
MBH32	14-03-2017	2.00		6.75	<0.03	<0.45	<0.4	
MBH32	16-03-2017				0.06	<0.45	2.40	<1
MBH32	17-09-2017						<0.4	<382
MBH32	16-12-2017							<0.002
MBH35	20-03-2017	<1		6.60	<0.03	<0.45	<0.4	
MBH36A	20-03-2017	1.00		6.82	<0.03	0.52	<0.4	
MBH40	14-03-2017	2.00		6.71	<0.03	<0.45	<0.4	
MBH41	15-03-2017	3.00		6.87	<0.03	<0.45	<0.4	
MBH45	20-03-2017	2.00		6.81	<0.03	<0.45	<0.4	
MBH46	20-03-2017	5.00		6.77	<0.03	<0.45	<0.4	
MBH47	20-03-2017	4.00		6.88	<0.03	<0.45	<0.4	
MWQ1	08-06-2016				<0.03		26.40	
MWQ1	14-11-2016				0.15	<0.45	103.00	
MWQ1	06-12-2016				0.07	<0.45	11.20	
MWQ1	19-01-2017				<0.03	<0.45	429.00	
MWQ1	20-02-2017				<0.03	<0.45	152.00	
MWQ1	16-03-2017				0.35	6.59	116.00	
MWQ1	17-05-2017						29.20	
MWQ1	17-06-2017						3523.00	
MWQ1	11-07-2017						782.00	
MWQ1	17-08-2017						16.80	
MWQ1	17-09-2017						759.00	
MWQ1	16-02-2018							0.28
MWQ1	16-03-2018							0.04
MWQ1	01-05-2018				0.01		37.00	
MWQ1	01-06-2018				0.04		226.00	
MWQ1	01-07-2018				0.03		94.00	
MWQ1	01-08-2018				<0.005		36.00	
MWQ1	Q1				0.03		119.00	
MWQ3	08-06-2016				<0.03		478.00	
MWQ3	14-10-2016				0.07	<0.45	524.00	
MWQ3	14-11-2016				0.17	0.90	451.00	
MWQ3	06-12-2016				0.05	<0.45	544.00	
MWQ3	19-01-2017				<0.03	<0.45	258.00	
MWQ3	20-02-2017				<0.03	<0.45	614.00	
MWQ3	16-03-2017				0.09	0.62	270.00	
MWQ3	17-05-2017						156.00	
MWQ3	17-06-2017						206.00	
MWQ3	11-07-2017						168.00	
MWQ3	11-08-2017						289.00	
MWQ3	11-09-2017						302.00	
MWQ3	16-02-2018							0.04
MWQ3	16-03-2018							0.01
MWQ3	01-06-2018				0.05		32.00	
MWQ3	01-07-2018				0.03		115.00	
MWQ3	Q1				0.04		73.50	
MWQ4	08-06-2016				0.06		103.00	
MWQ4	14-10-2016				2.89	4.82	12402.00	
MWQ4	14-11-2016				<0.03	<0.45	15.20	
MWQ4	16-03-2017				0.05	<0.45	64.80	
MWQ4	17-05-2017						10.00	
MWQ4	17-06-2017						3277.00	
MWQ4	11-07-2017						168.00	

