DE BEERS CONSOLIDATED MINES (PTY) LTD: VENETIA MINE

Geohydrological Impact Assessment as part of the Stormwater Management Project

Final Report

Report date: 08 November 2021

SHANGONI
AquiScience

A division of Shangoni Management Services Pty Ltd

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Project:	Geohydrological Impact Assessment
Client:	De Beers Consolidated Mine (Pty) Ltd: Venetia Mine
Site:	Venetia Mine
Location:	Alldays, Limpopo
Project Number:	DEB-VEN-21-02-03
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Compiled by:	Ockie Scholtz, *Pr.Sci.Nat*. (*M.Sc Geohydrology*)
Report date:	08 November 2021

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DECLARATION OF INDEPENDANCE

I, Ockert F. Scholtz declare that

General declaration:

- I act as the independent specialist in this application.
- I will perform the work relating to the application in an objective manner, even if this results in views and findings that are not favourable to the applicant.
- I declare that there are no circumstances that may compromise my objectivity in performing such work.
- I have expertise in conducting the specialist report relevant to this application.
- I have no, and will not engage in, conflicting interests in the undertaking of the activity.
- I undertake to disclose to the applicant and the competent authority all material information in my possession that reasonably has or may have the potential of influencing - any decision to be taken with respect to the application by the competent authority; and - the objectivity of any report, plan or document to be prepared by myself for submission to the competent authority.

Signature of the specialist: Ockert F. Scholtz, *Pr.Sci.Nat*

Shangoni AquiScience, a division of Shangoni Management Services (Pty) Ltd

Name of company:

08 November 2021

Date:

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1. INTRODUCTION AND BACKGROUND

Venetia Mine is situated on the farm Venetia 103 MS, located approximately 80 km west of Musina and 40 km northeast of Alldays in the Limpopo Province. Operations commenced in 1992 with an open pit process mining a diamond bearing kimberlite cluster, namely K1, K2 and K3 kimberlite pipes. The open pit will be mined to a depth of approximately 450 m, which is envisaged up to 2022/2023.

From a depth of below 450 m, open pit mining becomes uneconomical due to the amount of waste rock to be removed. As part of Venetia Mine's long-term strategy, the mine intends to exploit resources deeper than the current open pit horizons by changing the current mining method from an open pit mining process to an underground mining process, utilising sublevel caving, open benching and incline caving mining methods. This activity, termed the Venetia Underground Project (VUP), will extend the life of the mine from 2021 to approximately 2050.

Contaminated stormwater management is one of the areas where Venetia Mine does not fully meet the requirements of the Integrated Water Use Licence ("IWULA") and only partially achieved the requirements of GNR 704, specifically regarding the capacity to contain affected water on site. Jones and Wagener (2020a) developed a water balance for the mine, which showed that the required additional surface storage for GNR 704 compliance is 2.27 Mm^3 with the additional storage required to cater for the VUP alone equates to 0.780 Mm^3 The mine evaluated various alternatives as a mine wide solution for the containment of contaminated stormwater on site to ensure legal compliance as per the requirements of GN 704 and to limit the risk of spillage to less than once in 50 years on average. These alternatives include:

- PCD 1A – 120 000 m^3;
- PCD 2 – 130 000 m^3
- PCD 3 (Option PCD 3A);
- PCD 3 (Option PCD 3C);
- PCD 4B – 30 000 m^3;
- FRD 1 RWD (Proposed expansion, i.e., raising of the dam wall);
- OMWSD N&S (Proposed expansion, i.e., raising of the dam wall);
- MWSD Compartment 3 (Proposed);
- OMWSD Compartment 4 (Proposed);
- K3 (i.e., storage of mine affected water in this pit); and
- Discharging mine affected water as an interim measure.

The locations of the proposed storage facilities are shown in Figure 1 below.

The purpose of this desktop study was to develop a conceptual model of the hydrogeological regime and to provide a regional assessment of the potential impacts associated with the proposed storage facilities. The contents and results from various specialist geohydrological studies and other relevant reports were used to conclude the predicted level of impacts associated with the construction and operation of these facilities.

Figure 1: Master layout of Venetia Mine and proposed affected water storage alternatives

2. GEOGRAPHICAL SETTING

Venetia Mine is an operational diamond mine which is owned by De Beers Consolidated Mines and is located in the far north of South Africa. The mine is situated on the farm Venetia 103 MS in the Limpopo Province, approximately 40 km north east of Alldays and 80 km west of Musina. The Limpopo River which forms the border between South Africa and Botswana is located approximately 30 km to the north. Venetia Mine is the main producer of diamonds in South Africa and although the current operation is opencast, the intention will be to go to underground mining in 2022/2023.

2.1 Topography and drainage

The topography is usually a good first indication of the groundwater flow directions, and often hydraulic heads in an unconfined or semi-confined aquifer mimics surface flow.

The regional topography consists of low hills and wide valleys, varying in elevation from 700 mamsl in the south to 600 mamsl at the topographical lows in the north (Figure 2). The surface topography and associated landscape within the mine's boundary has been altered by various mine residue deposits such as fine residue deposits (FRDs), coarse residue deposits (CRDs), waste rock dumps (WRDs) and the open pits, K1-K3. On a regional scale, surface water flow is from south-east to north-west.

The site is located predominantly in the Matotwane River catchment, with the river located to the east of the mine boundary. The Kolope River runs along the western boundary of the mine. Prior to mining an unnamed tributary of the Matotwane River ran from south to north through the mine and is still thought to play an important role in the surface water and groundwater dynamics downstream of the site, especially downstream from the WRDs.

The mine is located within quaternary catchment A63E of the Limpopo Primary Drainage Region and in rainfall zone A6F.

2.2 Climate

Venetia Mine is located in a hot semi-arid region of the Limpopo Province of South Africa. The area is characterised by high average temperatures with low rainfall and high evaporation rates. The Mean Annual Precipitation (MAP) in this area varies between 300-400 mm, while the Mean Annual Evaporation (MAE) is approximately 2050 mm.

Monthly rainfall figures from 1999 to current as recorded from a rainfall station on the mine is shown in Table 1 and Figure 3 below. The data shows the majority of rainfall periods occur between the months of October to April.

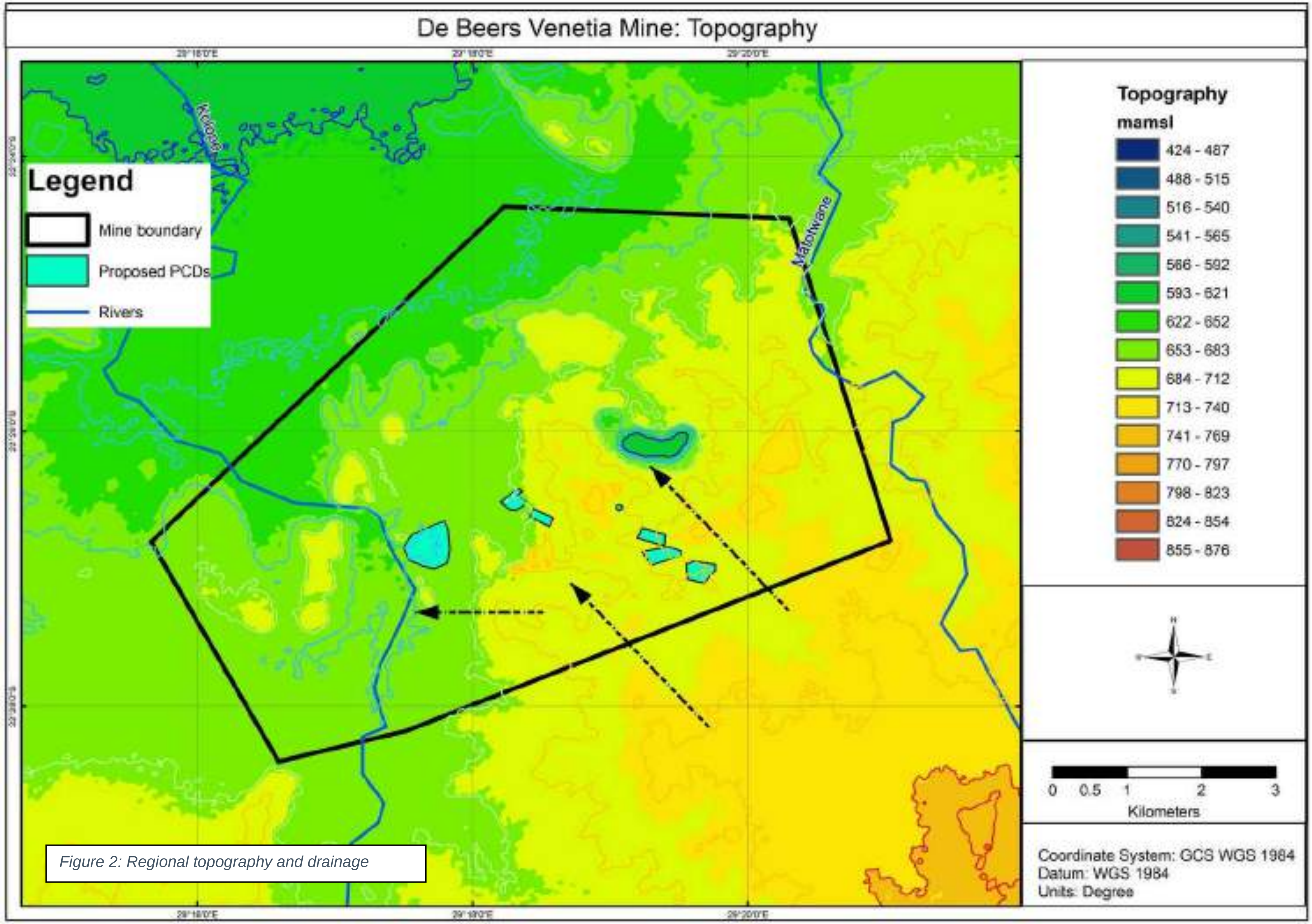

Figure 2: Regional topography and drainage

Table 1: Monthly rainfall data as received and recorded at Venetia Mine

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1999	75.0	36.0	14.0	38.0	12.0	0.0	2.0	0.0	0.0	21.0	64.0	86.0	**348.0**
2000	191.0	158.0	331.0	4.0	0.0	9.0	32.0	0.0	0.0	5.0	32.2	63.0	**825.2**
2001	28.0	80.8	24.2	28.8	10.2	11.2	0.0	0.0	2.8	10.0	34.2	69.0	**299.2**
2002	46.4	17.2	3.8	11.8	0.0	4.0	1.0	1.8	11.8	34.0	12.8	6.0	**150.6**
2003	40.4	97.0	37.0	0.0	0.0	16.4	0.0	0.0	0.0	28.4	58.0	143.0	**420.2**
2004	11.0	28.0	182.0	8.0	0.0	0.0	0.0	0.0	0.0	30.0	36.0	71.0	**366.0**
2005	67.0	33.5	21.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	44.5	31.4	**203.4**
2006	77.5	68.0	68.0	0.0	0.0	0.0	0.0	0.3	0.0	10.9	81.0	0.0	**305.7**
2007	5.2	3.1	73.9	2.1	0.3	0.6	0.3	0.0	108.0	41.3	118.0	126.6	**479.4**
2008	75.8	3.0	13.7	73.0	0.8	0.2	0.0	0.0	0.0	0.0	60.4	83.2	**310.1**
2009	250.1	26.1	111.7	0.3	17.5	2.5	0.8	0.0	20.0	8.3	121.6	12.6	**571.5**
2010	124.9	8.0	34.9	262.1	0.5	0.0	0.7	0.0	0.0	0.0	99.0	78.2	**608.3**
2011	165.0	11.8	10.8	32.5	0.0	0.0	1.2	0.0	0.0	50.5	127.9	31.0	**430.7**
2012	46.2	10.7	1.1	0.0	0.0	0.0	0.0	0.0	12.4	26.7	41.1	41.0	**179.2**
2013	452.0	21.8	15.4	24.1	0.0	0.0	2.0	3.8	0.0	40.6	45.2	76.8	**681.7**
2014	109.5	60.4	122.4	3.1	0.0	0.0	0.0	0.0	0.0	2.4	63.1	126.5	**487.4**
2015	3.3	35.9	54.6	37.8	0.0	0.6	0.0	0.0	45.0	12.5	28.5	44.5	**262.7**
2016	92.8	33.4	94.0	1.5	9.0	1.5	2.9	0.0	0.0	21.9	38.5	113.8	**409.3**
2017	116.9	48.4	14.0	5.0	0.6	0.0	0.0	0.0	0.0	57.5	61.3	4.9	**308.6**
2018	10.4	143.3	9.8	1.8	13.6	0.0	0.1	0.0	2.0	9.3	36.1	83.6	**310.0**
2019	102.4	139.1	0.6	46.9	0.0	0.0	0.0	0.0	0.0	0.0	99.4	43.6	**432.0**
2020	8.1	86.7	11.2	3.0	0.0	0.6	0.0	6.7	0.3	28.7	32.7	116.8	**294.8**
2021	231.0	161.2	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**395.9**
Avg	**101.3**	**57.0**	**54.5**	**25.6**	**2.8**	**2.0**	**1.9**	**0.5**	**8.8**	**19.1**	**58.1**	**63.2**	394.8

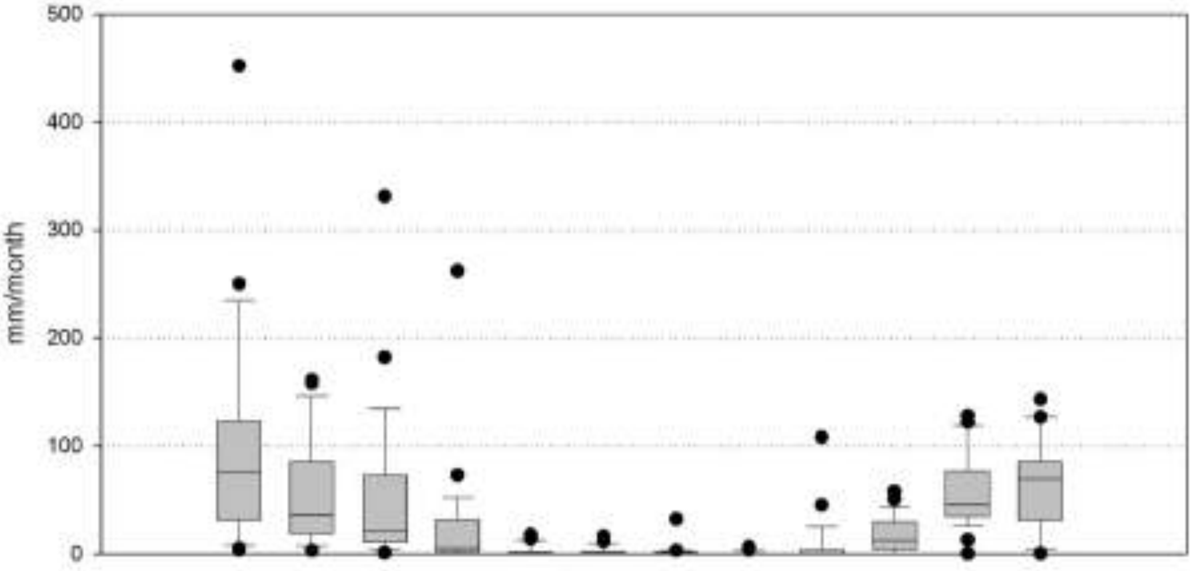

Figure 3: Box plot showing monthly rainfall data from the year 1999 to 2021

2.3 Aquifer testing

Hydraulic Testing was performed on the boreholes drilled by Jones and Wagener (2020) to supplement the existing aquifer parameter data that was available for the site. Constant rate pumping and slug tests were performed. More information on the tests and permeabilities calculated can be viewed in Section 5.3.3 of this report.

3. SCOPE OF WORK

The aims of the project were to i) determine baseline geohydrological conditions; ii) assess and rate probable groundwater water related impacts; and iii) to propose management plans and monitoring protocols to pro-actively manage all future potential water related impacts.

4. METHODOLOGY

The focus areas required to assess the geohydrological conditions were:

- Description of baseline environmental conditions.
- Determination of baseline (*status quo*) geohydrology of the area, which included a desktop study of the groundwater conditions and relevant environmental factors.
- Development of a conceptual model based on potential risks and current geohydrological conditions.
- Determination of the Darcy flux and seepage velocity and rate at which groundwater contamination will migrate.
- Risk assessment of the geohydrological impact resulting from the operations. This includes the description of possible negative groundwater related impacts during construction, operation and decommissioning and closure.

To meet the aims and objectives for the current study, the following were completed:

Desktop Assessment and Impact Assessment

- Review of relevant specialist reports and data.
- Review and discussion on baseline description of geohydrology for the study area.
- Combine and interpret available topographical, geohydrological and related information.
- Assessment of application and mine-wide potential sources of pollution.
- Development of a conceptual geohydrological model for the project areas.
- Identify relevant impacts associated with the application and rate them in a risk assessment.
- Review current monitoring programme and recommend additional monitoring (if needed) to manage risks.

