Glencore Eastern Chrome Mines:
Helena WRD and Thorncliffe Co-Disposal Design Numerical Model and Impact Assessment

Hydrogeological Specialist Investigation

Project no: **E44700225**

Prepared for: **Exigo Sustainability (Pty) Ltd**
Glencore Eastern Mines

7 April 2021

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DOCUMENT HISTORY

Report no	Date	Version	Status
E44700225_HG	7 April 2021	2.0	Draft

Notations and terms

Advection is the process by which solutes are transported by the bulk motion of the flowing groundwater.

Anisotropic is an indication of some physical property varying with direction.

Cone of depression is a depression in the groundwater table or potentiometric surface that has the shape of an inverted cone and develops around a borehole from which water is being withdrawn. It defines the area of influence of a borehole.

A confined aquifer is a formation in which the groundwater is isolated from the atmosphere at the point of discharge by impermeable geologic formations; confined groundwater is generally subject to pressure greater than atmospheric.

The darcy flux is the flow rate per unit area (m/d) in the aquifer and is controlled by the hydraulic conductivity and the piezometric gradient.

Dispersion is the measure of spreading and mixing of chemical constituents in groundwater caused by diffusion and mixing due to microscopic variations in velocities within and between pores.

Drawdown is the distance between the static water level and the surface of the cone of depression.

Effective porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices that are connected.

Groundwater table is the surface between the zone of saturation and the zone of aeration; the surface of an unconfined aquifer.

Fault is a fracture or a zone of fractures along which there has been displacement.

Hydrodynamic dispersion comprises of processes namely mechanical dispersion and molecular diffusion.

Hydraulic conductivity (**K**) is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured perpendicular to the area [L/T]. Hydraulic conductivity is a function of the permeability and the fluid's density and viscosity.

Hydraulic gradient is the rate of change in the total head per unit distance of flow in a given direction.

Heterogeneous indicates non-uniformity in a structure.

Karstic topography is a type of topography that is formed on limestone, gypsum, and other rocks by dissolution, and is characterised by sinkholes, caves and underground drainage.

Mechanical dispersion is the process whereby the initially close group of pollutants are spread in a longitudinal as well as a transverse direction because of velocity distributions.

Molecular diffusion is the dispersion of a chemical caused by the kinetic activity of the ionic or molecular constituents.

Observation borehole is a borehole drilled in a selected location for the purpose of observing parameters such as water levels.

Permeability is related to hydraulic conductivity but is independent of the fluid density and viscosity and has the dimensions L^2. Hydraulic conductivity is therefore used in all the calculations.

Piezometric head (ϕ) is the sum of the elevation and pressure head. An unconfined aquifer has a water table, and a confined aquifer has a *piezometric surface*, which represents a pressure

head. The piezometric head is also referred to as the hydraulic head.

Porosity is the percentage of the bulk volume of a rock or soil that is occupied by interstices, whether isolated or connected.

Pumping tests are conducted to determine aquifer or borehole characteristics.

Recharge is the addition of water to the zone of saturation; also, the amount of water added.

Sandstone is a sedimentary rock composed of abundant rounded or angular fragments of sand set in a fine-grained matrix (silt or clay) and more or less firmly united by a cementing material.

Shale is a fine-grained sedimentary rock formed by the consolidation of clay, silt, or mud. It is characterised by finely laminated structure and is sufficiently indurated so that it will not fall apart on wetting.

Specific storage *(S_0),* of a saturated confined aquifer is the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head. In the case of an unconfined (phreatic, water table) aquifer, *specific yield* is the water that is released or drained from storage per unit decline in the water table.

Static water level is the level of water in a borehole that is not being affected by withdrawal of groundwater.

Storativity is the two-dimensional form of the specific storage and is defined as the specific storage multiplied by the saturated aquifer thickness.

Total dissolved solids *(TDS)* is a term that expresses the quantity of dissolved material in a sample of water.

Transmissivity (T) is the two-dimensional form of hydraulic conductivity and is defined as the hydraulic conductivity multiplied by the saturated thickness.