Site Name	Date	Chemical Oxygen Demand O2 (mg/L)	Oxygen Absorbed O2 (mg/L)	Oxygen Dissolved O2 (mg/L)	Ortho Phosphate (P mg/L)	N_Ammonia (mg/L)	Suspended Solids (mg/L)	TPH (mg/L)
MWQ4	11-08-2017						289.00	
MWQ4	11-09-2017						302.00	
MWQ5	08-06-2016				<0.03		79.60	
MWQ5	14-10-2016				0.13	<0.45	107.00	
MWQ5	14-11-2016				0.31	<0.45	76.40	
MWQ5	06-12-2016				0.05	<0.45	14.00	
MWQ5	19-01-2017				<0.03	<0.45	12.80	
MWQ5	20-02-2017				<0.03	<0.45	14.40	
MWQ5	16-03-2017				0.12	<0.45	12.40	
MWQ5	17-05-2017						19.20	
MWQ5	17-06-2017						908.00	
MWQ5	11-07-2017						782.00	
MWQ5	11-08-2017						251.21	
MWQ5	11-09-2017						516.00	
MWQ5	16-02-2018							0.65
MWQ5	16-03-2018							0.01
MWQ5	01-05-2018				0.03		11.00	
MWQ5	01-06-2018				0.07		30.00	
MWQ5	01-07-2018				0.03		29.00	
MWQ5	01-08-2018				<0.005		25.00	
MWQ5	01-09-2018				0.01		50.00	
MWQ5	01-10-2018				0.25		97.00	
MWQ5	Q1				0.04		23.33	
MWQ5	Q2				0.13		57.33	
MWQ6	08-06-2016				<0.03		29.20	
MWQ6	06-12-2016				<0.03	<0.45	205.00	
MWQ6	19-01-2017				<0.03	<0.45	21.60	
MWQ6	20-02-2017				0.51	0.69	477.00	
MWQ6	17-05-2017						56.40	
MWQ6	17-06-2017						38.00	
MWQ6	16-02-2018							0.07
MWQ6	16-03-2018							0.01
MWQ6	01-05-2018				0.01		56.00	
MWQ6	01-06-2018				0.06		100.00	
MWQ6	Q1				0.03		78.00	
OB2	01-06-2018				0.04		19.00	
OB2	01-07-2018				0.03		19.00	
OB2	01-08-2018				<0.005		11.00	
OB2	01-09-2018				<0.005		22.00	
OB2	01-10-2018				0.02		25.00	
OB2	Q1				0.03		19.00	
OB2	Q2				0.02		19.33	
PCD	08-06-2016				<0.03		303.00	
PCD	14-10-2016				<0.03	<0.45	609.00	
PCD	14-11-2016				<0.03	<0.45	9.20	
PCD	06-12-2016				<0.03	<0.45	0.80	
PCD	20-02-2017				<0.03	<0.45	384.00	
PCD	16-03-2017				<0.03	0.76	14.80	
PCD	17-05-2017						371.00	
PCD	07-06-2017						211.00	
PCD	11-07-2017						7.20	
PCD	17-08-2017						92.80	
PCD	17-09-2017						25.40	
PCD	16-02-2018							0.01
PCD	16-03-2018							0.01
PCD	01-05-2018				<0.005		218.00	
PCD	01-06-2018				0.04		55.00	
PCD	01-07-2018				0.03		64.00	
PCD	01-08-2018				<0.005		70.00	
PCD	01-09-2018				<0.005		59.00	
PCD	01-10-2018				0.01		2824.00	
PCD	Q1				0.04		112.33	
PCD	Q2				0.01		984.33	
PCD Drainage	08-06-2016				<0.03		<0.4	
PCD Drainage	14-10-2016				0.04	<0.45	33.60	

Site Name	Date	Chemical Oxygen Demand O2 (mg/L)	Oxygen Absorbed O2 (mg/L)	Oxygen Dissolved O2 (mg/L)	Ortho Phosphate (P mg/L)	N_Ammonia (mg/L)	Suspended Solids (mg/L)	TPH (mg/L)
PCD Drainage	14-11-2016				<0.03	<0.45	<0.4	
PCD Drainage	06-12-2016				0.05	<0.45	<0.4	
PCD Drainage	20-02-2017				<0.03	<0.45	6.40	
PCD Drainage	16-03-2017				0.05	<0.45	2.44	
PCD Drainage	17-05-2017						8.80	
PCD Drainage	17-06-2017						4.40	
PCD Drainage	11-07-2017						4.40	
PCD Drainage	17-08-2017						3.20	
PCD Drainage	17-09-2017						2.80	
PCD Drainage	16-02-2018							0.01
PCD Drainage	16-03-2018							0.01
PCD Drainage	01-05-2018				<0.005		752.00	
PCD Drainage	01-06-2018				0.05		1820.00	
PCD Drainage	01-07-2018				0.03		23.00	
PCD Drainage	01-08-2018				<0.005		18.00	
PCD Drainage	01-09-2018				<0.005		<4.5	
PCD Drainage	01-10-2018				0.03		3271.00	
PCD Drainage	Q1				0.04		865.00	
PCD Drainage	Q2				0.03		1644.50	
Pit Area	08-06-2016				<0.03		36.80	
Pit Area	14-10-2016				<0.03	1.17	32216.00	
Pit Area	14-11-2016				<0.03	<0.45	321.00	
Pit Area	06-12-2016				<0.03	4.24	104.00	
Pit Area	20-02-2017				<0.03	4.11	10.00	
Pit Area	16-03-2017				<0.03	4.70	186.00	
Pit Area	17-06-2017						15.20	
Pit Area	11-07-2017						217.00	
Pit Area	17-08-2017						5.20	
Pit Area	17-09-2017						33.60	
Pit Area	16-02-2018							0.01
Pit Area	16-03-2018							0.01
Pit Area	01-05-2018				<0.005		1210.00	
Pit Area	01-06-2018				0.04		530.00	
Pit Area	01-09-2018				<0.005		1316.00	
Pit Area	01-10-2018				0.01		430.00	<10
Pit Area	Q1				0.04		870.00	
Pit Area	Q2				0.01		873.00	<10
WRD-1	26-03-2018	8.00	2.94	6.51	0.34	<0.45	<0.4	