4.1 Desk Study

A desk study was conducted to gather all relevant environmental information, including topographical, hydrological and geohydrological data. Typical information requirements for a geohydrological risk perspective include the following:

- Published and unpublished geological and hydrogeological reports, maps and documents.
- Boreholes positions and logs.
- Details of groundwater abstractions and groundwater users in the area.
- Conceptual and/or detailed groundwater model.
- Recharge estimations.
- Groundwater quality information.

Data/information was also gathered from previous monitoring reports as well as specialist geohydrological and geochemical studies conducted for Venetia Mine. Reports that were assessed as part of this specialist study, included:

- Groundwater Specialist Study for the Feasibility Level Environmental Impact Assessment of Venetia Diamond Mine. Prepared for Venetia Diamond Mine by SRK Consulting. SRK Project Number 424741 (SRK, 2011).
- Venetia Mine Water and Salt Balance Report as compiled by Jones and Wagner in 2014. Report No. JW011/14/D537 – Rev 1 (Jones and Wagener, 2014).
- Venetia Mine Waste Assessment. Compiled by Jones and Wagener in 2016 for De Beers Consolidated Mines Propriety Limited. Report No.: JW222/16/F614 – Rev 03 (Jones and Wagener, 2016).
- Integrated Water and Waste Management Programme (IWWMP, 2019) for De Beers Consolidated Mines (Pty) Ltd: Venetia Mine, as compiled by Prescali Environmental Consultants (Pty) Ltd.
- Venetia Mine Hydrogeological Assessment Final Report compiled by Jones and Wagener in 2018, revision 1 (17/08/2018). Report No. JW093/18/F630 (Jones and Wagener, 2018).

- Venetia Mine Water Balance Life of Mine and Scenario Report. Report No.: JW238/20/I142 - Rev 0 (Jones and Wagener, 2020a)
- Venetia Mine Hydrogeological Assessment Final Report compiled by Jones and Wagener in 2020, revision 2 (10/02/20). Report No. JW093/18/F630 (Jones and Wagener, 2020b).
- Review of water quality and water level database as updated by Aquatico for Venetia Mine (supplied in Excel format).

4.2 Hydrocensus

No new hydrocensus was performed for the present study. The investigation relied heavily on previous specialist studies conducted on the mine and on monitoring data.

Jones & Wagener conducted a hydrocensus in March 2017 (Jones and Wagener, 2020b) during which 11 boreholes were identified. The majority of these boreholes are located in the Venetia Limpopo Nature Reserve (VLNR) and are not in use, with the exception of VEN-HC9, VEN-HC10 and VEN-HC11; they are located south of the mine on private farms and are in use. Besides these, there are also 26 boreholes spread across the site (mostly on-mine) and are included in the Venetia monitoring programme. Table 2 lists the monitoring boreholes (hydrocensus and monitoring) while their positions relative to the mine are shown on Figure 4.

Table 2: Hydrocensus (Jones and Wagener, 2020b) and mine monitoring boreholes

Borehole ID	Coordinates			Application
	y	x	Z (mamsl)	
Hydrocensus boreholes				
VEN-HC1	-22.4487	29.29189	658	No use, within VLNR
VEN-HC2	-22.4495	29.29215	664	
VEN-HC3	-22.4135	29.27175	633	
VEN-HC4	-22.3979	29.27022	619	
VEN-HC5	-22.4023	29.3079	636	
VEN-HC6	-22.4028	29.31739	645	
VEN-HC7	-22.4104	29.37085	700	
VEN-HC8	-22.411	29.37109	700	
VEN-HC9	-22.4591	29.34055	716	Private use
VEN-HC10	-22.4652	29.34176	720	
VEN-HC11	-22.4609	29.31957	713	
Monitoring boreholes				
Abend Rhue	-22.482674	29.337065	(tap)	Private use
B01	-22.45756	29.32366	721	
B04	-22.46508	29.34178	672	
EMP A	-22.45174	29.292788	703	Mine monitoring
EMP R	-22.432877	29.308973	698	
KLM01	-22.446945	29.321547	658	
KLM03	-22.410247	29.324095	649	

Borehole ID	Coordinates			Application
	y	x	Z (mamsl)	
KLM04	-22.411988	29.314305	655	
KLM05	-22.42905	29.28759	680	
KLM06	-22.43939	29.28848	682	
KLM07	-22.43872	29.30546	696	
KLM08	-22.45443	29.31277	647	
MBH01	-22.42312	29.29358	705	
MBH01S	-22.42312	29.29358	721	
MBH02	-22.42253	29.29234	646	
MBH02S	-22.42253	29.29234	646	
MBH03	-22.418892	29.295078	643	
MBH03S	-22.418892	29.295078	643	
MBH04	-22.41815	29.29683	642	
MBH04S	-22.41815	29.29683	642	
MBH05	-22.41645	29.30157	639	
MBH05s	-22.41645	29.30157	639	
MBH06	-22.41539	29.29591	639	
MBH06S	-22.41539	29.29591	639	
MBH07	-22.41526	29.30072	638	
MBH07S	-22.41526	29.30072	638	

4.3 Geophysical survey

No geophysical surveys were done as part of this investigation. The study relied heavily on the resistivity investigation conducted by Jones and Wagener in 2017 (Jones and Wagener, 2020b). Results from their geophysical investigations were used by them to site characterisation boreholes.

The reader is referred to the report compiled by Jones and Wagener (2020b) for more information on the geophysical investigation.

4.4 Drilling and siting of boreholes

No new boreholes were drilled for this study. The investigation relied heavily on previously drilled boreholes on the site and especially those drilled by Jones and Wagener (2020b). They drilled 25 boreholes based on the geophysical exploration to identify the depth and extent of perched, weathering and fractured zones. Borehole depths drilled ranged between 5- and 58 meters below surface (mbs) and only minor seepages were encountered, mostly in the weathering zone. Water levels recorded ranged between 1.84- and 18.62 mbs. No clear distinction could be made in water levels for boreholes drilled into the weathered and fractured zones and, therefore, these systems may be hydraulically connected. No perched aquifers were encountered. Details of the drilled boreholes can be viewed in Table 3.

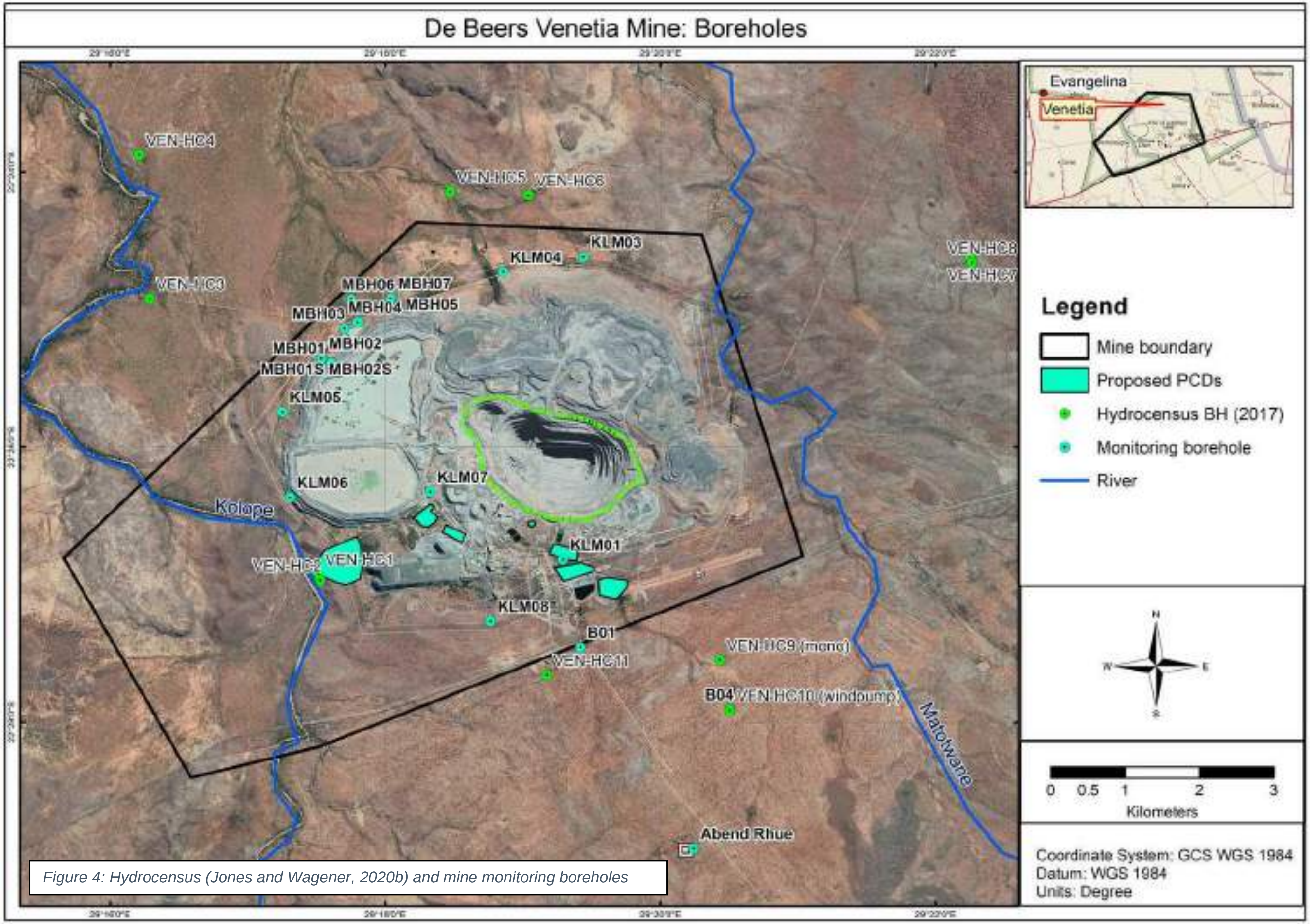

Figure 4: Hydrocensus (Jones and Wagener, 2020b) and mine monitoring boreholes

Table 3: Summary of boreholes drilled (Jones and Wagener, 2020b)

Borehole ID	Latitude	Longitude	Z (collar)	Depth	Zone	SWL (mbs)	Weathering (mbs)	Seepage (mbs)
VEN17-BH01P	-22.415	29.29487	636.4	5	Perched	Dry		
VEN17-BH01W	-22.415	29.29492	636.757	22	Weathered	10.38	22	15
VEN17-BH01F	-22.415	29.29499	636.697	40	Fractured	10.31	22	16
VEN17-BH02W	-22.4305	29.28451	657.306	14	Weathered	Dry	0	
VEN17-BH02F	-22.4305	29.28448	657.323	40	Fractured	16.62	14	25-26
VEN17-BH03W	-22.4406	29.2908	655.058	16	Weathered	4.59	14	08-Jul
VEN17-BH03F	-22.4406	29.29075	655.209	30	Fractured	5.54	12	10
VEN17-BH04P	-22.4165	29.29547	638.512	4	Perched	Dry		
VEN17-BH04W	-22.4165	29.29544	638.229	22	Weathered	9.86	22	16
VEN17-BH05W	-22.4351	29.30674	686.154	12	Weathered	Dry	0	
VEN17-BH05F	-22.4352	29.30674	685.597	40	Fractured	14.35	13	28
VEN17-BH06W	-22.415	29.28868	634.466	28	Weathered	10.25	28	0
VEN17-BH07W	-22.4443	29.29476	654.047	12	Weathered	3	12	05-Apr
VEN17-BH07F	-22.4443	29.29478	653.858	36	Fractured	3.3	12	5.19
VEN17-BH08W	-22.444	29.29593	656.658	20	Weathered	3.93	20	10.16
VEN17-BH08F	-22.4441	29.29594	656.784	40	Fractured	3.86	19	10.16
VEN17-BH09W	-22.4458	29.29633	657.633	16	Weathered	1.84	19	0
VEN17-BH09F	-22.4458	29.29634	657.55	40	Fractured	3.98	19	5
VEN17-BH10W	-22.4494	29.30681	683.909	7	Weathered	Dry	0	
VEN17-BH10F	-22.4494	29.30676	684.14	30	Fractured	18.62	7	-
VEN17-BH11W	-22.4413	29.30964	684.259	15	Weathered	11.02	15	-
VEN17-BH11F	-22.4413	29.3096	684.135	58	Fractured	10.8	15	-
VEN17-BH12W	-22.4422	29.30801	679.565	22	Weathered	6.27	22	-
VEN17-BH12F	-22.4421	29.30801	679.407	40	Fractured	5.93	22	12

4.5 Sampling and chemical analysis

Aquatico has been conducting groundwater monitoring at Venetia Mine for almost a decade. The monitoring data is presented and discussed in Section 6.6 of this report.

4.6 Groundwater recharge calculations

Recharge is defined as the process by which water is added to the zone of saturation of an aquifer, either directly into a formation, or indirectly by way of another formation. Any variation in groundwater recharge will depend on the permeability of the strata and the degree of development on site. Based on the historical investigations and previous groundwater modelling efforts for the immediate vicinity, it is estimated that the rainfall recharge figure is likely to be in the order of 2.5 mm to 3 mm per annum.

4.7 Groundwater modelling

No new groundwater model was developed specifically for this study regarding the construction and operation of the proposed storage facilities. The investigation relied heavily on previous modelling exercises for the project area.

4.8 Groundwater availability assessment

In a typical geohydrological setting, groundwater availability aquifer development is closely linked to the geology and the presence of preferential flow pathways such as fracture systems and weathering. As stated previously, the geological units underlying the study area are not favourable for good yielding aquifers due to the low permeability and effective porosities.

The catchment is water stressed and although the aquifers are considered minor, it is the sole source of water for local farmers and communities using the groundwater for domestic use and livestock watering. Boreholes drilled into granite/gneiss/schist mostly have yields of < 2 l/s and usually < 0.5 l/s with normal depths of < 80 m.

Raw water for use on the mine is abstracted from the Limpopo River via two wellfields (on the banks of the Limpopo River) situated on Greefswald and Schroda farms in the Mapungubwe National Park. Alluvial sediments and Quaternary-age sands overlying rocks of the central zone form the Limpopo alluvial aquifer. Substantially higher aquifer yields are observed in this alluvial aquifer located on the banks of the Limpopo River.

5. PREVAILING GROUNDWATER CONDITIONS

A variety of anthropogenic activities affect groundwater flow and chemistry, the extent of which can only be quantified if the pre-mining situation was known. The purpose of this section is, therefore, to describe the pre-mining environment to such an extent that it can be used as baseline information in the quantification of the impact of mining on the groundwater regime.

The current physical, hydrochemical and hydrogeochemical properties of the aquifers in the region are explained in the following sections.

5.1 Geology

5.1.1 Regional geology

The regional geology is dominated by the Limpopo Belt, which is located between the Kaapvaal and Zimbabwe Cratons. The Limpopo Belt comprises three zones i.e. Northern Marginal, Central and Southern Marginal and is a very complex geological province shaped by many tectono-metamorphic events. The Venetia Mine is situated in the Central Zone of the Limpopo Mobile Belt (Swazian Era).

The Limpopo Belt in the Venetia area is believed to be 10 km thick and contains an ensemble of rocks known as the Beit Bridge Complex that comprises rocks of the Gumbu, Malala Drift and Mount Dowe Groups (Figure 5). This country rock at Venetia Mine comprises mainly quartzofeldspathic gneisses, marbles, gneisses, shists and other metasediments. These rocks have undergone numerous phases of shearing and folding.

Outliers of Karoo rocks are present in the area. Diabase in the form of dolerite dykes and sills are also commonly found.

5.1.2 Local geology

At the Venetia Mine, kimberlite pipes are surrounded by four tectonic units. These units include the Gotha Granitic Complex, the Venetian Klippe, the Endora Klippe and the Krone Metamorphic Terrane. The Gotha Granitic Complex bounds the mine to the south and comprises mostly leucocratic tonalite, granodiorite and granite with minor lenses of amphibolite, quartzite and magnetite quartzite. The FRDs and CRD are situated primarily on the Venetia Klippe unit that comprises four units, the lowermost being quartsofeldspathic gneiss and ortho-amphibiolites. These rocks are overlain by an interlayered quartsofeldspathic gneiss, amphibolite and carbonate and calcsilicate rocks that in turn are overlain by a metasedimentary sequence of quartzite carbonate and calc-silicate rocks. The youngest unit comprises granite orthogneisses.

The Endora Klippe unit lies to the north of the mine and is primarily comprised of quartzite and magnetite quartsite. Layers in this unit are folded around a north-north west trending axis.