Unconfined-, water table- or phreatic-aquifer are different terms used for the same aquifer type, which is bounded from below by an impermeable layer. The upper boundary is the water table, which is in contact with the atmosphere so that the system is open.

Vadose zone is the zone containing water under pressure less than that of the atmosphere, including soil water, intermediate vadose water, and capillary water. This zone is limited above by the land surface and below by the surface of the zone of saturation, that is, the water table.

Water table is the surface between the vadose zone and the groundwater, that surface of a body of unconfined groundwater at which the pressure is equal to that of the atmosphere.

List of abbreviations

Abbreviation	Description
a	annum
BH	Borehole
CT	Contaminant Transport
CDPF	Co-Disposal Facility
DRIT	Double Ring Infitration Test
EIA	Environmental Impact Assessment
ha	hectare
km	kilometre
ℓ/s	Litre per second
m/d	Meter per day
m^3	Cubic metres.
Mm^3	Million cubic metres
mamsl	Meter Above Mean Sea Level
MAP	Mean Annual Precipitation
mbgl	Meter Below Ground Level (i.e. depth)
mbwl	Meter Below Water Level
mg/ℓ	Milligrams per litre
mm	Millimetre
mm/a	Millimetre per annum
NO_3	Nitrate
RQO	Resource Quality Objective
SANS	South African National Standards
SO_4	Sulphate
SoW	Scope of Work
TSF	Tailings Storage Facility
TDS	Total Dissolved Solids
WGS84	World Geodetic System of 1984
WM	With Mitigation
WOM	Without Mitigation
WRD	Waste Rock Dump
ZOI	Zone of influence

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1 INTRODUCTION

KC Vivier (Pty) Ltd was appointed by Exigo Sustainability (Pty) Ltd (Exigo) to perform a review and update on the geochemical and hydrogeological assessment of the processing plants' waste that are planned to be co-disposed as a mixture of waste rock and tailings at Glencore Eastern Chrome Mine's (ECM) Thorncliffe operations. In addition, both the updated co-disposal facility design for the Glencore Thorncliffe operations and Waste Rock Dump (WRD) design for the Helena Mine were included within the numerical model update. This update was conducted in fulfilment of the groundwater specialist component to quantify impacts from the proposed mine infrastructure extension that forms part of the Environmental Impact Assessment (EIA) and Environmental Management Program Report (EMPR).

1.1 Objective

The objective of the investigation was to:

1. Review and assess the Amava plant's waste and mixture with the other plants' (THC and PGM) waste in terms of GNR635 to determine updated source terms for the numerical model update;
2. Update the numerical flow and mass migration model; and
3. Assess the cumulative hydrogeological risks and impacts to receptors associated with the extension of the underground workings and updated facility designs at both the Thorncliffe and Helena operations.

1.2 Scope of work

The scope of work for the updated hydrogeological specialist investigation included the following:

1. Review of historic waste assessment reports and data relevant to co-disposal facility.
2. Assessment of mixed waste's source term and geochemical properties by mixing all three plant's waste streams to determine the relevant co-disposal waste source terms.
3. Update the conceptual groundwater flow model with the various proposed activities and possible impacts.
4. Update the numerical groundwater flow model and re-calibration.
5. Update the mass transport model.
6. Model simulations used to quantify risks and impacts:
    - Groundwater flow directions and velocities
    - Mitigation measures
    - Mass transport potential from mine co-disposal and WRD facilities and risks to the Dwars River receptor.
7. Conduct an updated risk and impact assessment.
8. GIS spatial analysis and map compilation.

9. Compilation of an updated technical report addressing the following:
    - Fatal flaw and gap analyses
    - Waste mixing assessment
    - Risk and impact assessment
    - Identification of mitigation and management measures
    - Groundwater management recommendations

2 SITE DESCRIPTION

2.1 Project location

The three Glencore Eastern Chrome Mines (Helena, Thorncliffe, and Magareng) are located close to the boundary between the Limpopo- and Mpumalanga Provinces, approximately 30 km southwest from the town of Steelpoort (Figure 2-1).