Appendix VII – Geochemical Evaluation

(By Geostratum)

Appendix VIII – Risk Assessment Tables

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MANUNGU GROUNDWATER STUDY ASSESSMENT

Submitted to Groundwater Square
July 2019

Vik Cogho Consulting

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1.0 Project Introduction

Vik Cogho Consulting (VCC) was appointed by Groundwater Square (GW^2) to perform a review on a groundwater assessment of the Manungu Colliery.

Groundwater Square was approached to perform an update of the existing Manungu groundwater study, ensuring compliance with the WUL conditions, as well as to update the existing study to cover the proposed extended LOM of 30 years. Manungu Colliery is situated roughly 8 km south of the town of Delmas.

The Manungu Colliery is situated in quaternary catchments B20A and has a MAP of 661mm. It is bounded by quaternary catchments B20B in the north, C21E in the west and C21A in the south. The mean annual evaporation for the area varies between 1,600mm and 1,700mm.

Figure 1 depicts the study area and its surroundings.

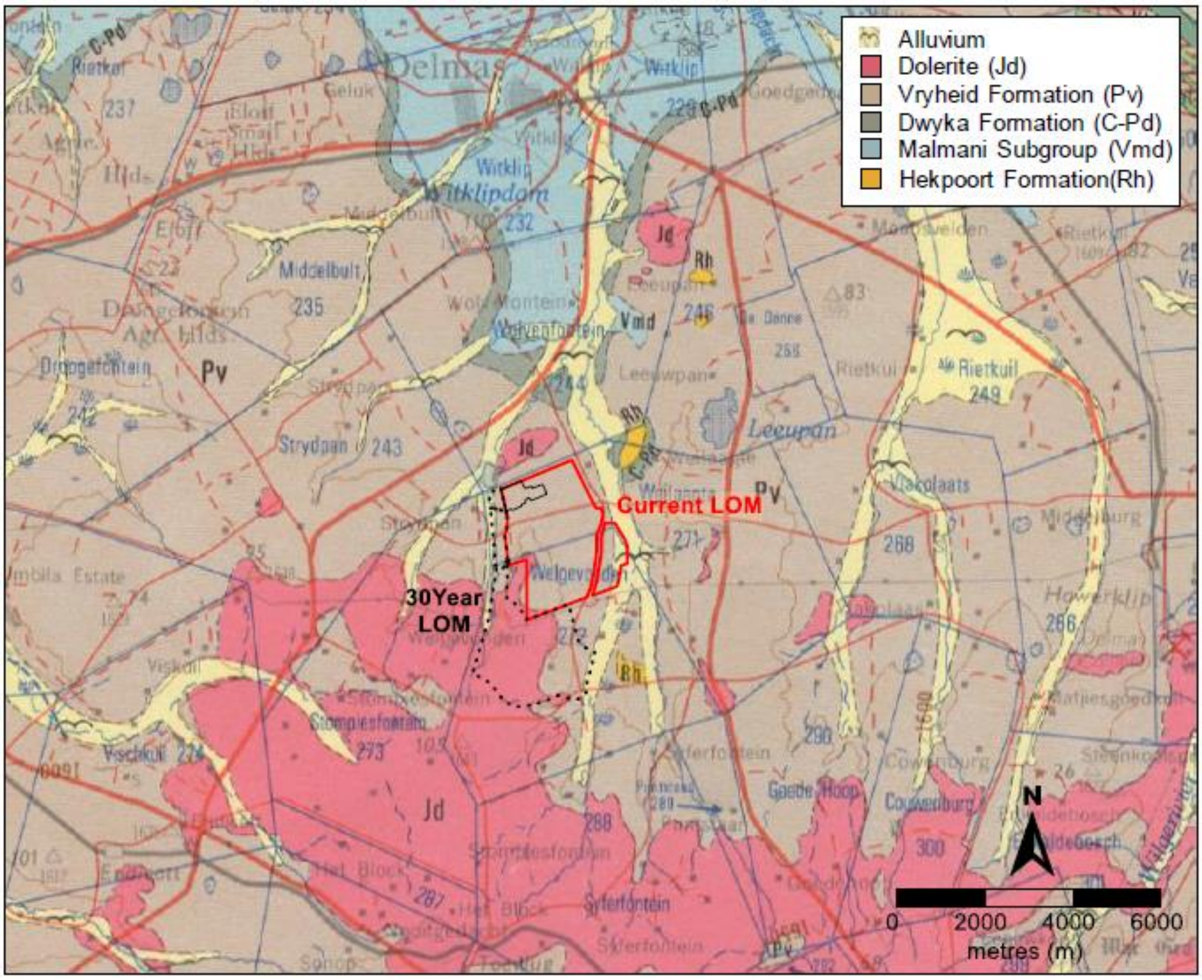

Figure 1 Locality and geological plan of the study area (Botha, 2019)

From a geological perspective as depicted in Figure 1, the mining area is situated within the coal bearing formations of the Karoo sediments. Dolerite sills outcrop to the north and across the southern extent of the mining area. Further to the north of the mining area, dolomites of the Malmani Subgroup outcrop, while rocks of the West Rand Group's Hospital Hill Subgroup outcrop to the northeast and southeast. Alluvium can be seen along the natural surface water drainage lines. Based on this it is important to evaluate and understand how the presence of the respective geological units will impact on the underlying and surrounding groundwater resource.

2.0 Scope of Studies

The following scope of work summarises the work to be performed by Groundwater Square to update the earlier groundwater assessment:

- Desktop study to generate baseline infrastructure information and maps;
- Collect data relevant to the study, including:
  - Geology;
  - Geometry (XYZ) of coal seam floors;
  - Current and LOM mine layouts;
  - Relevant site information from visual inspection and discussions;
- Collect field data:
  - Perform geophysical surveys (during two phases), in addition to Mine aeromagnetic survey (magnetic, gravity and resistivity to investigate the occurrence of dykes and preferential flow zones/cavities in critical areas);