The Krone Metamorphic Terrane lies to the north west, the area drained by the Kolope River. It comprises mostly of quartsofeldspathic gneisses with variable compositions ranging from granitic to tonalitic. Amphibolite, garnet-amphibolite and magnetite quartzite occur as lenses within the quartsofeldspathic gneisses. The contact between the Krone Metamorphic Terrane and the Venetia Klippe is exposed along the west and south west edges of the klippe.

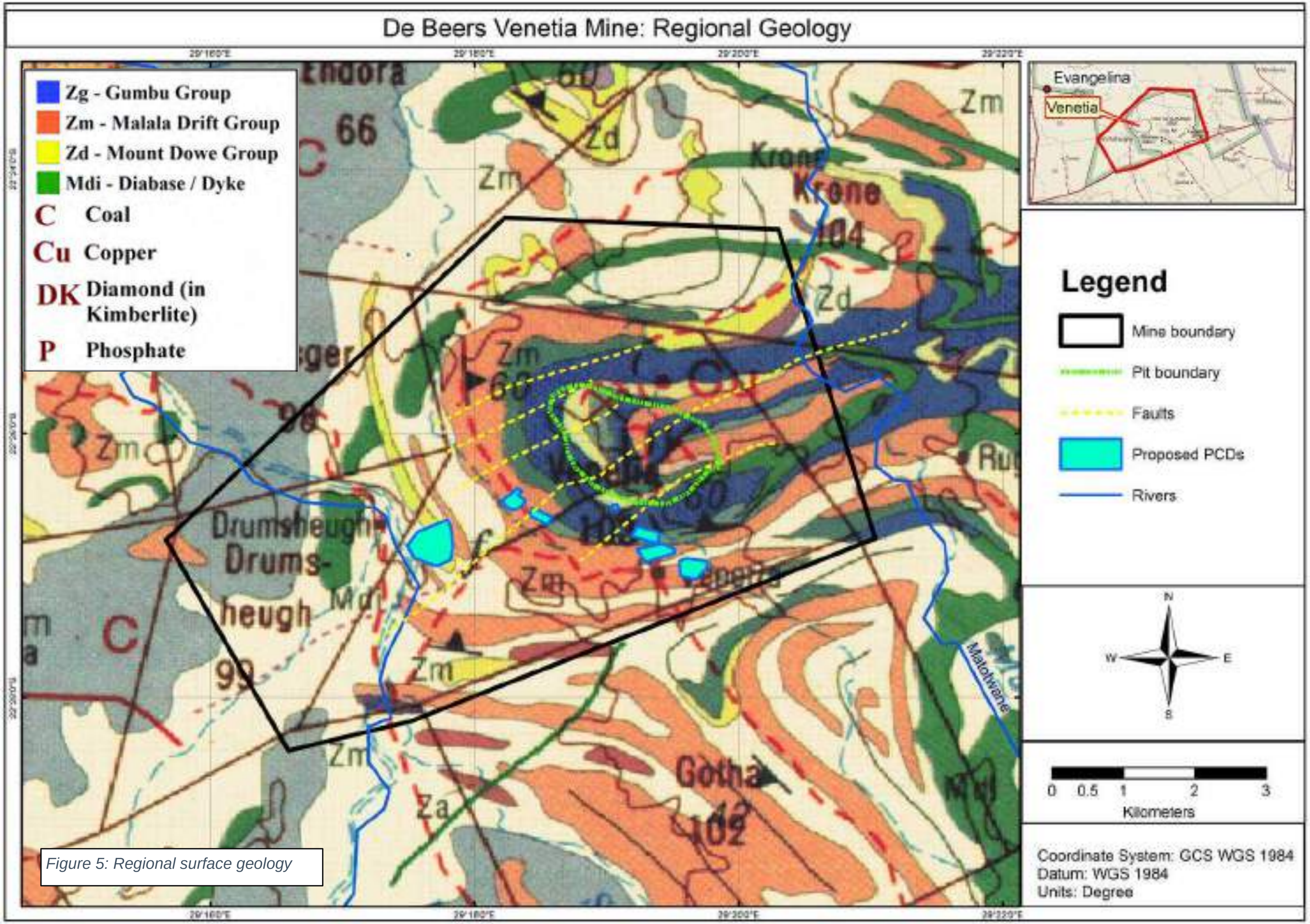

Figure 5: Regional surface geology

5.1.3 Dykes, sills and faults

Various dolerite sills have intruded the above formations at different depths prior to emplacement of the kimberlite pipes. One of the sills, approximately 25 to 60 m thick, intrudes at a depth of 250 m below ground (mbg). The sills show strong evidence of hydrothermal alteration, especially along joints. Dolerite dykes occasionally extend from the sill upwards.

Also exposed at Venetia mine are faults that vary in strike from east-west to north-west southeast and could be related to the Dowe-Tokwe fault system extending from Musina to the north of Alldays.

5.2 Acid generation capacity

Jones and Wagener conducted a geochemical assessment, which included a static leach, aqua regia digestion and acid potentials of waste rock, coarse residue (CRD) and fines residue (FRD) deposits (Jones and Wagener, 2016). Their conclusion was that the waste rock, FRD and CRD do not contain significant amounts of sulphide minerals, which can lead to the generation of sulfuric acid and lowering of the pH, and hence the mobilisation of heavy metals. The three (3) residues have all been assessed as non-acid generating. The minerology of the residues confirms these as phyllosilicate minerals, such as smectite, which are alkaline in nature.

They also sampled and analysed various surface water samples, including discharge from the FRD, return and seepage water and CRD seepage water, which all recorded alkaline pH levels of > 9.5.

5.3 Hydrogeology

5.3.1 Unsaturated zone (vadose zone)

The characteristics of vadose zone vulnerability dominating factors are closely related to the migration and transformation mechanisms of contaminants in the vadose zone, which directly affect the state of the contaminants percolating to the groundwater. The permeability and thickness of the unsaturated zone are some of the main factors determining the infiltration rate, the amount of runoff and consequently the effective recharge percentage of rainfall to the aquifer. The type of material forming the unsaturated zone as well as the permeability and texture will significantly influence the mass transport of surface contamination to the underlying aquifer(s). Factors like ion exchange, retardation, biodegradation and dispersion all play a role in the unsaturated zone.

Recharge from rainfall percolates through the dumps and unsaturated zone into the weathered aquifer thereby mobilizing soluble contaminants. The average depth to groundwater is in the order of 8 m with depths up to 31 m immediately adjacent to the pit. This unsaturated zone provides some attenuation capacity for the vertical migration of contaminants.

5.3.2 Saturated zone

The subsurface zone below the water table where interstices are filled with water under pressure greater than that of the atmosphere are known as the saturated zone. Once the vertical migration of dissolved contaminants reaches the groundwater, the dominant migration pathway alters from a vertical to a lateral direction. Flow directions mimic the topography with possible dissolved contaminants migrating towards the surface water systems to the west and north on a regional scale.

5.3.3 Hydraulic conductivity

Abstraction rates during the constant rate tests conducted (refer to Section 4.5) ranged between 0.1- and 0.51 l/s and drawdown ranged between 6.93 m and 46.5 m, a first indication of the low permeability of the aquifer/s. The calculated mean hydraulic parameters for the tested boreholes are shown in Table 4. These values support the initial view of highly impermeable and tight hydrostratigraphic units.

Table 4: Aquifer test information (Jones and *Wagener*, 2020b)

Parameter	**Transmissivity (T)**	**Hydraulic conductivity (K)**
	m²/d	**m/d**
Weathered aquifer		
Calculated Harmonic Mean	0.23	0.01
Calculated Geometric Mean	0.7	0.04
Fractured aquifer		
Calculated Harmonic Mean	0.23	0.001
Calculated Geometric Mean	0.03	0.009

5.4 Groundwater levels

Groundwater level information is collected on a quarterly schedule from 23 monitoring boreholes by Aquatico, which is interpreted by Groundwater Complete on an annual basis.

Average groundwater level depths generally varied between 2.2 and 11 mbs during the 2019/2020 annual monitoring period. Much deeper water levels were, however, measured in monitoring borehole EMP R, which displayed an average depth of 32.4 mbs.

Groundwater trend analyses for the 2020/2021 monitoring period show relatively constant water levels for most boreholes but regarding longer term trends, increasing water levels are noted for boreholes KLM01, KLM03, KLM04 MBH03s, MBH04, MBH04s, MBH05 and MBH07 and indicate seepage effects. Some of these boreholes are located within old paleochannels underlying the site and it is believed that these old paleochannels play a big role in subsurface water movement. Other boreholes with increasing water level trends are mostly located downgradient from FRD2 and RWD2.

Averaged water levels and hydraulic heads calculated for the database period can be viewed in Table 5 and Figure 6. Note the outlier, EMPR, which cannot be explained at present with the data available.

Table 5: Monitoring borehole information and averaged water levels

Field ID	Coordinates			SWL (mbs)	Hydraulic head (mamsl)
	y	x	Z (mamsl)		
B01	-22.45756	29.32366	705	9.9	695.1
B04	-22.46508	29.34178	721	13.1	707.9
EMP A	-22.45174	29.292788	672	7.7	664.3
EMP R	**-22.432877**	**29.308973**	**703**	**32.2**	**670.8**
KLM01	-22.446945	29.321547	698	9.7	688.3
KLM03	-22.410247	29.324095	658	9.8	648.2
KLM04	-22.411988	29.314305	649	5.1	643.9
KLM05	-22.42905	29.28759	655	7.1	647.9
KLM06	-22.43939	29.28848	680	12.1	667.9
KLM07	-22.43872	29.30546	682	7.5	674.5
KLM08	-22.45443	29.31277	696	10.0	686.0
MBH01	-22.42312	29.29358	647	4.6	642.4
MBH01s	-22.42312	29.29358	647	5.4	641.6
MBH02	-22.42253	29.29234	646	6.1	639.9
MBH02s	-22.42253	29.29234	646	6.6	639.4
MBH03	-22.418892	29.295078	643	10.5	632.5
MBH03s	-22.418892	29.295078	646	8.6	637.4
MBH04	-22.41815	29.29683	642	6.3	635.7
MBH04s	-22.41815	29.29683	642	5.8	636.2
MBH05	-22.41645	29.30157	639	3.8	635.2
MBH05s	-22.41645	29.30157	639	3.5	635.5
MBH06	-22.41539	29.29591	639	8.0	631.0
MBH06s	-22.41539	29.29591	639	8.2	630.8
MBH07	-22.41526	29.30072	638	2.9	635.1
MBH07s	-22.4153	29.30072	638	3.1	634.9

Water levels measured ranged between 2.9- and 32.2 mbs. One borehole, EMP R, recorded considerably deeper water levels for which the reason is at this stage uncertain with the data gathered. Relatively similar water levels were recorded for the shallow boreholes compared to the deeper boreholes, indicating that the weathered and fractured aquifers are hydraulically connected.

Figure 6 shows the measured water levels and hydraulic head elevations graphically.

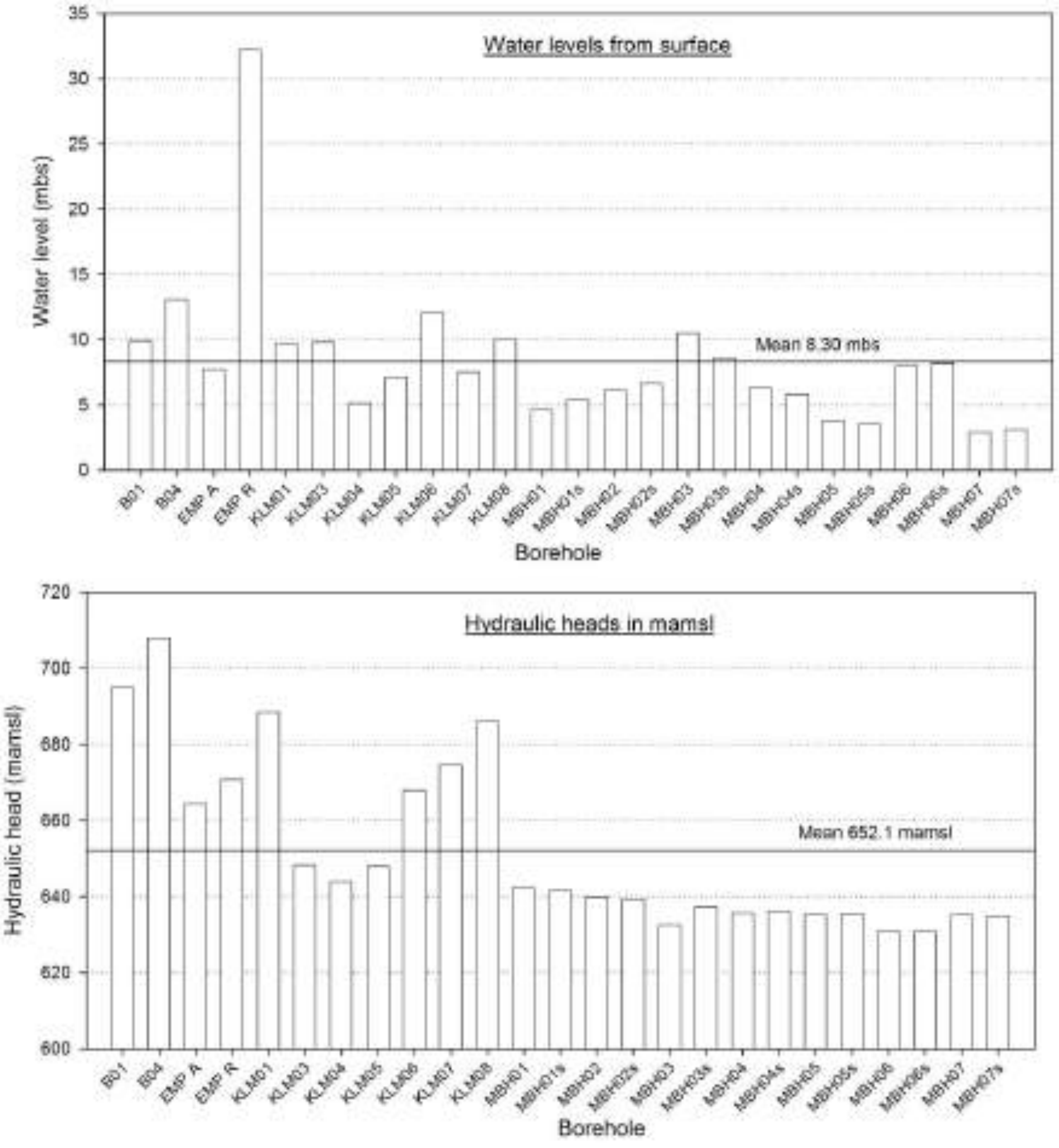

Figure 6: Groundwater levels from surface and hydraulic heads in meters above mean sea level

Figures 7 and 8 show linear regressions between the hydraulic heads of the aquifers and topography. A fair correlation of 0.96 was achieved for the all hydraulic heads calculated and the topography. The water level of borehole EMP R is however suspected to be dynamic/affected and was subsequently removed after which a better correlation of 0.99 was achieved. Given this correlation, it can be assumed with relative confidence that the natural groundwater flow mimics surface water flow directions and that certain water levels are dynamic heads affected by drawdown.