2.2 Hydrogeology and surface water

The mining area falls within quaternary catchment B41G which forms part of the Olifants water management area. Previous studies indicated a mean annual precipitation (MAP) of approximately 641 mm/a over the regional area with an average recharge percentage of between 2.0 to 3.5 percent of the MAP. The hydrogeology is controlled by the subsurface geology which includes the following important geological layers and features (AGES 2009, AS-R-2009-08-14):

- Upper soil zone that is almost absent in the mountainous areas but vary to thickness' of 0.1-2 m in the low lying areas.
- The weathered, layered norite/anorthosite present at a vertical depth of 5-20 m which is more pronounced in the topographic low-lying areas.
- The fractured/solid bedrock aquifer that underlies the weathered zone, formed by the basal pyroxenite and gabbro, norite and anorthosite at depths of 10 m to +50m. The solid/fractured bedrock zone is a non-aquifer as evidenced by the fact that Thorncliffe Mine does not experience any fissure water inflow and Helena Underground Mine only dewaters at 280 m^3/d;
- Dyke structures and dyke –contact zones occur and they strike north-north-east and east-west.
- Localised alluvial and deep weathering zones along the Dwars River.

The aquifers are classified as Minor with yields ranging from <0.5 ℓ/s to 2.5 ℓ/s and are formed by the weathered zones/basins that are controlled by local relief with deeper weathering in the low-lying areas (Figure 4-10).

The groundwater monitoring data aided the interpretation of the current groundwater regime

and possible impacts from small scale mine dewatering (Figure 2-2). The topography indicates an elevated hill and mountainous area located in the centre of the project study area. The surface elevation decreases towards the north and east in the direction of the Groot Dwars River and to the west in the direction of the Klein Dwars River. The groundwater flow pattern would follow the elevation regime as indicated from the observed water levels in Figure 2-2 and would indicate a limited impact from small scale mine-dewatering. Figure 7-4 indicates the proposed new extent of the underground workings towards the west.