  - Drill hydrogeological boreholes (based on mine plan, geophysics, structural geology and potential impacts) during two phases:
  - Perform EC profiling on borehole water columns;
  - Perform water sampling of boreholes, springs, surface water and private boreholes;
  - Perform aquifer and borehole hydraulic testing:
- Slug-tests on all newly drilled boreholes (surrounding boreholes might be included);
- A combination of yield tests, step-tests and long-term tests on a selection of borehole(s);
- Laboratory analysis of sampled water:
  - Minimum pH, EC, TDS, Ca, Mg, Na, K, Cl, SO4, NO3, T.Alk, Si, F, Al, Fe, Mn;
- Evaluate data in the context of geological information provided by the mine:
  - Computerise/analyse/interpret field test data;
  - Interpret/describe aquifer conditions and hydraulic attributes;
- Review project objectives and modelling scenarios, and discuss with Mine Management;
- Geochemical assessment for opencast operation and Wash Plant:
  - Analyse client database of mineralogical and elemental composition of the rock/coal material;
  - Perform laboratory analysis on core/pulp/drill samples for e.g. ABA/XRD/XRF/NAG/%S;
  - Determine the potential for acidic mine drainage over the long term;
  - Specifically evaluate the option of placing discard from the planned Wash Plant back into the pit;
  - Perform oxygen diffusion and geochemical trend numerical modelling to determine the expected variations in mine water quality during mining and at post-closure;
- Perform groundwater modelling assessment:
  - Compile conceptual model;
  - Compile and calibrate detailed numerical 3D model(s) to quantify/assess impacts;
  - Incorporate geochemical assessment data in numerical models, to enable prediction of contaminant movement;
- Groundwater impact calculations:
  - Identify/describe/calculate impacts on the groundwater environment through analytical equations and numerical modelling;
  - Propose mitigation/management measures;
  - Identify data gaps and focus areas for additional research if required;
- Provide guidance on:
  - Water monitoring;

- Mitigation measures.

The proposed above activities adequately cover all aspects of a detailed investigation to determine existing and potential groundwater impacts resulting from the current and proposed extended mining operation.