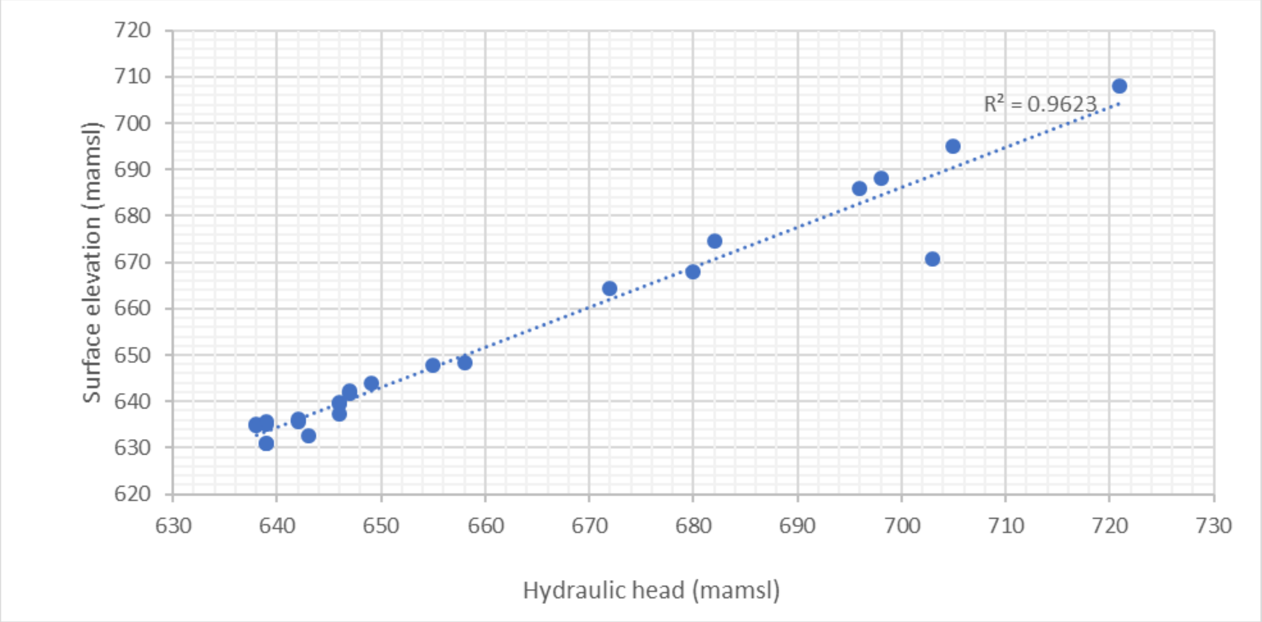

Figure 7: Linear regression between topography and hydraulic heads

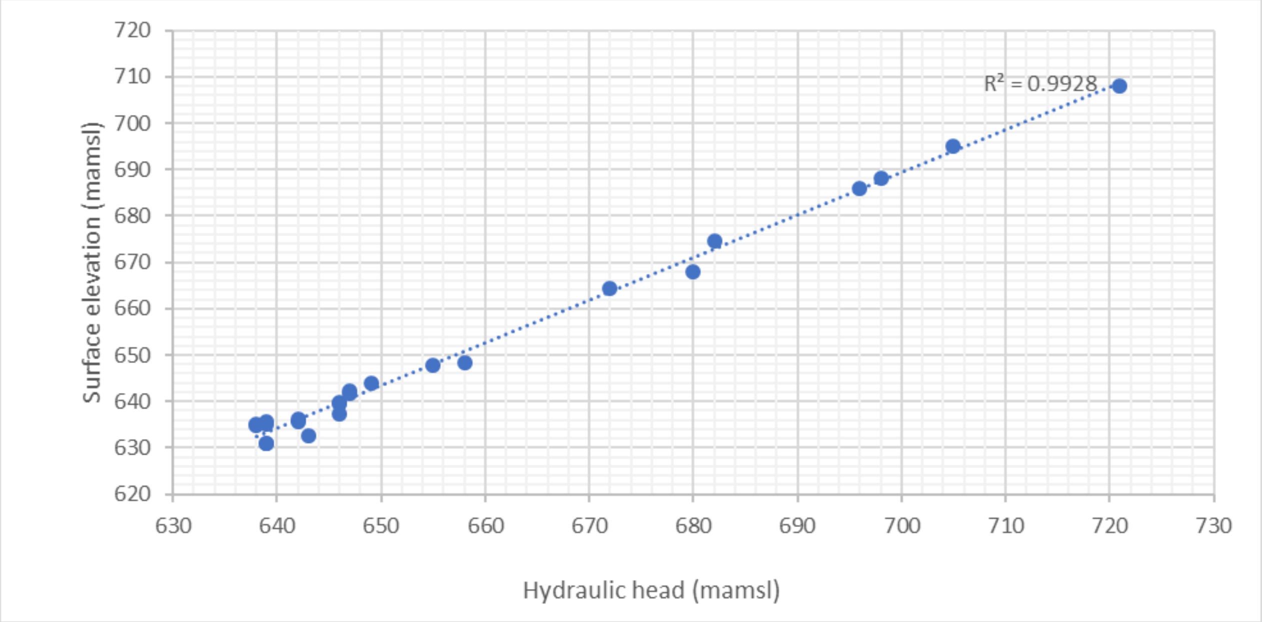

Figure 8: Linear regression between topography and hydraulic heads with suspected dynamic levels removed

5.5 Groundwater potential contaminants

5.5.1 Geochemical assessment on mineral waste

As discussed previously (refer to Section 5.2) Jones and Wagener (2016) conducted a waste assessment on mine residue deposits to identify potential contaminants of concern (CoCs).

Although a number of metals, such as antimony (Sb), barium (Ba), cadmium (Cd), cobalt (Co), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) recorded in concentrations (total concentrations; aqua regia digestion) exceeding the average Crustal Abundance concentrations, the distilled water leach tests performed on the WRDs, FRDs and CRD indicate that none of these metals leached in substantial concentrations. Given the that the residue deposits do not pose an acidifying risk, the risk for these metals to become soluble and pollute the groundwater resources are very low. The paste pH of the residue deposits all recorded > 9.5 confirming the alkaline nature of the geological formations at the mine.

5.5.2 Quality of mine water

Water quality analyses of mine water can also provide an indication of the potential groundwater contaminants that pose a risk towards the natural water resources at Venetia Mine. To determine the CoCs, the affected surface water quality monitoring database as managed and updated by Aquatico was reviewed. Relevant data was extracted and averaged for the database period. A short summary on the chemistry and CoCs are discussed in Table 6 below. Stiff diagrams are shown in Figure 9 below.

Table 6: Summary on hydrochemical quality of mine water at Venetia Mine

Source	**Monitoring IDs**	**Water quality summary (database period)**
		Seepages
CRD Seepage	CRD, CRD2, CRD West	• Circum-neutral pH with elevated salinity and total hardness. • Trace metals are low to undetected except for molybdenum (Mo) and boron (B), with ranges of between 0.88 mg/l and 5.56 mg/l, and 0.71 mg/l and 8.86 mg/l recorded during the database period, respectively. • Average TDS is elevated at 9839 mg/l. • Major ions including potassium (K), calcium (Ca), and magnesium (Mg) are high while chloride (Cl), sodium (Na) and sulphate (SO_4) are elevated. • Nitrate (NO_3), ammonium (NH_4) and phosphate (PO_4) are relatively low. • Na and SO_4 are the dominant ions in solution followed by Cl and Mg.
FRD Seepage	DB1, FRD2 NS Dam	• Circum-neutral pH with elevated salinity and total hardness. • Trace metals are low to undetected except for Mo and B, with ranges of between 0.035 mg/l and 0.57 mg/l, and 0.94 mg/l and 18.5 mg/l as recorded during the database period, respectively. Manganese (Mn) levels are also frequently raised with a maximum concentration of 4.71 mg/l recorded for DB1 (“Old FRD Seepage on Southern Perimeter”). • Average TDS is elevated at 13 039 mg/l. • Mineralisation of K, Ca and Mg are high while Cl, Na and SO_4 are extremely elevated. • NO_3, NH_4 and PO_4 are relatively raised. • Na and Mg are the dominant cations and Cl and SO_4 the dominant anions in solution.

Krone Waste Rock Dump seepage	KD	• Circum-neutral pH with elevated salinity and total hardness. • Trace metals are low to undetected except for Mo, B and F. o Mo and B concentrations range between 0.168 mg/l and 0.48 mg/l, and 6.04 mg/l and 21.9 mg/l, respectively. o F concentrations range between 0.071 mg/l and 1.86 mg/l. • Average TDS is elevated at 11 473 mg/l. • Mineralisation of K and Mg are high while Cl, Na and SO_4 are extremely elevated. • NO_3 levels are elevated (0.22 – 82.1 mg N/l) while NH_4 and PO_4 are relatively low. • Na and Cl are the dominant anions in solution.
Venetia Waste Rock Dump seepage	DBVS05, VD1, VD2	• Circum-neutral pH with high salinity and total hardness. • Trace metals are low to undetected except for Mo and B, with ranges of between 0.05 mg/l and 0.46 mg/l, and 0.42 mg/l and 4.51 mg/l respectively. • Average TDS is high at 5286 mg/l. • Mineralisation of Cl, Na and SO_4 are high. • NO_3 levels are elevated (1.5 – 165 mg N/l) while NH_4 and PO_4 are also frequently raised. • Na, Cl and SO_4 are the dominant anions in solution.
Return water dams		
RWD at old slimes dam	S17	• Circum-neutral pH with high salinity and total hardness. • Trace metals are low to undetected except for Mo and B, with ranges of between 0.034 mg/l and 1.37 mg/l and 1.08 mg/l and 5.01 mg/l respectively. • Average TDS is high at 5388 mg/l. • Mineralisation of Cl, Na and SO_4 are high. • NO_3 levels are frequently elevated (0.5 – 102 mg N/l) while NH_4 levels also frequently raised. • Na, Mg, Cl and SO_4 are the dominant mineralised ions in solution.
RWD at Sub 13 & Sub 15	Sub 13 & Sub 15 RWD	• Circum-neutral pH with high salinity and total hardness. • Mo, B, Al, Mn and F have frequently been recorded in relatively raised levels in the return water dams. • Average TDS is high at 3145 mg/l. • Mineralisation of Cl, Na and SO_4 are high. • NO_3 levels are frequently elevated (0.49 – 66.4 mg N/l) while NH_4 and PO_4 levels are also frequently raised. • Na, Cl and SO_4 are the dominant mineralised ions in solution.
Pit storm water control dam	Pit storm WCD	• Circum-neutral pH with relatively low salinity and total hardness. • Trace metals are low to undetected except for Mo and B, with ranges of between 0.021 mg/l and 0.64 mg/l and 0.027 mg/l and 1.09 mg/l, respectively. • NO_3 levels are frequently elevated (0.30 – 102 mg N/l) while NH_4 and PO_4 levels are also frequently raised. • Average TDS is slightly raised at 1493 mg/l. • Na, Cl and SO_4 are the dominant mineralised ions in solution.

Underground water		
U/G water	UG VUP Decline, VUP CWD	- Circum-neutral pH with relatively low salinity and total hardness. - Trace metals are low to undetected except for B, which ranges between 0.2 mg/l and 1.27 mg/l. - Inorganic nitrogen (as NO_3 and NH_4) levels are elevated with up to 820 mg/l NO_3-N and 434 mg/l NH_4-N recorded. - Average TDS is raised at 2932 mg/l. - Na, Cl and SO_4 are the dominant mineralised ions in solution.

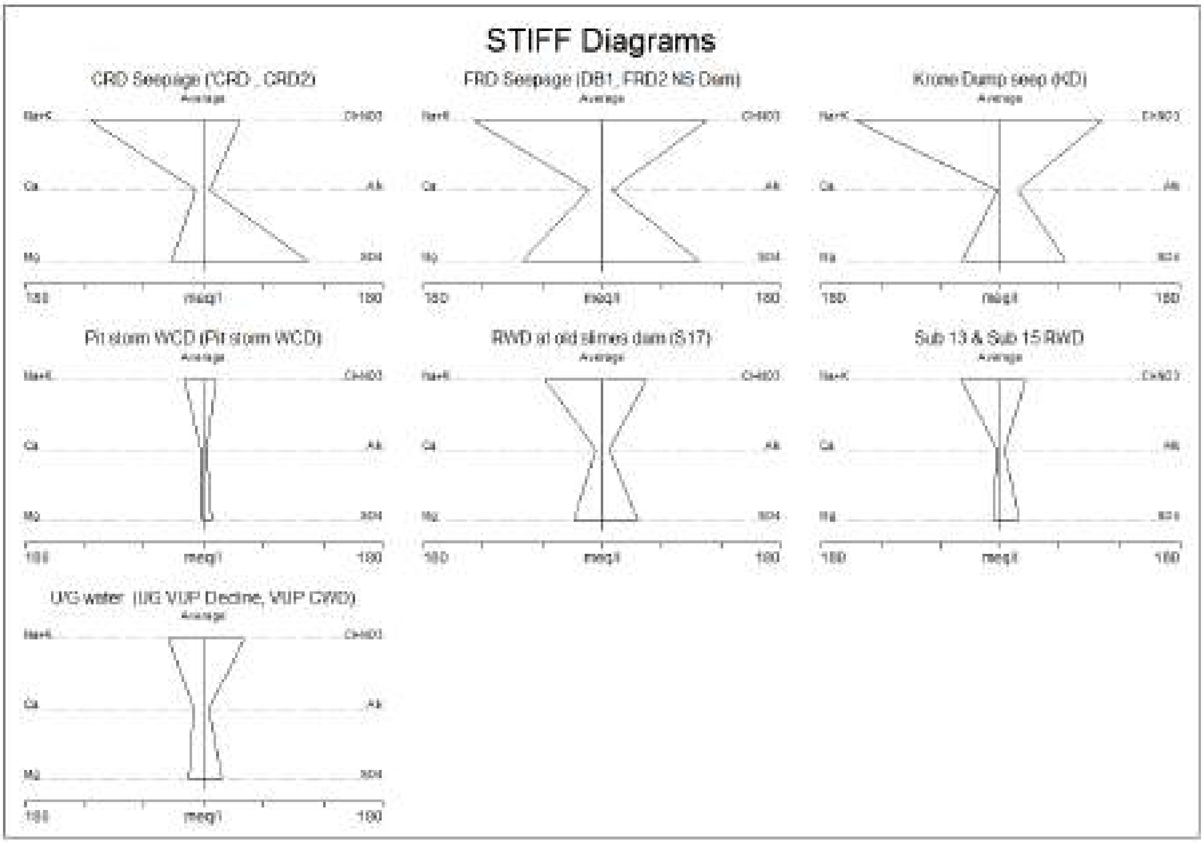

Figure 9: Stiff diagrams based on meq/l of averaged mine water for the monitoring database period

5.6 Groundwater quality

As stated previously, groundwater quality monitoring is performed by Aquatico on a quarterly basis and interpreted and discussed by Groundwater Complete on an annual basis. For the purpose of this study and to describe status quo groundwater conditions, the on-mine groundwater quality data for the 2019/2020 were reviewed.

A total of 22 purpose-drilled mine monitoring boreholes were sampled during the 2019 evaluation period (refer to Figure 4 for their positions relative to mine infrastructure).

The discussion that follows was extracted from the annual assessment by Groundwater Complete (Aquatico, 2020):

Most of the mine boreholes displayed average groundwater EC values of between ±200 mS/m and 710 mS/m. The highest EC values were measured to the north (i.e. downgradient) of the New FRD and its return water dam. No significant increasing or decreasing trends are evident in the time-series graphs, however a definite long-term increase in EC is observed for borehole KML04 when considering the entire database.

Long-term monitoring information collected from upgradient monitoring borehole B01 suggests that the average ambient/unaffected groundwater EC value is in the order of 150 mS/m (95th percentile). This information suggests that most of the mine monitoring boreholes, especially those located downgradient from the New FRD and its return water dam, are affected by seepage/leachate from the mining and related activities and infrastructure.

Boreholes KLM04, KLM07, MBH03S, MBH05/05S and MBH06/06s display average sulphate concentrations of between ~580 mg/l and 1560 mg/l, which also exceed the WUL limit of 400 mg/l. Similar to EC, no significant trends are indicated on the time-series graphs, however borehole KLM04 shows a definite long-term increase in SO_4 when considering the entire data record.

Long-term monitoring information suggests that the average ambient/unaffected groundwater SO_4 content is in the order of 20 mg/l (95th percentile). Most monitoring boreholes are therefore affected by SO_4 type contamination – especially downgradient from the Old FRD (KLM07), New FRD and RWD (MBH03s, MBH05/05s, MBH06/06s) and Venetia WRD (KLM04).

Monitoring boreholes KLM08 and MBH05s recorded average groundwater NO_3 concentrations of ~15 mg/l. An even higher average concentration of approximately 55 mg N/l was measured downgradient from the Venetia WRD in monitoring borehole KLM04. The NO_3-N content in KLM04 not only increased during the past year, but also shows a long-term increasing trend when considering the entire data record. Historical monitoring information also shows a long-term increasing trend for KLM08.

Based on averaged results, the majority of the mine monitoring boreholes recorded groundwater Cl concentrations of between ~310 mg/l and 1260 mg/l. Generally higher concentrations were measured downgradient from the Venetia WRD in borehole KLM04. A long-term increase in the Cl content of KLM04 is evident when considering the entire data record.

The average ambient/unaffected groundwater Cl content was in the order of 120 mg/l (95th percentile), which suggests that most boreholes, especially those downgradient from the Venetia WRD, Old FRD, New FRD and return water dam are affected by Cl type contamination.

5.6.1 Hydrogeochemical profiles

According to the Expanded Durov (Figure 10) and Stiff diagrams (Figure 11) the Venetia mining area is dominated by a variety of groundwater types:

- Field 3 - Fresh, clean, relatively young groundwater that has undergone Na ion exchange (sometimes in Na enriched granites or other felsic rocks). The dominance in Na may also be because of sodium enriched pollution.
- Field 5 - Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4 and NaCl mixing/contamination or old stagnant NaCl dominated water that has mixed with clean water.
- Field 6 - Groundwater from field 5 that has been in contact with a source rich in Na or old stagnant NaCl dominated water that resides in Na rich host rock/material.
- Field 8 - Groundwater that is usually a mix of different types – either clean water from fields 1 and 2 that has undergone SO_4, but especially Cl mixing/contamination or old stagnant NaCl dominated water that has mixed with water richer in Mg.
- Field 9 - Old or stagnant water that has reached the end of the geohydrological cycle (deserts, salty pans etc.) or water that has moved a long time and/or distance through the aquifer or on surface and has undergone significant ion exchange because of the long distance or residence time in the aquifer.