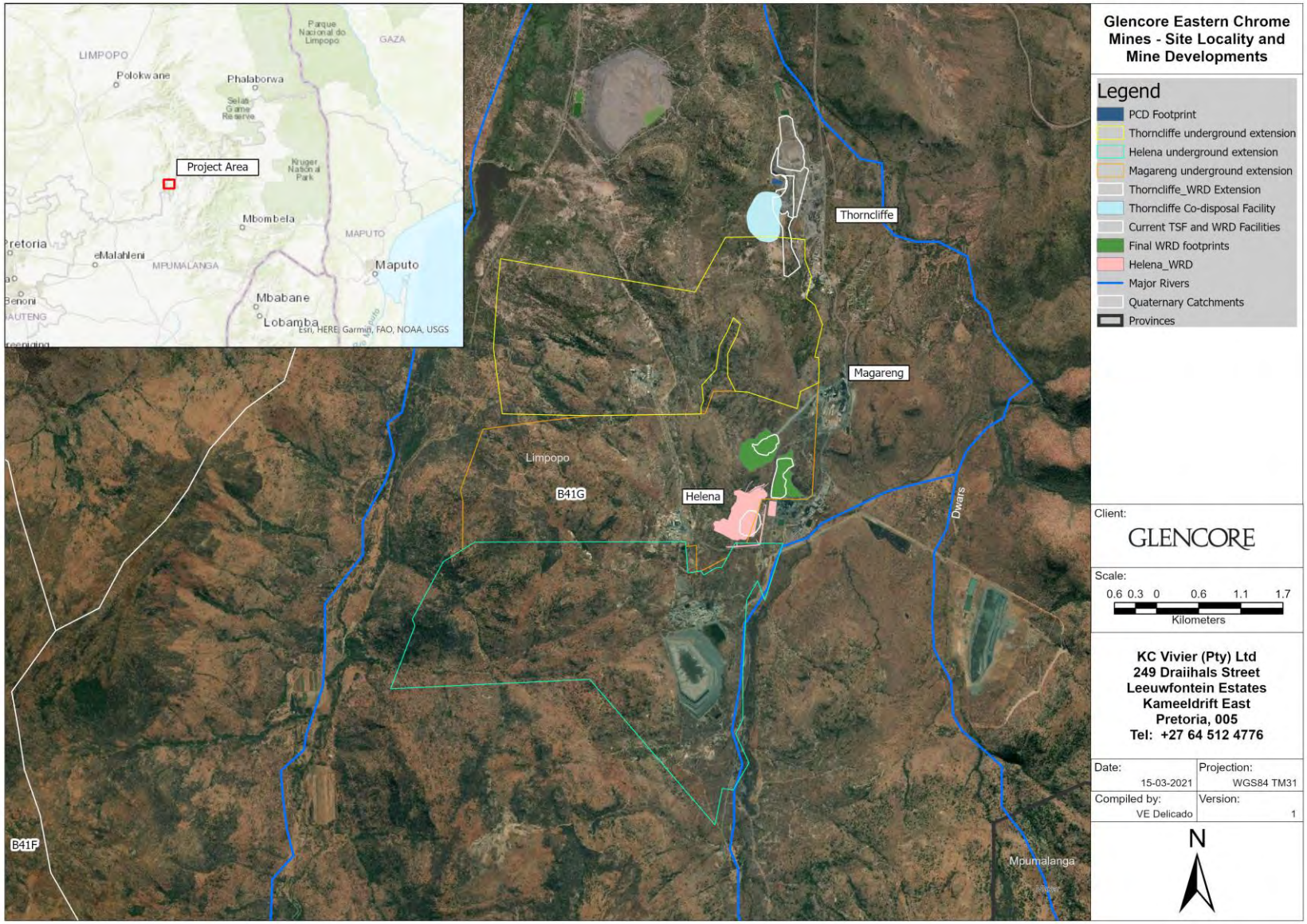

Figure 2-1: Site location with updated infrastructure development

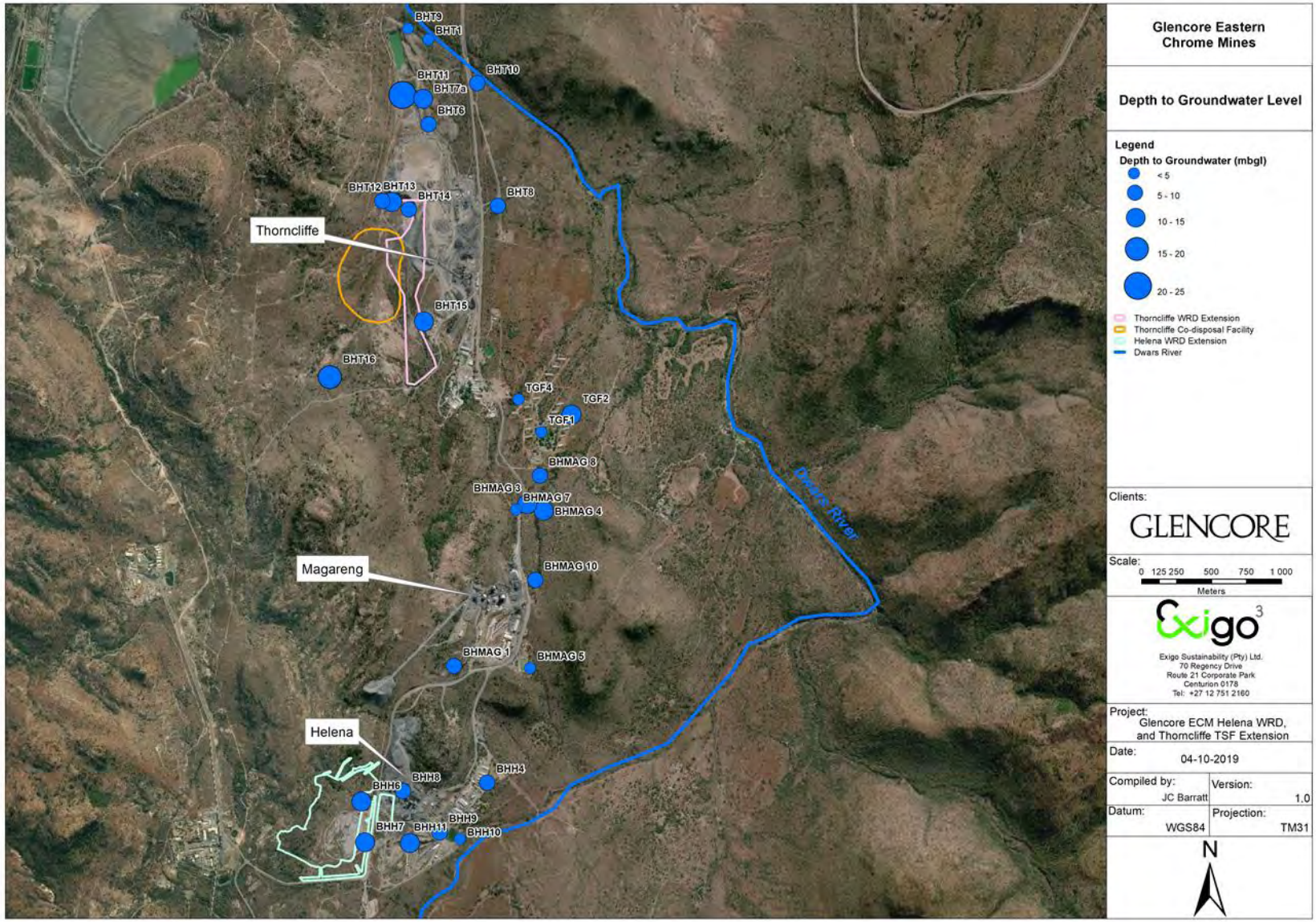

Figure 2-2 **Depth to groundwater level for Helena, Magareng and Thorncliffe (Exigo Scoping Report, 2019)**

3 SURFACE- AND GROUNDWATER MONITORING AND BASELINE ANALYSIS

The surface- and groundwater baseline information was obtained through review of both the Exigo Scoping report (2019) as well as the Exigo Glencore Eastern Mines groundwater Specialist Investigation report (2018). Additional information of the updated water level and quality for the individual mining operations can be obtained by reviewing the latest Exigo Sustainability Quarterly monitoring reports (January 2021).

Water monitoring data was available for a period of 12 years from 2007-2019. The information showed that the mine dewatering has a negligible effect on the regional groundwater system, and therefore the information proved sufficient for the current required use. The up-to-date water level and hydrochemical information was used for the model update and calibration purposes.

3.1 Water levels

The proposed new mining developments are indicated in Figure 2-1 and include the construction of the co-disposal TSF and extension of WRD at Thorncliffe and construction of a WRD at Helena. The following findings were made from the September 2019 water level measurements (Figure 3-1):

- The water monitoring data from 2007 to 2019 has indicated a negligible effect on the groundwater system regarding mine dewatering in a regional context. The mean water levels at monitoring holes are shallow at 9.27 m, ranging between 6.52 m to 14 m depth at Helena. At Thorncliffe the mean water level is at 9.40 m ranging between 3.41 m to 16.63 m.
- In Figure 3-1 the recent groundwater levels indicate the limited impact from mine dewatering.
- Only two boreholes (BHT16 and BHMAG4) indicate groundwater levels exceeding the P95 measured from all groundwater levels.