3.0 Investigation and Contents

A substantial amount of investigative work was completed to understand the prevailing groundwater conditions within the mining rights area. The investigation commenced with a desktop study of all previous groundwater work done in the area. This was followed up by extensive geophysical investigations, including:

- Aeromagnetic and radiometric surveys;
- A gravimetric geophysical survey comprising a total of 310 stations; and
- A Stratagem Magneto Telluric (AMT) geophysical traverse line along the boundary between the existing mining area and the proposed extension to the south which also corresponds with the major central EW gravity survey lined performed during the initial investigation.

These geophysical surveys were done to identify preferential groundwater flow zones within the mining rights area, as well as to fully understand the underlying geohydrological conditions that would be used to construct a representative groundwater model for the mining area. This also included the drilling of numerous boreholes (shallow, medium and deep), evaluating the aquifer characteristics of the prevailing aquifers within the area.

Further to the geophysics a substantial amount of geohydrological information, covering a number of years, as well as new information was processed and forms part of the report. The scientific processing and evaluation of this information in the report is based on proven geohydrological methodologies and is adequate. In addition to this the aquifer vulnerability of the underlying and surrounding groundwater regime was satisfactorily evaluated

A conceptual groundwater model was compiled, based on the underlying and surrounding geological and geohydrological conditions. The complex geohydrological regime of the area is adequately addressed in the conceptual model and was used as the basis for the numerical groundwater model.

The FEFLOW finite element numerical groundwater flow and transport software package was used to determine the groundwater balance during and post mining, as well as an estimate was made of the potential spread of affected groundwater over time. The numerical groundwater model of the area was checked and comprises the following:

- The numerical model grid consisted of 9 layers and 2.1 million mesh elements to accommodate the complex geometry of the coal seams and aquifer layers:
    - Karoo-Ecca aquifers were incorporated as the top 4 model-layers;
    - The underlying Dwyka was represented by model-layer-5;
    - Intrusive rocks were represented by model-layer-6;
    - A layer to minimum 70m deep, below the intrusive rocks was represented by model-layer-7;
    - The Black Reef was represented by model-layer-8;
    - The bottom layer of the model, to a depth of 305m was represented in model-layer-9;
    - Model-layers were incorporated/adapted to reflect the expected changing aquifer hydraulics with depth for both the Karoo- and non-Karoo geology;

- All underground mining areas were incorporated as discrete elements, which enabled the simulation of free-flow;
- Post-mining aquifer parameters were incorporated as follows:
  - Opencast mining was assumed to have an aquifer hydraulic conductivity of 100m/d;
  - Recharge on all rehabilitated opencast mining was assumed 12% of MAP;
  - The extent of the model grid and cell size are believed to be sufficient to simulate groundwater flow accurately;
- Steady-state groundwater flow modelling was performed to simulate pre-mining and post-mining groundwater level elevations and flow directions;
- Transient flow modelling was performed to determine:
  - Groundwater base-flow volumes during mining/operation and post-mining;
  - Dewatering impact zone;
  - Time to decant;
  - Contamination movement;
- Water balance calculations took cognisance of groundwater base-flow/inflow and rainfall recharge.

The extent of the model domain was chosen along local non-perennial streams, rivers and local topographical highs, which are located far enough from the Manungu mining area, to have no influence on the model accuracy. The conceptual model developed includes a variety of aquifers present within the area and is aligned with the geology of the bigger surrounding area. This information was accurately transferred into the numerical model and adequately covers the somewhat complex geohydrology of the area. This is viewed as good practice.

The groundwater quality and potential long-term water quality impacts were well covered, including an in-depth geochemical evaluation of the mining area to predict the expected long-term decant water qualities.

The large amount of data and scientifically processed information were well utilised to evaluate possible impacts from the mining operation on the surrounding groundwater resource. This was also used to recommend mitigatory measures to manage the potential impacts over the LOM and post-mining.

The index and grouping of chapters is good. The language and style of the report is good. Some comments were made in the report that require attention in this regard. In general the size of the plans in the report are adequate to assist the reader with the interpretation thereof, however, there are some diagrams that require improvement, to ensure better readability.

4.0 Conclusions and Recommendations

With this assessment GW^2 demonstrate their understanding and insight of the geohydrological aspects/parameters associated with rather complex geology and its surroundings. The impact the current and future mining activities will have on the surrounding groundwater regime are well documented and should assist the operator to implement appropriate management systems to limit their impact on the resource.