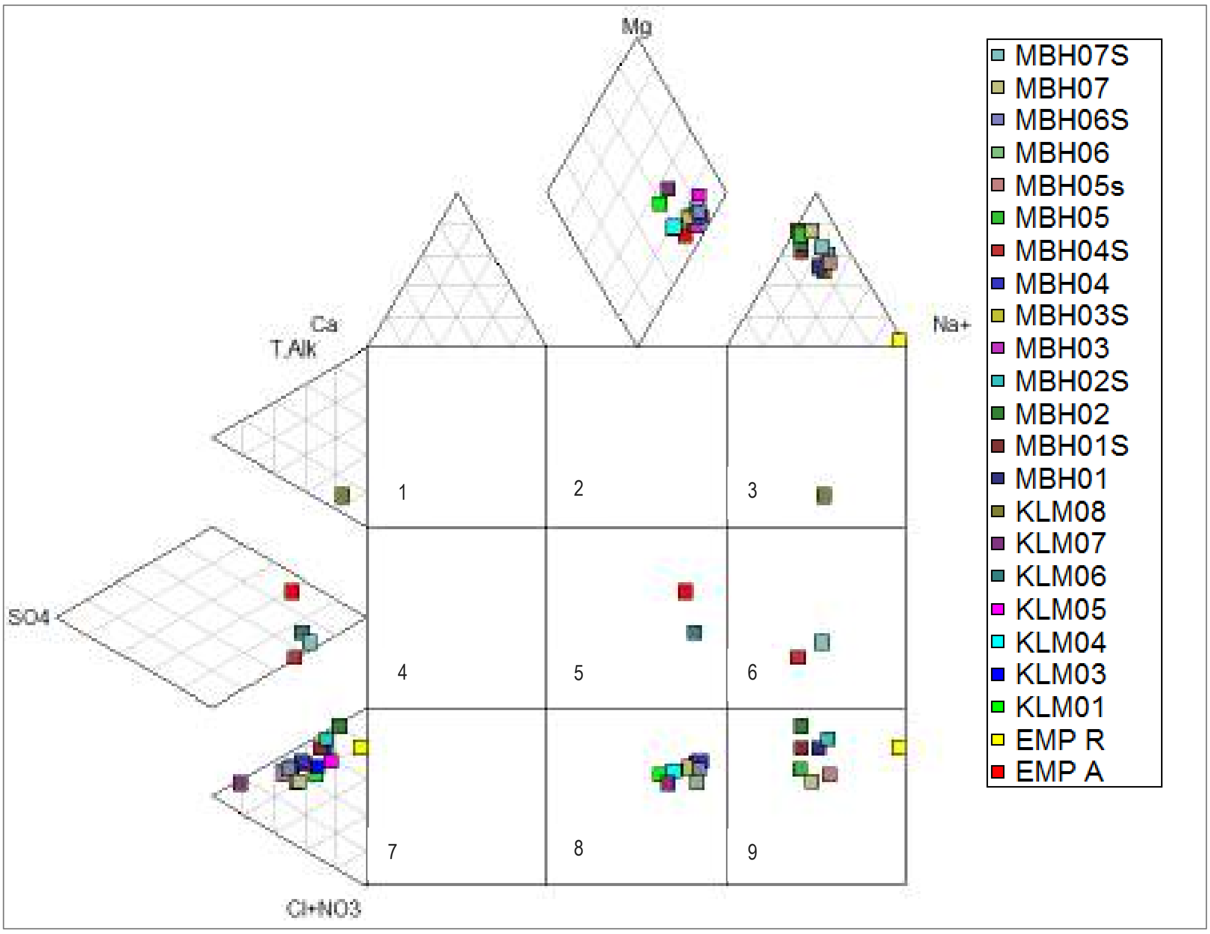

Figure 10: Expanded Durov diagram showing relative ratios in meq/l

The on-mine groundwater profiles are all dominated by Na and SO_4 and/or Cl and Mg as displayed by their Stiff diagrams in Figure 11 while; the background/upgradient boreholes (Abend Rhue, B01, B04, KLM08) are Na(Mg)-HCO_3 type groundwater. A clear distinction can therefore be made regarding chemistry between on-mine/downgradient/source monitoring boreholes and background/upgradient boreholes.

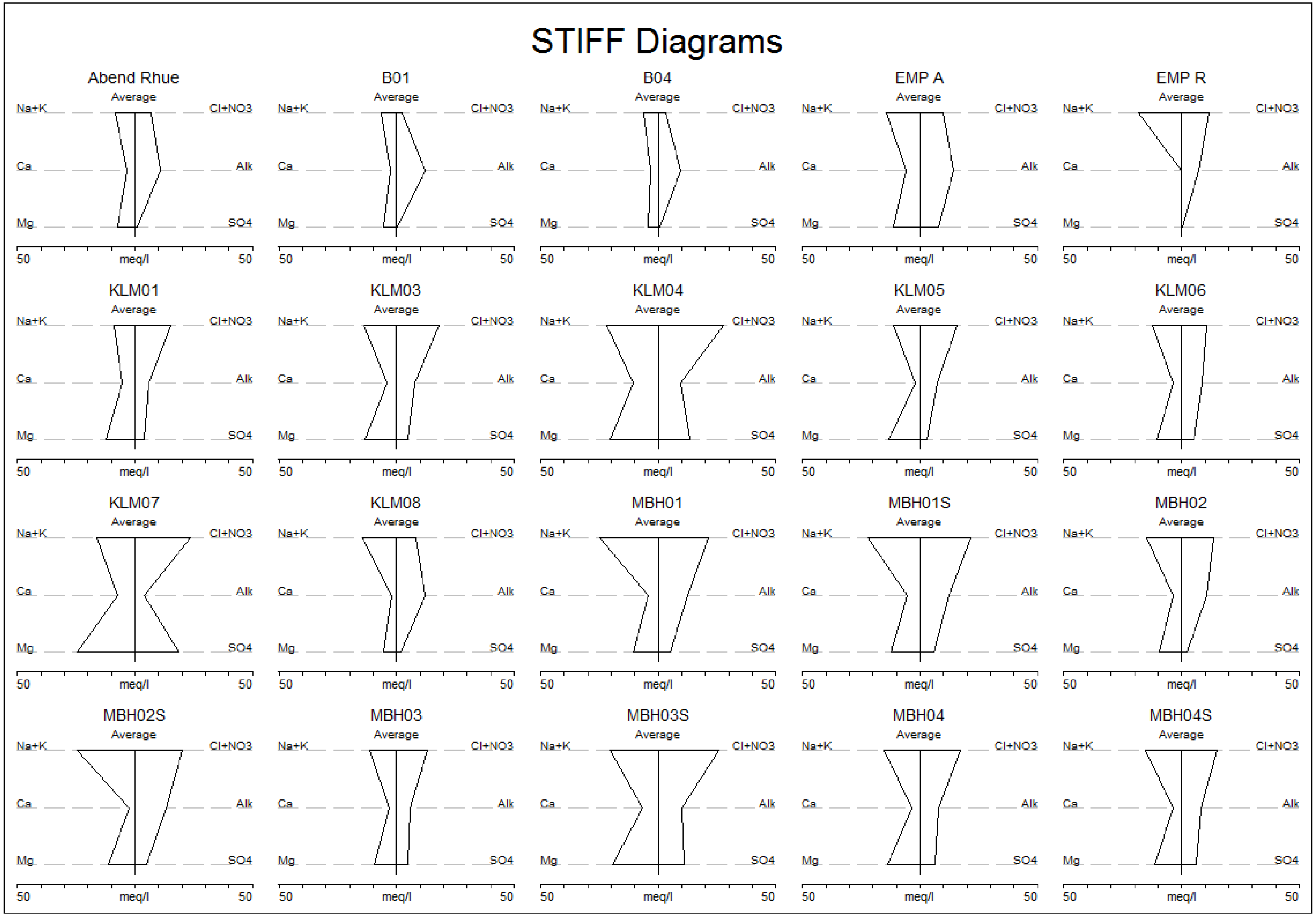

Figure 11: Stiff Diagrams for groundwater based on meq/l

6. AQUIFER CHARACTERISATION

6.1 Aquifer vulnerability

Groundwater plays an important role in supplying water to many regions of Southern Africa due to its low annual average precipitation of 460 mm, which is well below the world average of 860 mm. The quality of groundwater resources in South Africa has therefore received considerable focus and attention on the need for a proactive approach to protect these sources from contamination (Lynch *et. al*., 1994). Groundwater protection needs to be prioritised based upon the susceptibility of an aquifer towards pollution. This can be done in two ways, namely i) pollution risk assessments and ii) aquifer vulnerability. Pollution risk assessments consider the characteristics of a specific pollutant, including source and loading while aquifer vulnerability considers the characteristics of the aquifer itself or parts of the aquifer in terms of its sensitivity to being adversely affected by a contaminant should it be released.

The DRASTIC model concept developed for the USA (Aller *et. al*., 1987) is well suited for producing a groundwater vulnerability evaluation for South African aquifers. The DRASTIC evaluates the intrinsic vulnerability (*IV*) of an aquifer by considering factors including **D**epth to water table, natural **R**echarge rates, **A**quifer media, **S**oil media, **T**opographic aspect, **I**mpact of vadose zone media, and hydraulic **C**onductivity. Different ratings are assigned to each factor and then summed together with respective constant weights to obtain a numerical value to quantify the vulnerability:

$$\text{DRASTIC Index } (IV) = DrDw + RrRw + ArAw + SrSw + TrTw + IrIw + CrCw$$

Where D, R, A, S, T, I, and C are the parameters, r is the rating value, and w the constant weight assigned to each parameter (Lynch *et al*, 1994). The scores associated with the vulnerability of South African aquifers are shown in Table 7.

Table 7: South African National Groundwater Vulnerability Index to Pollution (Lynch et al, 1994)

Score	Vulnerability
50-87	Least susceptible
87 - 109	Moderate susceptible
109 - 226	Most susceptible

The concept of DRASTIC in vulnerability assessments is based on:

- A contaminant is introduced at the surface of the earth or just below it.
- A contaminant is flushed into the groundwater by precipitation.
- A contaminant has the mobility of water.
- The area evaluated is 0.4 km^2 or larger.

The weighting for each parameter is constant. The minimum value for the DRASTIC index that one can calculate (assuming all seven factors were used in the calculation) is therefore 24 with the maximum value being 226. The higher the DRASTIC index the greater the vulnerability and possibility of the aquifer to become polluted if a pollutant is introduced at the surface or just below it.

Table 8 summarizes the aquifer classification vulnerability scores for the aquifer/s in vicinity of the project area. The final DRASTIC score of 94 indicates that the fractured aquifer in the region has a medium susceptibility to pollution.

Table 8: DRASTIC vulnerability scores (fractured aquifer)

Factor	Range/Type	Weight	Rating	Total
D	5 - 15 m	5	7	35
R	0 - 5 mm	4	1	4
A	Fractured and weathered	3	3	18
S	Sandy loam	2	6	12
T	0-2%	1	10	10
I	Gneiss	5	3	15
C	-	3	-	-
DRASTIC SCORE = 94				

6.2 Aquifer classification

The Department of Water and Sanitation ("DWS"), has characterised South African aquifers based on the rock formations in which they occur together with its capacity to transmit water to boreholes drilled into specific formations. The water bearing properties of rock formations in South Africa can be classified into four classes defined as:

1. **Class A - Intergranular**
    - Aquifers associated either with loose and unconsolidated formations such as sands and gravels or with rock that has weathered to only partially consolidated material.
2. **Class B - Fractured**
    - Aquifers associated with hard and compact rock formations in which fractures, fissures and/or joints occur that are capable of both storing and transmitting water in useful quantities.
3. **Class C - Karst**
    - Aquifers associated with carbonate rocks such as limestone and dolomite in which groundwater is predominantly stored in and transmitted through cavities that can develop in these rocks.
4. **Class D - Intergranular and fractured**
    - Aquifers that represent a combination of Class A and B aquifer types. This is a common characteristic of South African aquifers. Substantial quantities of water are stored in

the intergranular voids of weathered rock but can only be tapped via fractures penetrated by boreholes drilled into the fractured aquifer.

Each of these classes is further subdivided into groups relating to the capacity of an aquifer to transmit water to boreholes, typically measured in l/s. The groups therefore represent various ranges of borehole yields.

According to the 1: 500 000 hydrogeological map (2127) for Messina (Figure 12) the study area is predominantly located in a d3 and d4 aquifer class region. The groundwater yield potential is classed as low to medium on the basis that most of the boreholes on record in vicinity of the study area produce between 0.5 and 5.0 l/s.

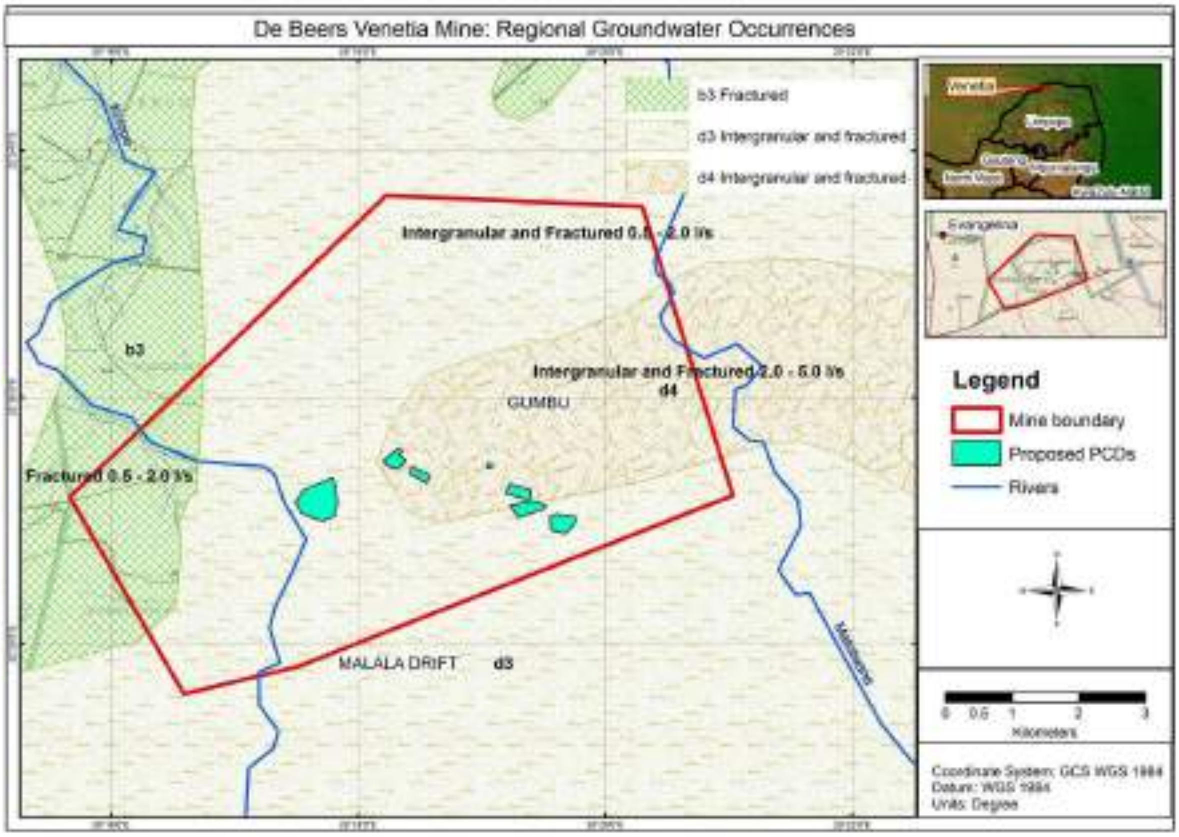

Figure 12: Regional groundwater occurrences within the study area

The different modes of undisturbed/natural groundwater occurrences associated with the study area include:

- Saturated unconsolidated alluvial deposits along some river systems.
- The fractured transitional zone occurring between weathered and unweathered crystalline and metamorphic bedrock.
- Fractures that occur along the contact zone between dykes / sills and the host rocks. The fractures developed due to the heating and cooling of the rocks involved in these intrusions.

According to the regional aquifer classification map of South Africa, the aquifer has been identified as a poor/non- aquifer[1] with poor groundwater quality (300 - 1000 mS/m, a medium vulnerability and a medium to high susceptibility towards contamination. Drill logs (Jones Wagener, 2020b) indicate that the study area is underlain by two types of aquifers. Based on the ‘undisturbed’ underlying hydrogeology of the project area, the aquifers can be classified as follows according to the Parsons (1995) classification system:

i) Weathered unconfined aquifer
    a. Poor/non- aquifer
ii) Fractured confined or semi-confined aquifer
    a. Poor/non- aquifer

6.3 Aquifer protection classification

In order to achieve the Groundwater Quality Management Index a point scoring system as presented in tables 9 and 10 was used for the naturally occurring undisturbed aquifers in the study area.