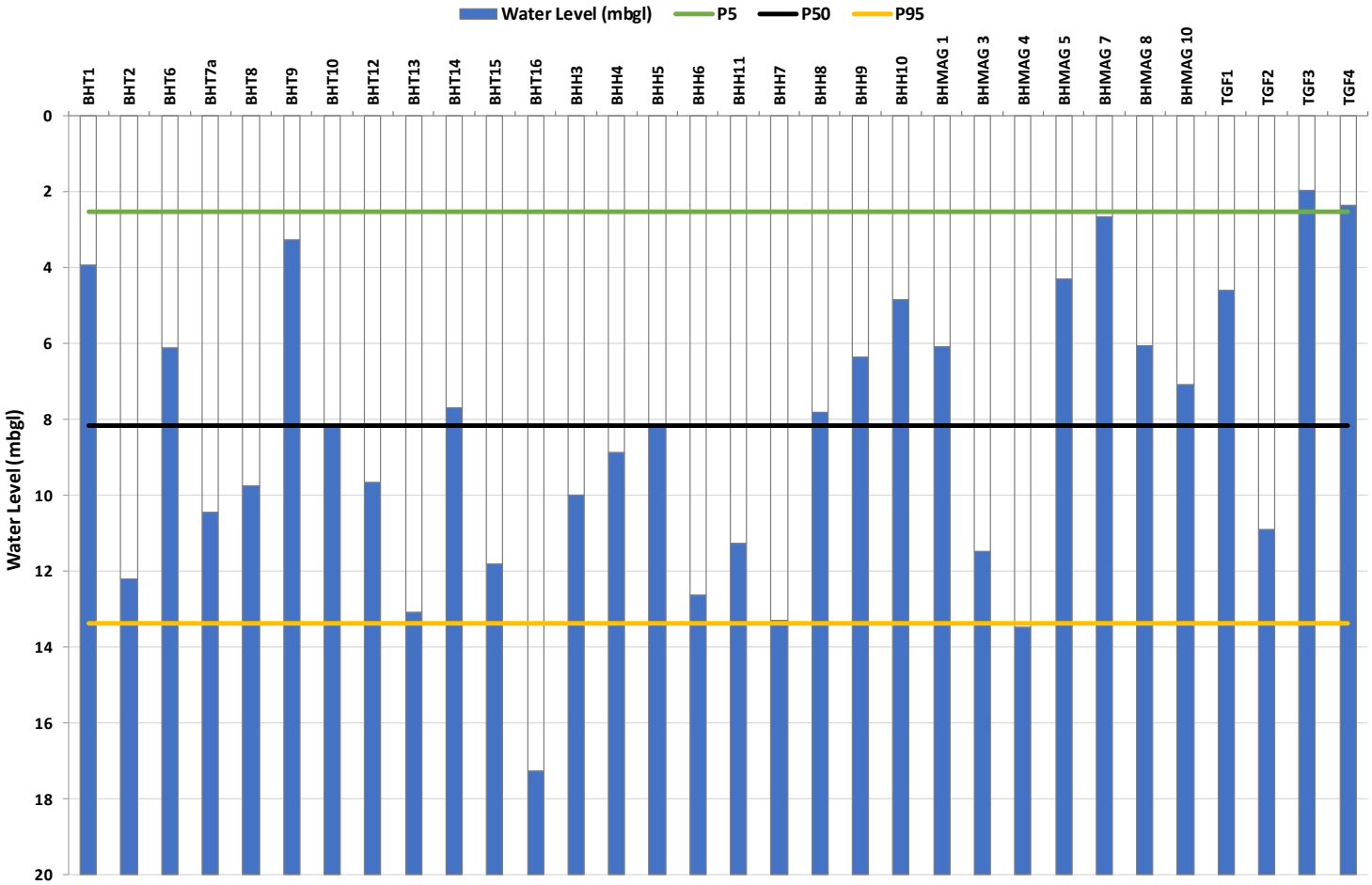

Figure 3-1 **September 2019 groundwater levels measured over the mining area**

The new mining developments could increase mine dewatering as well as water supply to the mining operations. The proposed final mining depth for both Helena and Magareng mines would be 800 m below ground surface, with Thorncliffe planned for 600 m below ground surface.

The estimated abstraction from monitoring data is indicated in Table 3-1. A total abstraction of approximately 807 m^3/d from all three mines was determined. The Thorncliffe mine contributed the most to groundwater abstraction (362 m^3/d) and Magareng mine the least at 177 m^3/d. Helena mine has no groundwater abstraction from boreholes, however 268 m^3/d is abstracted for mine water supply purposes. These low rates would indicate low permeability at depth and limited seepage from the shallow aquifer system to the deep underground.