The model appears to adequately predict the dewatering cone of depression in groundwater levels during and post mining. However, looking closely at the post-mining dewatering cone of depression associated with the bigger underground mine, i.e. to the south of the mining area, the water levels in this area do not seem to recover over time. This could negatively impact on the vulnerability of the underlying/surrounding aquifers and requires additional attention, i.e. to ensure the mechanisms driving this process are understood and that appropriate mitigatory measures can be implemented during the operational phase.

Section 10.4 suggests that to mitigate the generation of AMD in opencast workings, fly ash from close by power stations could be used. It is important to note that not all fly ash may be effective neutralization agents, as the process of calcium carbonate crystallisation (pozzolanic action) may be in an advanced stage within the ash dams and will thus restrict he release of alkalinity when exposed to water percolating through the ash layer.

Detailed research was done on the use of fly ash in opencast mines by the Institute for Groundwater Studies and a summary of the pros and cons are listed in Table 1, and should be considered prior to the implementation thereof.

Managing the groundwater levels within the mined out and rehabilitated opencast area is a good practice and will definitively assist to limit the spread of mine affected after closure. However, suggesting that a tree plantation may assist in this regard is risky and not a proven management alternative. Numerous trials with trees have been done on some of the larger opencast mines in the region that were not successful. Furthermore, economically viable plantations require large areas and in the case of the Manungu operation, this may not be an effective alternative. If trees are considered to manage the groundwater levels post mining, it is therefore suggested that the appropriate specialists are appointed to develop a **sustainable tree management strategy**, yielding the required outcomes over the long-term.

Regarding the management of coal residues (coal discard and slurry), GW^2 suggests that the in-pit disposal of mine residues, well below the decant water level, should be considered rather than the development of a surface mine residue storage facility. The GW^2 suggestion is deemed to be good practice and will definitively be more sustainable over the long-term, especially after mine closure. Successfully maintaining surface mine residue facilities sustainably post closure, will require continuous/ongoing management interventions, even if a costly clay capping is applied to the mine residue facility.

With this groundwater assessment of the Manungu mining area, Groundwater Square clearly demonstrate their good understanding and insight of all the groundwater issues related to the current and proposed future mining operations within the area. Prediction of the long-term decant volumes and water quality are well structured and based on sound science and are a good estimated based on all the existing available data. It should be stressed that it is of the utmost importance that the Colliery continues with regular monitoring of all the listed surface and groundwater monitoring points. This will assist any future effort to predict and verify the long-term water qualities and decant volumes that may emanate from the mined-out workings.

Based on the content of the report and recent discussions with Groundwater Square it can be stated that the aims and objectives of the 2019 Manungu groundwater assessment were met and adequately cover all requirements of the DWS WULA process.

Table 1 Pros and cons of fly ash application in opencast mines (IGS, 2000)

Application scenario	Advantages	Disadvantages	Recommendation
In-pit, below the final decanting level.	• No long-term advantage.	• Heavy metal mobilisation from the ash after acidification of the mine water will present a problem. • The sporadic application of the fly ash in ramps and voids will not have an overall beneficial impact on the mine water.	• This should not be done unless the whole of the pit is to be covered with sufficient ash to eliminate oxidation of the pyrite in the mine. • The Matla fly ash disposal in and on top of Kriel Pit 3N is a good example of safe disposal, because the whole pit will be covered with fly ash, thus eliminating future pyrite oxidation.
In-pit, above the final decanting level.	• Fly ash could be applied as a cover to minimise rain-water and oxygen ingress into the spoil. • The fly ash could be treated by addition of cement or bentonite to reduce rain-water and oxygen penetration.	• The alkalinity to be released from an ash cover is insufficient to neutralise acid production in the spoil below. • The cost of ash application could be high because of the undulating spoil surface. • Vegetation and maintenance of the ash surface will be required.	• Perform trial permeability and leaching tests in the field. • Design the ash cover to meet the objectives. • Implement as a cover in high risk areas, such as above coal discards.
Ash water introduction.	• This will introduce additional alkalinity into the spoil. • It will improve the mine water quality through gypsum and heavy metal precipitation. • Water is an easy medium to work with and can be introduced into the spoil through boreholes where and when required.	• Ash water will have to be tapped as soon as possible from fresh ash and injected through boreholes into the spoil to ensure maximum efficiency. • Ash water from the ash dams has insufficient alkalinity and will not be an effective neutralising medium.	• A trial investigation should be done to determine design parameters. Measurements should be done by experienced individuals to ensure that definitive answers are obtained.

DR VE COGHO
Pr.Sci.Nat. (400019/93)

5.0 References

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