The occurring aquifer, in terms of the above definitions, is classified as a non-aquifer system. 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 medium. The level of groundwater protection based on the Groundwater Quality Management Classification is shown in Table 11.

Table 9: Ratings for the Aquifer System Management and Second Variable Classifications

Aquifer System Management Classification		
Class	**Points**	**Study Area**
Sole Source Aquifer System	6	
Major Aquifer System	4	
Minor Aquifer System	2	
Non-Aquifer System	0	1
Special Aquifer System	0-6	
Second Variable Classification (fractured)		
High	3	
Medium	2	2
Low	1	

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[1] These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities or water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and need to be considered when assessing the risk associated with persistent pollutants. Insignificantly yielding aquifer (< 1.0 L/s) of good quality water or moderately yielding aquifer (1.0- 5.0 L/s) of poor quality or aquifer which will never be utilised for water supply and which will not contaminate other aquifers.

Table 10: Ratings for the Groundwater Quality Management (GQM) Classification System

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

GQM Index = Aquifer System Management x Aquifer Vulnerability:

2 X 1 = 2

Table 11: GQM index for the study area

GQM Index	Level of Protection	Study Area
<1	Limited	
1-3	**Low level**	**2**
3-6	Medium level	
6-10	High level	
>10	Strictly non-degradation	

The ratings for the Aquifer System Management Classification and Aquifer Vulnerability Classification yield a GQM index of 2 for the study area, indicating that **low level groundwater protection** is required to adhere to DWS's water quality objectives. However, reasonable and sound groundwater protection measures are nevertheless recommended to ensure that no cumulative pollution affects the aquifer, during short- and long-term. DWS's water quality management objectives are to protect human health and the environment. Therefore, the significance of this aquifer classification is that if any potential risk exists, measures must be taken to limit the risk to the environment, which in this case is the protection of the underlying aquifer.

7. GROUNDWATER MODELLING

7.1 Software model choice

No new groundwater model was developed for the Venetia SWMP. The investigation relied heavily on the model developed by Jones and Wagener (2020b). Their model which simulated predicted impacts of the main sources of potential pollution at Venetia Mine was developed using the 3D Feflow version 7 software code.

7.2 Model setup and boundary

Initially, an aquifer delineation will indicate the lateral extent of the aquifer(s) in the area. An aquifer can be delineated by means of the following:

i. Mapping structures such as intrusive dykes, progressive sills or displacement faults that act as groundwater flow barriers to form aquifer compartments, and
ii. Using high or low topographical areas over which flow is not possible.

Method (i) is probably the most accurate for delineating aquifer boundaries but intricate detail is needed to map the structures of an area and these are seldom available. Therefore, the modelling area was selected based on method (ii) – the use of natural groundwater barriers and flow boundaries, such as topographical highs and drainage features. The rationale for using topographical highs as groundwater boundaries is the fact that a good Bayesian correlation exist between hydraulic heads and topography for the study area. It can therefore be assumed with confidence that groundwater flow mimics surface water flow with topographical highs and lows functioning as groundwater barriers or discharge areas. Due thereto, Jones and Wagener (2020b) used the surrounding watersheds as no flow or Neuman (or specified flux) boundary conditions as shown in Figure 13. It can also be seen from this Figure that constant head or Dirichlet boundaries, which are constrained to only remove water from the groundwater model were assigned to the surface water systems. The open cast pit was also assigned as a constant head or Dirichlet boundary.

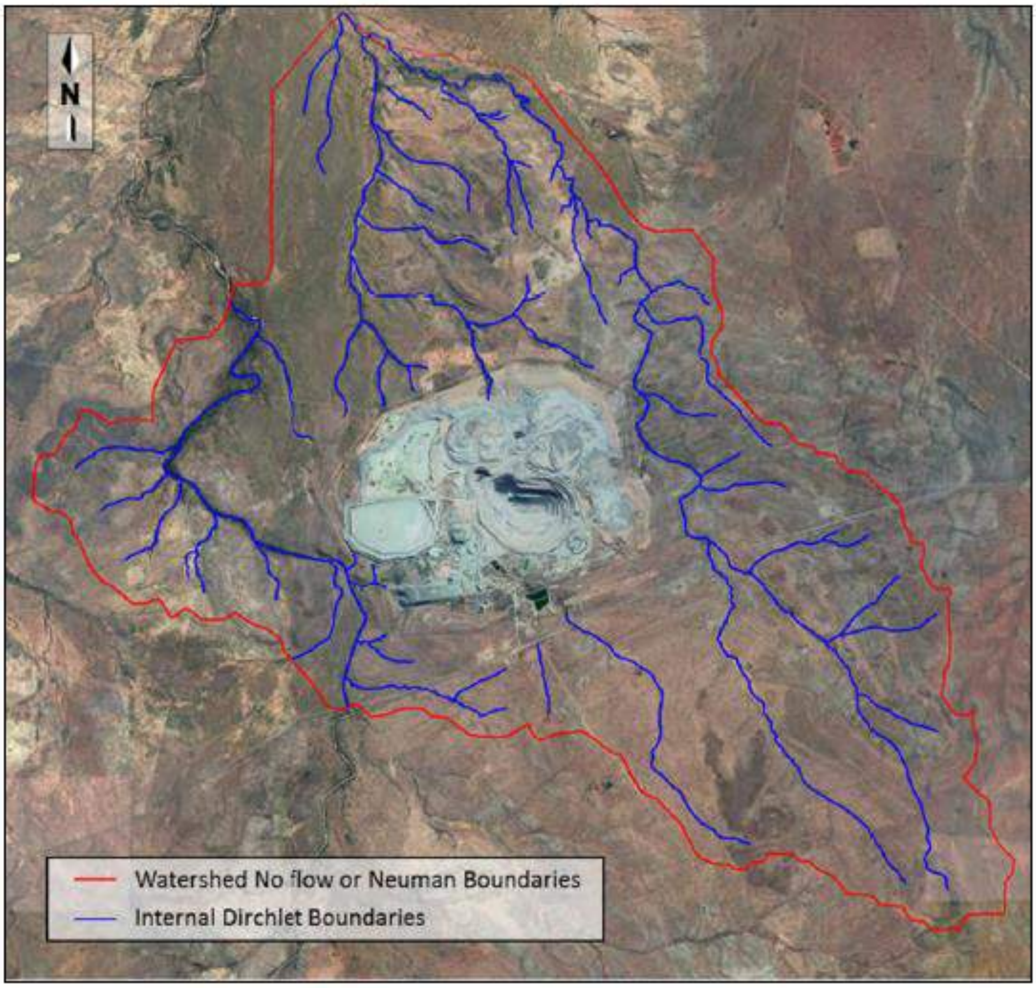

Figure 13: Model Domain and Model Boundary Conditions (from Jones and Wagener, 2020)

7.3 Groundwater elevation and gradients

The groundwater elevations or hydraulic heads were calculated by subtracting static water levels from the topography.

The hydraulic heads were used to construct a regional hydraulic head contour map for the aquifer from which flow directions were assessed. Where data points lacked, an interpolation technique known as Kriging was used to interpolate data points at locations with respect to data points in close relation to it (mathematically related to regression analysis). The contour map is shown in Figure 14. Based on the contours and flow vectors, the first indication of groundwater flow is relatively similar to surface topography with flow being largely from south to north and west towards the Kolope River.

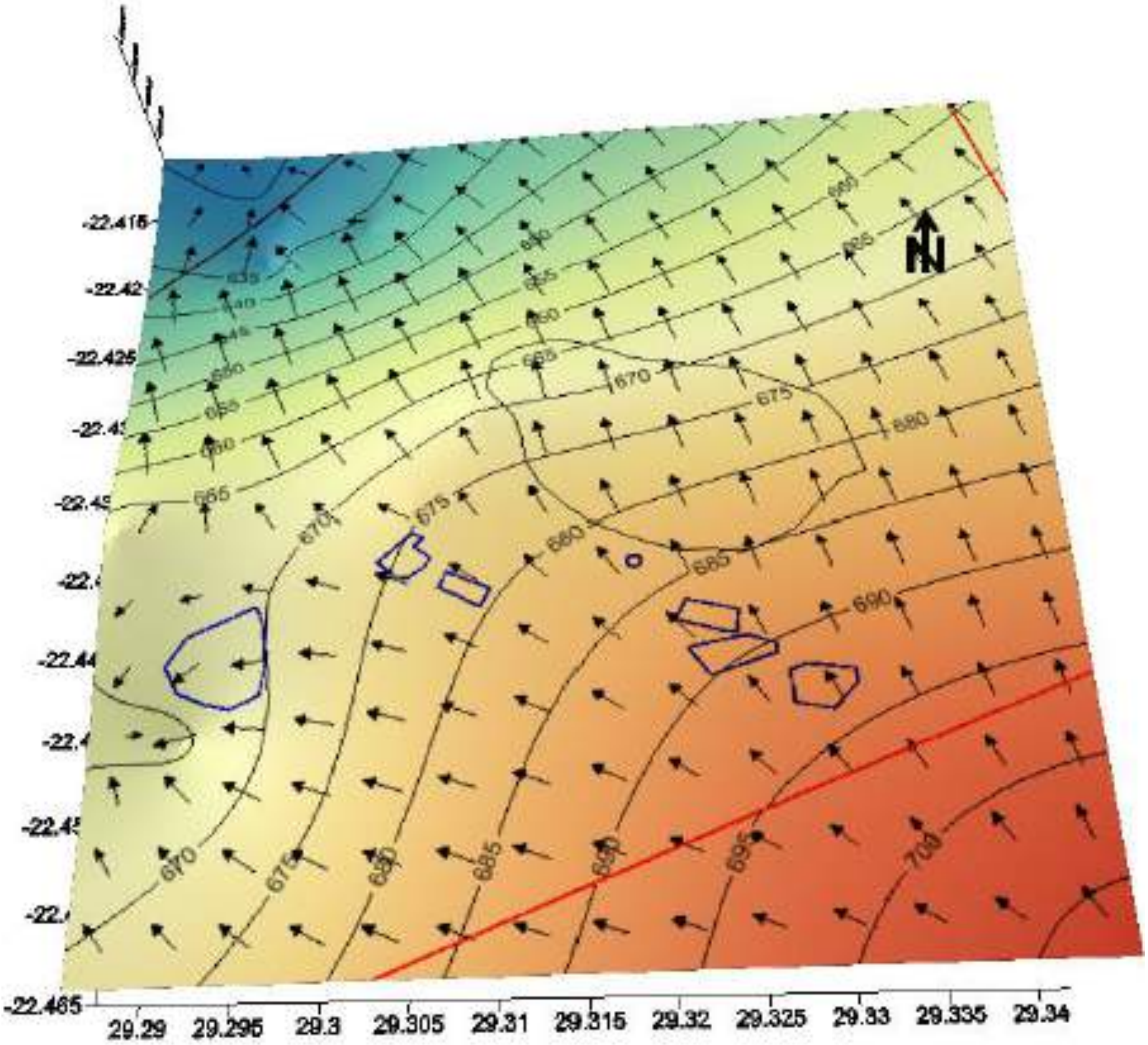

Figure 14: Interpolated hydraulic head contour and vector map

7.4 Geometric structure of the model

Previous investigations have indicated that the dominant groundwater flow occurs within the upper 75 m at Venetia. Jones and Wagener (2020b) therefore constructed their model to consist of two layers representing the shallow weathered and deeper fractured aquifers. The upper layer was defined by the surface topography and the base of the weathering determined from geological logs. The lower fractured aquifer was defined from the base of the weathering to a depth of 75 m below surface.

Their mesh consisted of 1 109 674 mesh elements and 834 975 mesh nodes. Mesh quality was acceptable since obtuse angles greater than 90° totalled 4.7% and Delaunay-violating triangles totalled 0.5%.

7.5 Groundwater sources and sinks

Groundwater sources are predominantly from rainfall recharge at an average of between 0.5 to 1% of MAP or between 2 and 4 mm/a. For Venetia Mine with a total of 42.67 km_2 in size (mine boundary), that equates to between 0.085 Mm^3/a to 0.71 Mm^3/a.

The main groundwater sources in the area of interest are:

- direct rainfall recharge of the shallow weathered aquifer with vertical leakage to the fractured aquifer;
- seepage from mineral waste deposits and
- regional groundwater inflow.

Groundwater on a local scale will tend to seep towards the opencast pit for as long as the mining operations are active and pit dewatering occurs and, therefore, is the main sink within the study area. Groundwater inflows into the pit are estimated at 880 m^3/day (Jones and Wagener, 2020a). Limited groundwater contribution to baseflow is expected to occur.

7.6 Conceptual model

The geology in any geohydrological setting forms the basis for groundwater flow and aquifer development. The geohydrology in the study area is no exception and will conform thereto.

A conceptual model was developed based on the review of available data and the information gathered during the field investigations. The conceptual model is a simplified representation of the geohydrological conditions and processes taking place in the study area and forms the cornerstone for understanding and describing the geohydrological environment and its behaviour. It describes the simplifying assumptions necessary to represent the real-world system in a numerical model.

7.6.1 Geohydrology

Three distinct undisturbed saturated groundwater regions are recognized underlying the study area, and include:

i. Weathered aquifer
ii. Fractured aquifer

A good correlation of 0.99 was achieved between static hydraulic heads and surface elevation and it can therefore be assumed with relative accuracy that groundwater flow directions largely correlate with surface flow. Groundwater flow patterns based on hydraulic head contours also verified this with flows being largely directed from a higher hydraulic head to a lower hydraulic head perpendicular to head contours, following a similar pattern and gradients compared to surface flows.

The groundwater levels within the weathered and fractured aquifer are relatively shallow being of semi-confined to confined nature and also influenced by a cone of depression resulting from dewatering. Despite mining for more than 30 years, this cone is confined to the immediate vicinity of the pit, mainly as a result of the low hydraulic conductivity of the host rock. Previous studies have shown that a 1 km radius of influence exist (based on worst case scenarios), but still does not extend beyond the mine boundary.

The history of mining has resulted in an altered surface topography with various mine residue deposits and affected water storage facilities on surface. Recharge from rainfall percolates through the dumps and the unsaturated zone into the weathered aquifer resulting in mineralisation of salts and nutrients. This study revealed that TDS mostly contributed by the salts Na, Cl, SO_4, trace metals B and Mo and inorganic nitrogen (as NH_4 and NO_3) are the main contaminants of concern. There are also various controlled and uncontrolled seepage points at Venetia Mine. The uncontrolled seepages flow directly into the surface water environment whereas the controlled seepages flow into affected water storage facilities.

The average depth to groundwater is in the order of 8 m with depths up to 31 m immediately adjacent to the pit. This unsaturation zone provides some attenuation capacity for the vertical migration of contaminants. Once the vertical migration of dissolved contaminants reaches the groundwater, the dominant migration pathway alters from a vertical to a lateral direction. Flow directions mimic the topography with possible dissolved contaminants migrating towards the surface water systems to the west and north of the dumps. Some migration from the WRD is also expected towards the pit as a result of the influence from the dewatering cone.

Due to the low permeability of the host rock, contaminant migration is a very slow process. Jones and Wagener (2020) assigned natural recharge rates of 8.22×10^{-6} m/d to the base of the PCDs and very limited plume migration from the PCDs occurred within their model. Although some seepage is expected from unlined water storage facilities, the migration thereof would be limited and local (within dam footprint) due to the low aquifer permeability, flat natural aquifer gradients and the low recharge of 3 mm/a.

7.6.2 Best practice for reducing the groundwater pollution risks from PCDs

The DWS has developed a Best Practice Guideline (BPG) for PCDs in line with international principles and approaches towards sustainability (DWAF, 2007). Relevant (to groundwater) guidelines are discussed in this section.

The purpose of PCDs for the mine and in the water management circuit is to:

- Minimise the impact of polluted water on the water resource;
- Minimise the area that is polluted as far as possible, by separating out clean and dirty catchments, and
- Capture and retain the dirty water contribution to the PCDs that cannot be discharged to the water resource, due to water quality constraints, and manage this dirty water through recycling, reuse, evaporation and/or treatment and authorised discharge.