Apart from the licensed abstraction from the Dwars River of 500 m^3/d for mine water supply and base flow interception of less than 10% of abstraction from Helena, the mining operations do not have a significant negative effect on the flow of the Dwars River. The combined impact on the Dwars River represents a flow reduction of ±1%.

Table 3-1 Monitoring data indicating estimated groundwater abstraction at Glencore Eastern mines

Component	Outflows (m^3/d)
Abstraction from boreholes: Thorncliffe	196
Abstraction from boreholes: Magareng	32
Mine Dewatering (fissure water): Thorncliffe	166
Mine Dewatering (fissure water): Magareng	145
Mine Dewatering (fissure water): Helena	268
Total	**807**

3.2 Water Quality

The monitoring program was conducted from as early as 2007 at Thorncliffe and Helena mines. Prior to the monitoring program a hydrocensus was conducted in 2003 which provided baseline data for both surface water as well as groundwater (Figure 3-3, Figure 3-4,Figure 3-5). The major chemical parameters that were focused on were total dissolved solids (TDS), nitrate (NO_3-N), and sulphate (SO_4). Nitrate, TDS, and sulphate increased in the process water over the last 10 years of mining and in groundwater close to mine residue facilities. These increased nitrate, TDS, and sulphate observations cluster in the immediate mining area which is due to the low transmissivity in the subsurface geology (Exigo, 2017). The receptor is the Groot Dwars River.

Monitoring data were analysed against the SANS 241:2015 limits as well as baseline and the RQO (Resource Quality Objective) limits set by DWS for the specific river system and catchment. The following observations were analysed from the data:

3.2.1 Sulphate Analysis (Figure 3-3)

The monitoring data were analysed according to date and observation with the following results:

1. All surface water quality is within the RQO limits set for the Olifants and Dwars River systems and catchment area.
2. All groundwater quality is within the SANS 241:2015 drinking water limits.
3. The downstream surface water position in the Groot Dwars River exceeds the mean baseline by 9.1 mg/ℓ which is relatively low considering the SANS 241:2015 sulphate limit (500 mg/ℓ).
4. The average impact on the Groot Dwars River is +0.15 mg/ℓ annually, which is insignificant although a slight increasing trend exists.

3.2.2 Nitrate Analysis (Figure 3-4)

The groundwater baseline for nitrate was developed from groundwater monitoring positions at Thorncliffe and Helena all up-gradient from the mining areas with monitoring data covering the

last twelve years (2007 - 2019). The groundwater baseline was estimated at 1.1 mg/ℓ and the surface water baseline was estimated at 1.8 mg/ℓ SANS Drinking Water limit is 11 mg/ ℓ. The data analysis indicated the following:

1. The baseline concentration exceeds the upstream average by 1.0 mg/ℓ for surface water.
2. The downstream concentrations slightly exceed the RQO limit by 2.3 mg/ℓ for surface water.
3. An annual increasing impact of 0.5 mg/ℓ on the Dwars River is insignificant with a slight increasing trend from 2003 to 2017 after which there was a decreasing trend. Nitrate however decays naturally with time (Figure 3-4). The downstream mean for SWT3 in 2019 was 8.84 mg/ℓ, which exceeds the baseline but still below the SANS 241 Drinking water limit.
4. The mean onsite locations for groundwater quality exceed the SANS 214:2015 drinking water limit as well as baseline conditions, situated locally around the mining activities.

Nitrate concentrations that were measured at BHT8 near Thorncliffe mine indicated the decay potential along the flow path. The NO3 concentrations measured from 2012 to 2017 shows that it decayed linearly from 80 mg/ℓ to <1 mg/ℓ in 500 - 600 days (1.5 years) (Figure 3-2). This verifies a half-life of ±300 days.