The design, operation and closure of PCDs are important aspects in the successful operation of Venetia, given the inherent safety and environmental risks posed by structural failure, spillage or overtopping of these facilities. The design of the PCDs should meet the following broad requirements:

- PCDs should be appropriately sized to meet the requirement of Government Notice No. 704 in terms of spillage frequency.
- PCDs should adhere to the relevant dam safety criteria, based on the safety risk classification of the dam. This includes appropriate design and assessment of:
    - Geotechnical conditions at the dam site;
    - Slope stability;
    - Seepage analysis; and
    - Construction requirement, including the material selection for the dam wall.
- PCDs should safely accommodate the appropriate design floods, based on the safety risk classification of the dam.
- PCDs should be provided with a suitable liner system to limit/prevent contaminated seepage from entering the local groundwater system and/or the surface water catchments
- Appropriate water flow and water quality monitoring measures must be designed, implemented and audited in all PCDs so as to ensure effective water balance systems and the management of water on a mine.

Table 12 provides details on the general aspects that should be considered in the design, operation and closure of PCDs.

Table 12: General considerations in the design, operation and closure of PCDs

Aspect	Description	General considerations
Pollution prevention	Deterioration of water quality must be prevented wherever possible and minimised where complete prevention is not possible	• Identify and apply opportunities for the prevention of water pollution. • Implement the necessary management measures to minimise impacts in the case where pollution prevention is not possible, e.g. management of the spillage frequency from PCDs. • Ensure that the water use practices on a mine do not result in unnecessary water quality deterioration, e.g. separate clean and dirty storm water wherever possible. • Minimise contact between water and major pollution sources, where possible.
Conservation of water resources	Losses of water and consumptive use of water must be minimised	• Design PCDs to minimise the evaporative losses by limiting the exposed surface area. • Ensure that seepage and/or overflow losses from storage facilities are minimised, e.g. facilities that can impact on the water resource through seepage may have to be lined, and PCDs should be designed with sufficient capacity and operated at a level to allow it to accommodate storm events and hence manage the spillage frequency.

		• Use raw water only for processes requiring such good water quality and additional water requirements that cannot be supplied within the water network. • Assess the technology being used for the design, operations and closure of PCDs including whether alternative technologies could be applied (particularly important for new mines) or whether the technology could be modified or improved.
Sustainability	Water management practices and designs should be sustainable over the life cycle of the PCD	• Develop water and salt balance projections for future mining scenarios, including mine closure and post closure. • The design, operation and closure of PCDs should incorporate consideration of the risk of changes in the mining and plant operations, and hence the mine water balance, through the life cycle of the mine.

7.6.3 Identifying groundwater related impacts

Typically, the data gathered from the first phases of the geohydrological assessment (hydrocensus, geophysics, aquifer testing etc.) are used to identify certain risks associated with PCDs. Such risks include (refer to Section 8 for the risk assessment and ratings):

- The impact on downstream water users.
- Impacts on sensitive or protected areas.
- Impacts on any open-cast or underground workings, shafts or occupied premises.
- Geological structures.
- Effects of seepage.
- Groundwater quality impacts.

7.7 Numerical model

No new model was developed for the current geohydrological study but relied heavily on the model developed by Jones and Wagener (2020b) for Venetia Mine

7.8 Results of the model

7.8.1 Pre-facility

As stated previously, Venetia Mine has been in operation since 1992 mining a diamond bearing kimberlite cluster (K1, K2 and K3) mainly with opencast methods. The open pit will be mined to a depth of approximately 450 m, which is envisaged up to 2022/2023 where after mining will shift towards underground.

The pre-facility flow scenario can be reasonably represented by the steady state flow model as displayed in Figure 15 below (from Jones and Wagener, 2020b). Also refer to Figure 14 for interpolated hydraulic heads using averaged water levels.

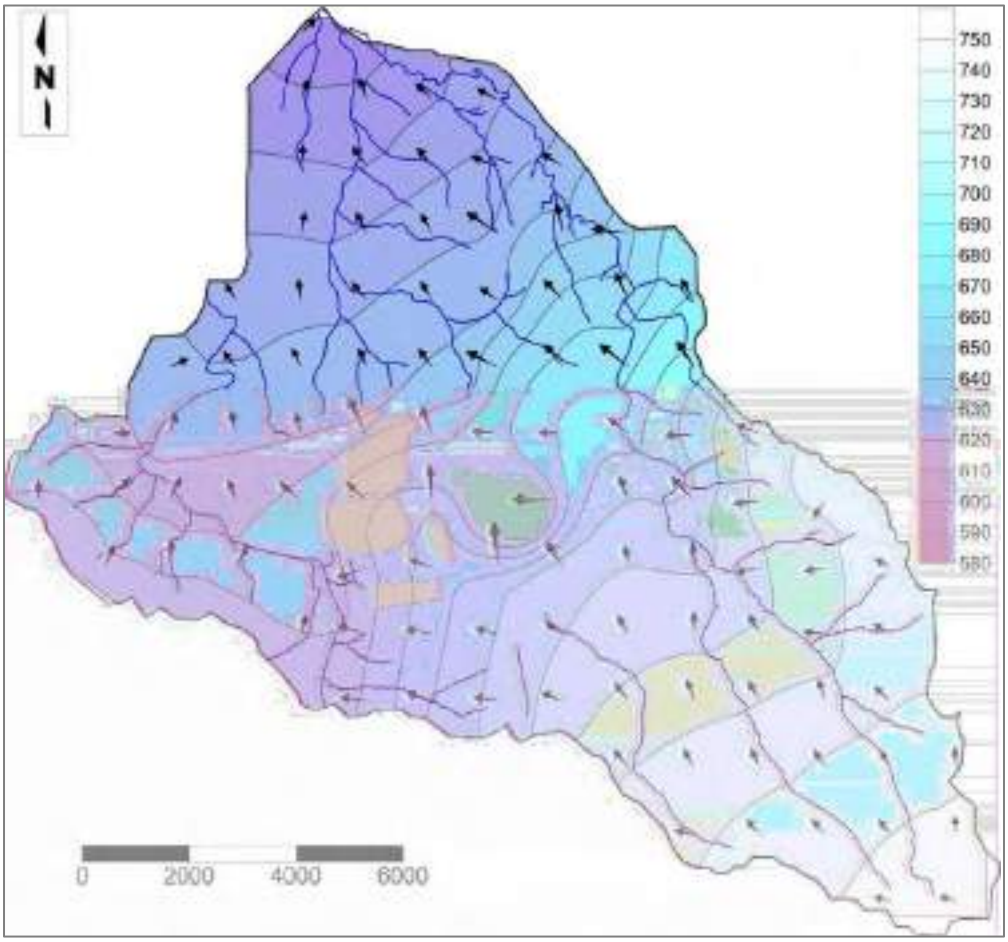

Figure 15: Simulated steady state groundwater gradients (from Jones and Wagener, 2020)

7.8.2 During facility (operation of PCDs)

Jones and Wagener (2020) developed a transient state contaminant transport model using steady state heads as initial conditions for the main sources of pollution at Venetia, including the FRDs, CRD, WRDs and current affected water containment facilities and the planned PCDs. For the purpose of this study only the contaminant transport results of the planned PCDs will be discussed further.

Jones and Wagener determined source concentrations in the PCDs from the water quality datasets for the current affected storage facilities at Venetia. They used averaged concentration and determined a source concentration of 4000 mg TDS/l.

The leakage rates were combined with the source concentration to produce a mass flux into the groundwater regime during the contaminant transport simulations. However, according to Jones and Wagener (2020b) there was limited simulated contamination migration from the potential contaminant sources in contrast to the observed groundwater concentrations for the current status at the mine. They decided to rather use a constant concentration as the source term to remove any potential errors associated with the calculated leakage rates. In this instance the source concentration is placed directly in the groundwater regime which is a very conservative approach. Nonetheless there was still limited simulated contaminant migration which is attributed to the relatively low permeability and low recharge and flat groundwater gradients of <0.01.

Jones and Wagener (2020b) reported that the contaminant transport simulation from the PCDs is observed in the weathered aquifer for all of the PCDs whereas only PCD1 and PCD2 have simulated plumes in the fractured aquifer by 2045. For the LOM plumes it is evident that enough residence time has allowed contaminated groundwater to have migrated into the fractured aquifer for most of the sources. However, they concluded that the plumes from the PCDs do not migrate substantially and even after 120 years, will remain small and localised within the mine boundary. No sensitive groundwater receptors will be impacted during the operational phase.

7.8.3 Decommissioning and closure

Post closure, the mine will no longer remove water from underground and dewatering will cease. Jones and Wagener (2020b) simulated the planned PCDs for a total of 120 years, up until 2145 and concluded that because of the very low hydraulic conductivity (permeability), plume movements would not have migrated substantially and will remain within the mine boundary.

8. GEOHYDROLOGICAL IMPACTS

The groundwater impact assessment focussed on the identification of the major groundwater related impacts that the activities, processes and actions may have on the receiving groundwater environment. The assessment as contained within this report aimed to achieve the following:

- To provide a detailed assessment of the potentially affected groundwater environment.
- To assess impacts on the study area in terms of groundwater criteria.
- To identify and recommend appropriate mitigation measures for potentially significant groundwater related impacts.

An environmental risk of any aspect is determined through a combination of parameters associated with the impact. Each parameter connects the physical characteristics of an impact to a quantifiable value to rate the environmental risk.

The methodology that was employed during the impact assessment follows international best practice. The impact assessment considered the potential impacts of the Mine’s activities on groundwater resources, specifically groundwater quality and quantity impacts that could be expected from the activities. It is based on defining and understanding the three basic components of the risk, i.e. the source of the risk, the pathway and the target that experiences the risk (receptor).

After identification of the impacts, the nature and scale of each impact is quantified. The impact prediction provides a basis from which the significance of each impact is determined. Appropriate mitigation measures are subsequently developed with the impact and scale of impact as reference.

Table 13 and Table 14 indicate the methodology that was used to assess the Probability and Magnitude of the impact, while Table 15 provides the Risk Matrix that was used to plot the Probability against the Magnitude to determine the Severity of the impact.

The discussion of each impact begins with the background; a description of the baseline conditions and the Mine's activities. This is followed by an assessment of the significance of the impacts pre-mitigation, the presentation of recommended mitigation measures, and an assessment of the residual impact that would remain after the implementation of the mitigation measures. Because mining is not currently active, except for the processing and associated support facilities, and no new constructing activities will occur, no impact assessment was included for the construction phase.

The impact assessment is discussed for each of the following phases:

- Operational phase
- Operational Phase
- Decommissioning and Closure Phases

The calibrated groundwater flow and contaminant (mass) transport models were used to address the objectives of the hydrogeological investigation, including an assessment of the potential groundwater impacts from the proposed PCDs. All activities and potential contamination facilities were considered in an integrated manner, and where known, future facilities and activities were included. Jones and Wagener (2020b) stated that other than continuous monitoring and the lining of PCDs, no additional mitigation measures were considered or simulated in their model. According to them, the motivation for this was that their field results and simulated plumes indicated minimal groundwater plume migration as a result of the tight country rock formations with their very low permeabilities. The greatest contribution to downstream contamination is believed to be as a result of controlled and uncontrolled seepages and surface water flow from the mine.

Table 13: Determining the Probability of impact

FREQUENCY OF ASPECT / UNWANTED EVENT	SCORE	AVAILABILITY OF PATHWAY FROM THE SOURCE TO THE RECEPTOR	SCORE	AVAILABILITY OF RECEPTOR	SCORE
Rare/Never known to have happened, but may happen	1	A pathway to allow for the impact to occur is never available	1	The receptor is never available	1
Unlikely/Known to happen in industry	2	A pathway to allow for the impact to occur is almost never available	2	The receptor is almost never available	2
Possible/< once a year	3	A pathway to allow for the impact to occur is sometimes available	3	The receptor is sometimes available	3
Likely/Once per year to up to once per month	4	A pathway to allow for the impact to occur is almost always available	4	The receptor is almost always available	4
Almost certain/Once a month - Continuous	5	A pathway to allow for the impact to occur is always available	5	The receptor is always available	5

Table 14: Determining the Magnitude of impact

SOURCE								RECEPTOR			
Duration of impact	Score	Extent	Score	Volume / Quantity / Intensity	Score	Toxicity / Destruction Effect	Score	Reversibility	Score	Sensitivity of environmental component	Score
Lasting days to a month	1	Effect limited to the site. (metres);	1	Very small quantities / volumes / intensity (e.g. < 50L or < 1Ha)	1	Non-toxic (e.g. water) / Very low potential to create damage or destruction to the environment	1	Bio-physical and/or social functions and/or processes will remain unaltered.	1	Current environmental component(s) are largely disturbed from the natural state. Receptor of low significance / sensitivity	1
Lasting 1 month to 1 year	2	Effect limited to the activity and its immediate	2	Small quantities / volumes / intensity (e.g.	2	Slightly toxic / Harmful (e.g. diluted brine) / Low potential to create	2	Bio-physical and/or social functions and/or processes might be negligibly altered or enhanced / Still reversible	2	Current environmental component(s) are moderately disturbed from the natural state.	2

SOURCE								**RECEPTOR**			
Duration of impact	Score	Extent	Score	Volume / Quantity / Intensity	Score	Toxicity / Destruction Effect	Score	Reversibility	Score	Sensitivity of environmental component	Score
		surroundings. (tens of metres)		50L to 210L or 1Ha to 5Ha)		damage or destruction to the environment				No environmentally sensitive components.	
Lasting 1 – 5 years	3	Impacts on extended area beyond site boundary (hundreds of metres)	3	Moderate quantities / volumes / intensity (e.g. > 210 L < 5000L or 5 – 8Ha)	3	Moderately toxic (e.g. slimes) Potential to create damage or destruction to the environment	3	Bio-physical and/or social functions and/or processes might be notably altered or enhanced / Partially reversible	3	Current environmental component(s) are a mix of disturbed and undisturbed areas. Area with some environmental sensitivity (scarce / valuable environment etc.).	3
Lasting 5 years to Life of Organisation	4	Impact on local scale / adjacent sites (km's)	4	Very large quantities / volumes / intensity (e.g. 5000 L – 10 000L or 8Ha–12Ha)	4	Toxic (e.g. diesel & Sodium Hydroxide)	4	Bio-physical and/or social functions and/or processes might be considerably altered or enhanced / potentially irreversible	4	Current environmental component(s) are in a natural state. Environmentally sensitive environment / receptor (endangered species / habitats etc.).	4
Beyond life of Organisation / Permanent impacts	5	Extends widely (nationally or globally)	5	Very large quantities / volumes / intensity (e.g. >	5	Highly toxic (e.g. arsenic or TCE)	5	Bio-physical and/or social functions and/or processes might be severely/substantially altered or enhanced / Irreversible	5	Current environmental component(s) are in a pristine natural state. Highly Sensitive area (endangered species,	5

SOURCE								**RECEPTOR**			
Duration of impact	Score	Extent	Score	Volume / Quantity / Intensity	Score	Toxicity / Destruction Effect	Score	Reversibility	Score	Sensitivity of environmental component	Score
				10 000 L or > 12Ha)						protected habitats etc.)	

Table 15: Determining the severity of impact

ENVIRONMENTAL IMPACT RATING / PRIORITY					
PROBABILITY	**MAGNITUDE**				
	1 Minor	**2 Low**	**3 Medium**	**4 High**	**5 Major**
5 Almost Certain	Low	Medium	High	High	High
4 Likely	Low	Medium	High	High	High
3 Possible	Low	Medium	Medium	High	High
2 Unlikely	Low	Low	Medium	Medium	High
1 Rare	Low	Low	Low	Medium	Medium

8.1 Construction phase

This phase will be initiated when the construction of infrastructure associated with the PCDs commences.

8.1.1 Impacts on groundwater quantity

Site clearing and removal of topsoil may lead to ponding of surface water in the cleared areas during the wet season and could potentially lead to increased infiltration to aquifers on generally flat areas and increased run-off (reduced recharge) on steeper areas. The construction of infrastructure will also cause a very small reduction in recharge to the aquifer due to the compaction of the surface area. This impact is countered by the fact that vegetation clearing, and soil compaction may result in increased run-off and slight decreases in recharge. Runoff water, which would otherwise have contributed to the catchment yield, is expected to be minimal given the low annual rainfall in the area and short time period associated with the construction phase.

Due to its localised nature, no measurable reduction or increase of groundwater in storage is expected during the construction phase and therefore, no significant impacts are expected on groundwater quantity during the construction activities.

8.1.2 Impacts on groundwater quality

The only foreseeable potential impact on the ambient groundwater quality during the construction phase is due to accidental hydrocarbon or other chemical spillages from the construction vehicles. Such spillages are localised, quickly reversible if properly contained and/or excavated and are unlikely to occur. The severity of groundwater being negatively impacted by accidental spillages is rated as low during the short construction phase before and after mitigation.

The impact assessment and final risk rating for impacts on groundwater quality during the construction phase can be viewed in Table 16 and the recommended management and mitigation measures in Table 17.

Table 16: Impact assessment on groundwater quality during the construction phase

No.	Aspect affected	Activity	Potential Impact	Reversibility	Irreplaceable loss	Phase	Size and scale of disturbance	Significance pre-mitigation			Mitigation Type	Significance post-mitigation		
								Probability	Magnitude	Significance		Probability	Magnitude	Significance
1	Groundwater quality	Construction of PCDs	The impacts on groundwater quality are primarily related to the management of materials, wastes and spills and unauthorised disposal of affected/contaminated water. Contamination of groundwater may also arise due to incorrect handling and disposal of waste materials. This risk is considered low. Due to the short exposure and small scale of these potential spills, the impacts will be negligible during the construction phase. Except for lesser oil and diesel spills, there are no activities expected that could impact on regional groundwater quality. This phase should thus cause very little additional impacts. It is expected that the current status quo will be maintained. A very limited groundwater quality impact is expected during the construction phase, generally because of the small surface areas involved and the short duration thereof.	Reversible	Low Degree	Construction	PCD footprint	2	1	Low	Prevent or contain groundwater contamination	1	1	Low

Table 17: Groundwater related mitigation and management measures for the proposed activity – construction phases

No.	Aspect affected	Activity	Potential Impact	Phase	Mitigation type	Impact management actions / Mitigation measures	Impact management outcome	Standard to be Achieved	Time period for implementation
1	Groundwater quality	Construction of PCDs	Lesser oil and diesel spills	Construction	Avoid, modify, remedy, control or stop	Management measures: • Develop and maintain a Standard Operating Procedure to contain and remediate any accidental hydrocarbon or other chemical spillages. Action plans: • Contain spillage, excavate and dispose of soil if required. Utilisation of spill kits and/or excavation of affected soil with subsequent disposal at an accredited disposal site is crucial. • Continue with the status quo groundwater monitoring programme. • Do not discharge affected water into the environment that does not comply with regulatory standards, unless authorised to do so. • All vehicles must be properly maintained and serviced so that no oil leaks occur on site.	Prevent or contain groundwater contamination	N/A	N/A

8.1.3 Impacts on surface water

No direct impacts are expected on surface water resources during the construction of the PCDs. Indirect impacts could occur as a result of discharge of substandard water that does not comply to release standards or from poor housekeeping. Effective stormwater management, especially clean and dirty water separation, is imperative to reduce the risk of affected water flowing into the receiving surface water environment.

The probability of impacts on surface water during the operational phase is unlikely due to the ephemeral nature of the receiving surface waters and expectation that little or no baseflow occurs.

8.1.4 Groundwater management

The main management objectives and principles during the construction phase is to develop and maintain a Standard Operating Procedure (“SOP”) to contain and remediate any accidental hydrocarbon or other chemical spillages. Action plans include:

- Contain spillage, excavate and dispose of soil if required. Utilisation of spill kits and/or excavation of affected soil with subsequent disposal at an accredited disposal site is vital.

8.2 Operational phase

The utilisation of water and waste management measures and PCDs must inadvertently have some form of impact on groundwater, although the primary purpose of the facilities is to minimize or contain water contamination. PCDs will be constructed should comply with the relevant DWS requirements.

The results of the investigation were used to identify the potential groundwater impacts for the proposed PCDs. Such impacts include (quality and quantity):

- The impact on downstream water users;
- Impacts on sensitive or protected areas;
- Impacts on any open-cast or underground workings, shafts or occupied premises;
- Geological structures; and/or
- Effects of seepage.

8.2.1 Impacts on groundwater quantity

Affected water containment facilities that are unlined can result in mounding of the water levels due to artificial and increased recharge to the aquifer. Elevated water elevations result in an increase in flow gradients which means higher rates of groundwater flow and mass transport. The dams are, however, expected to be lined and a decrease in status quo recharge from rainfall is expected. Under natural conditions, recharge into the aquifer/s at Venetia is very low and the impacts on groundwater quantity is therefore expected to be insignificant.

8.2.2 Impacts on groundwater quality

Elevated water elevations result in an increase in flow gradients which means higher rates of groundwater flow and mass transport. Given that the areas where the PCDs will be constructed are already affected, will be lined and small footprints, the facilities are not expected to contribute to the current extent of contamination. The PCDs themselves are seen as remedial measures. The impact on the receiving surface and groundwater environment is rated as low.

No potential fatal flaws in terms of groundwater quality impacts were identified during this stage.

The impact assessment and final risk rating for impacts on groundwater quality during the operational phase can be viewed in Table 18 and the recommended management and mitigation measures in Table 19.

8.2.3 Impacts on surface water

As stated previously, the facilities will be lined, and seepage is therefore not expected to occur. The only possible surface water impact to occur will be due to spills and overflows. It is therefore imperative that the proposed PCDs should be designed to have sufficient capacity to contain the volume of water expected during the 1:50 year flood event, as required by GNR 704 and to maintain sufficient freeboard.

8.2.4 Groundwater management

Regular routine inspections of PCDs should be carried out by Venetia or a suitably qualified person appointed by Venetia Mine.
It is recommended that the inspection route to be followed include the following:

- The full length of the wall crest and toe;
- Observation of upstream and downstream slopes;
- Spillway crest and downstream spillway channel;
- Pumps stations and pipelines;
- Control and instrumentation;
- Outlet works;
- Functioning of the liner system;
- Functioning of sediment control systems; and
- The area downstream of the dam wall.

The areas of particular importance are the PCD freeboard, the water quality within the PCDs and the maintenance of monitoring data.

Table 18: Impact assessment on groundwater quality during the operational phase

No.	Aspect affected	Activity	Potential Impact	Reversibility	Irreplaceable loss	Phase	Size and scale of disturbance	Significance pre-mitigation			Mitigation Type	Significance post-mitigation		
								Probability	Magnitude	Significance		Probability	Magnitude	Significance
1	Groundwater quality	Operation of PCDs	Unlined dams can result in mounding of the water levels due to artificial and increased recharge to the aquifer. Elevated water elevations result in an increase in flow gradients which means higher rates of groundwater flow and mass transport. Due to the PCDs being lined, their localities and small footprints, these facilities are not expected to contribute to the current extent of contamination observed. The PCDs themselves are seen as remedial measures.	Reversible	Low Degree	Operation	PCD footprint	2	2	Low	Prevent or contain groundwater contamination	1	1	Low

Table 19: Groundwater related mitigation and management measures for the proposed activity – operational phase

No.	Aspect affected	Activity	Potential Impact	Phase	Mitigation type	Impact management actions / Mitigation measures	Impact management outcome	Standard to be Achieved	Time period for implementation
1	Groundwater quality	Operation of PCDs	Unlined dams can result in mounding of the water levels due to artificial and increased recharge to the aquifer. Elevated water elevations result in an increase in flow	Construction	Avoid, modify, remedy, control or stop	<u>Management measures:</u> • Prevent cumulative contamination of the receiving groundwater environment.	Prevent or contain groundwater contamination	N/A	N/A

			gradients which means higher rates of groundwater flow and mass transport.			• Minimize seepage, prevent contact between clean and dirty areas, and to recycle contaminated water. Action plans: • Continue with the status quo groundwater monitoring programme. • Do not discharge affected water into the environment that does not comply with regulatory standards, unless authorised to do so. • Contain all affected water within the affected water circuit. • PCDs to be designed so that no polluted water system at the mine is likely to spill into any clean water system more than once in 50 years and will have a minimum of 800 mm freeboard above spillway level. • Line with suitable low permeable pollution control layer. • Conduct regular inspections (refer to Section 8.2.4). • Prepare and maintain an Operations Management Plan (Operation Manual).			

						• Regular routine inspections of PCDs should be carried out by Venetia or a suitably qualified person appointed by Venetia Mine.			

8.3 Decommissioning and closure

Site decommissioning for the PCDs should generally commence at the cessation of operations. Some surface infrastructure will be removed, site areas made safe and final reclamation and revegetation operations will begin to ensure disturbed areas can sustainably meet the adopted final land uses. The post-operational period is important to both the regulatory authorities and the proponent since it affects the timing of both site relinquishment and the applicable rehabilitation funds and/or the transfer of unused funds. Closure planning and operational processes put in place during the operational period will determine the post-operational success (or otherwise) of rehabilitation and re-vegetation operations.

Discussions with regulatory authorities and associated closure planning, addressing matters such as site reclamation and final landforms, vegetation and land use, must commence during the operational period. Interim closure plans arising from this planning must be reviewed at regular intervals (~3 to 5 years) to ensure that the closure plans are appropriate and modified when necessary to account for changed circumstances.

It is important that the role and use of the PCDs are defined in the post-closure scenario, as this will impact on the closure objectives and closure design requirements. The options for post-closure use of the PCDs could include one of the following:

- Demolish the PCD wall and return the area back to free draining.
- Keep the PCD for beneficial long-term use, such as:
    - A farm dam or water supply dam for the local communities, or
    - Long-term use of the PCD for pollution control measures.
- Provide an in-situ cap for the PCDs.

The specific closure objectives stipulated for the PCD area must take account of the post-closure role of the PCD and be aligned to the overall closure objectives and final land use pattern set for the infrastructural complex.

The closure objectives for the PCD area, relevant to groundwater and limiting the impacts on it post-closure, must address at least the following:

- Final shaping and surface drainage of the PCD area (in line with land use/land capability requirements for the area).
- Soil clean-up and safe disposal.
- Safe disposal of impounded contaminated water.
- Decontamination of embankment material, including spillway material.
- Removal and safe disposal of liner material.
- Assessment and possible soil clean-up underneath the liner system.
- Disposal of demolition waste and salvage of equipment (pumps, pipelines, etc.).
- Re-vegetation and the sustaining of cover.

9. GROUNDWATER MONITORING SYSTEM

9.1 Groundwater monitoring network

9.1.1 Source plume, impact and background monitoring

Prior to the design of any monitoring programme, the current understanding of the groundwater system must be understood in terms of i) flow dynamics and behaviour, ii) potential sources of groundwater and related surface water impacts; iii) receptors that may be affected by impacts to groundwater and surface water; and iv) the pathways that could potentially connect them. No risk exists if an impact source is not linked to a potential receptor.

A deterioration in groundwater quality is the most significant risk associated with the activity.

The source-pathway-receiver model provides a conceptual portrayal of the mode through which contaminants act and the potential harm they may inflict on a receiving water body and/or organism. The conceptual model is used to develop management action plans and reclamation alternatives that are directed towards mitigating potentially harmful effects caused by the contaminants of concern. Refer to the conceptual site model discussion under Section 7.6 for a more detailed discussion on interaction between potential sources of contamination and receptors that could be affected using the source – pathway – receptor methodology.

9.1.2 System response monitoring network

A Water Management Plan is required to ensure that mine does not impact negatively on groundwater levels and quality to unacceptable levels. It will also serve as early warning systems to implement mitigation measures at early stages to reduce cumulative impacts. To ensure that the groundwater environment is protected, monitoring of water quality and levels are required on an on-going basis.

Monitoring is required for the following purposes:

1. To detect the actual impact on groundwater quality timeously.
2. To assess whether the mitigation measures given in Section 9 are effective, supporting the update of mitigation measures where necessary.
3. Models can be updated and refined based on new information to support adaptive management measures. Model confidence levels can be increased, and groundwater impacts be predicted with more accuracy. With updated and high confidence predictions, the client can act in a pre-emptive manner, thus reducing risks, rather than acting retrospectively when monitoring data reveals a problem.
4. To interrogate unknowns identified in this report, in which various field investigations can be carried out to test and improve the conceptual hydrogeological understanding of the aquifer system.

Monitoring in general should follow the risk-based approach to define or characterise the risks that the operations and associated infrastructure may pose on the receiving environment.

Risk assessments involve the understanding of the generation of a hazard, the probability that the hazard will occur, and the consequences should it occur, i.e. understanding the complete cause and effect cycle. The most basic risk assessment methodology is based on defining and understanding the three basic components of the risk, i.e. the source of the risk (source term), the pathway along which the risk propagates, and finally the target that experiences the risk (receptor). The risk assessment approach is aimed at describing and defining the relationship between cause and effect.

9.1.3 Monitoring frequency

No new monitoring boreholes are recommended to be drilled and it is recommended that the status quo monitoring should continue. The PCDs to be monitored on a monthly schedule as per the status quo surface water monitoring programme.

9.2 Monitoring parameters

Monitoring as per the current monitoring programme to continue.

9.3 Monitoring boreholes

Monitoring as per the current monitoring programme to continue except for the inclusion of hydrocensus boreholes VEN-HC1 and VEN-HC2, located downgradient of PCD 3 Complex (Table 20). If these boreholes are to be destroyed during the construction phases, it is recommended that a shallow weathered (~15m) and deeper fractured (~50 m) borehole be drilled to replace them and included in the programme.

Table 20: Additional monitoring locations at Venetia Mine

Monitoring ID	Coordinates	
Groundwater/boreholes		
VEN-HC1	-22.448683	29.291891
VEN-HC1	-22.449458	29.292149

10. CONCLUSION AND RECOMMENDATIONS

Shangoni AquiScience, a division of Shangoni Management Services, was appointed by De Beers Venetia Mine, to conduct a geohydrological investigation for new affected storage dams to be constructed forming part of their Stormwater Management Project. The study was compiled using all relevant available information and generated data for the site and region to define the groundwater regime and to highlight current and foreseeable risks towards the receiving surface and groundwater environment. This specialist geohydrological study was undertaken to fulfil in the requirements of a Water Use Licence Application (WULA) and Environmental Impact Assessment (EIA).

The specialist groundwater investigation relating to this application concluded and recommended the following:

- No substantial groundwater related impacts, quality and quantity, are foreseen during construction, operation or post-closure phases.
- Status quo monitoring should continue to include quality and water level monitoring with regular interpretation of results by a qualified and professional geohydrologist.
- Do not discharge affected water into the environment that does not comply with regulatory standards, unless authorised to do so.
- The management measures as recommended in this report should be used in the EMP or closure plan and conditions should apply to the environmental authorisation.

Based on the findings of the geohydrological assessment, no fatal flaws have been identified that may limit the expansion activities. It is the opinion of the specialist that the proposed project may proceed on condition that all mitigation measures as outlined and discussed in this report are adhered to.

REFERENCES

Aller, L., Bennet, T., Lehr, J.H., Petty, R.J. and Hacket, G. 1987. DRASTIC: A standardized system for evaluating groundwater pollution using hydrological settings. Prepared by the National Water Well Association for the US EPA Office of Research and Development, Ada, USA.

Bouwer, H and Rice, R.C. 1976. A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. *Water Resources Research*, Vol 12 (3).

Cooper, H.H. and C.E. Jacob, 1946. A generalized graphical method for evaluating formation constants

Department: Water Affairs and Forestry, 2007. Best Practice Guideline A4: Pollution control dams.

GDRM, 2010. Groundwater Resource Directed Measures, 4th Edition. Department of Water Affairs (DWA).

IWWMP, 2018. Updated of the Integrated Water and Waste Management Plan and Rehabilitation Strategy Implementation Plan (2018).

Jones and Wagener, 2014. Venetia Mine Water and Salt Balance Report as compiled by Jones and Wagner in 2014. Report No. JW011/14/D537 – Rev 1.

Jones and Wagener, 2016. Venetia Mine Waste Assessment. Compiled by Jones and Wagener in 2016 for De Beers Consolidated Mines Propriety Limited. Report No.: JW222/16/F614 – Rev 03.

Integrated Water and Waste Management Programme (IWWMP, 2019) for De Beers Consolidated Mines (Pty) Ltd: Venetia Mine, as compiled by Prescali Environmental Consultants (Pty) Ltd.

Jones and Wagener, 2018. Venetia Mine Hydrogeological Assessment Final Report compiled by Jones and Wagener in 2018, revision 1 (17/08/2018). Report No. JW093/18/F630.

Jones and Wagener, 2020a. Venetia Mine Water Balance Life of Mine and Scenario Report. Report No.: JW238/20/I142 - Rev 0.

Jones and Wagener, 2020b. Venetia Mine Hydrogeological Assessment Final Report compiled by Jones and Wagener in 2020, revision 2 (10/02/20). Report No. JW093/18/F630.

Lynch, S.D., Reynders, A.G. and Schulze, R.E., 1994: A DRASTIC approach to groundwater vulnerability mapping in South Africa. SA Jour. Sci., Vol. 93, pp 56 - 60.

Parsons, R.P., 1995: A South African aquifer system management classification; WRC Report No. 77/95, Water Research Commission, Pretoria.

South African National Standards, 241: 2015 Drinking Water Standards.

SRK, 2011. Groundwater Specialist Study for the Feasibility Level Environmental Impact Assessment of Venetia Diamond Mine. Prepared for Venetia Diamond Mine by SRK Consulting. SRK Project Number 424741.

Vegter, J.R. 1995. An explanation of a set of national groundwater maps; Report TT 74/95 Water Research Commission.

WRC, 1998. Quality of Domestic Water Supplies Vol. 1 Assessment Guide (TT 101/98).