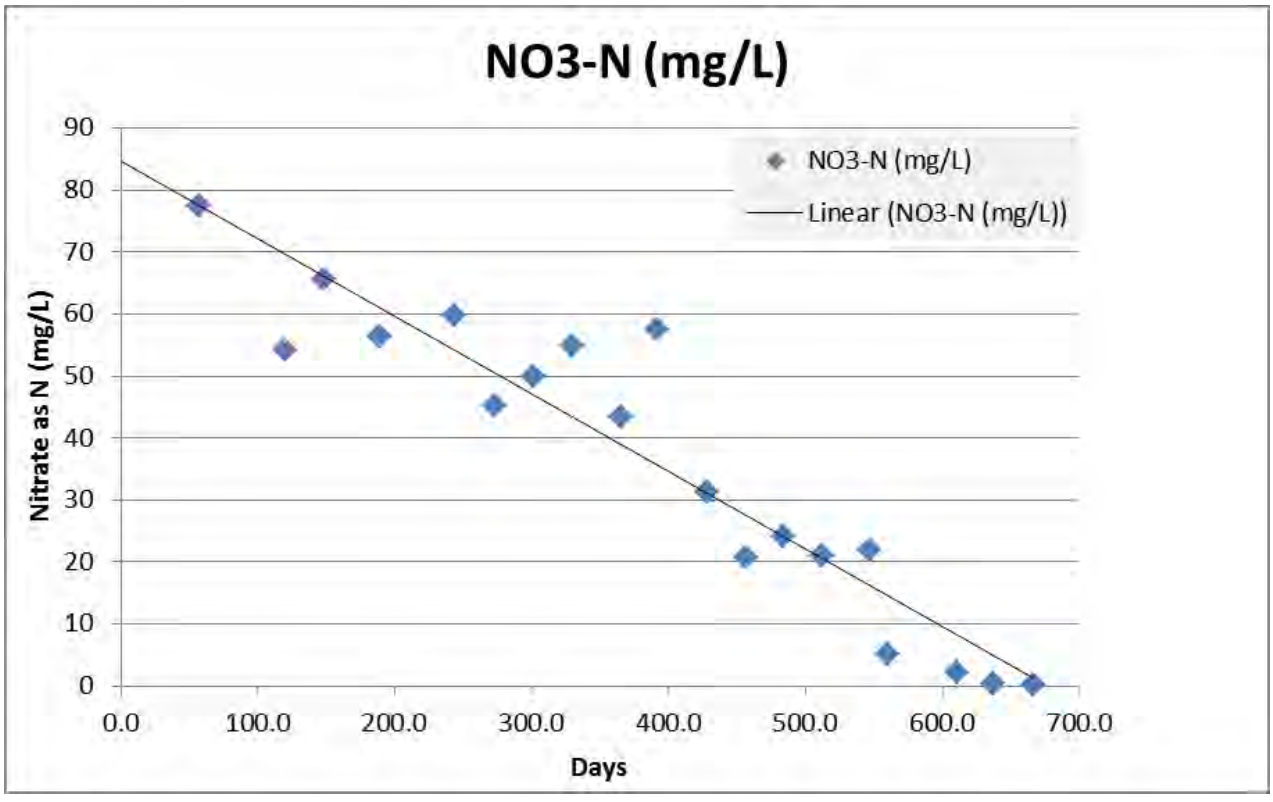

Figure 3-2 Graph indicating the nitrate decay over time at borehole BHT8

3.2.3 TDS Analysis (Figure 3-5)

There is no RQO limit set for TDS and the SANS 241:2015 limits were utilized for the surface water analysis as well. The following observations were made regarding the TDS analysis (Figure 3-5):

- All of the surface water quality is within the SANS 241:2015 limits.
- The mean surface water quality concentrations are below the baseline conditions with a slight mean concentration increase of 53 mg/ℓ over the last twelve years at the downstream position. The chemical constituents are calcium and magnesium bicarbonates, which are natural rock forming minerals.
- A slight increasing trend exists from the current impact with an annual TDS increase of 4.4 mg/ℓ measured over the last twelve years. The mean downstream TDS at Thorncliffe in 2018 was t 251 mg/ ℓ, which is good water quality. The impact on the Dwars River receptor is insignificant.
- All of the elevated groundwater TDS quality clusters around the immediate mining areas where baseline conditions are exceeded. Helena and Magareng have elevated TDS concentrations above the SANS 241:2015 limit.

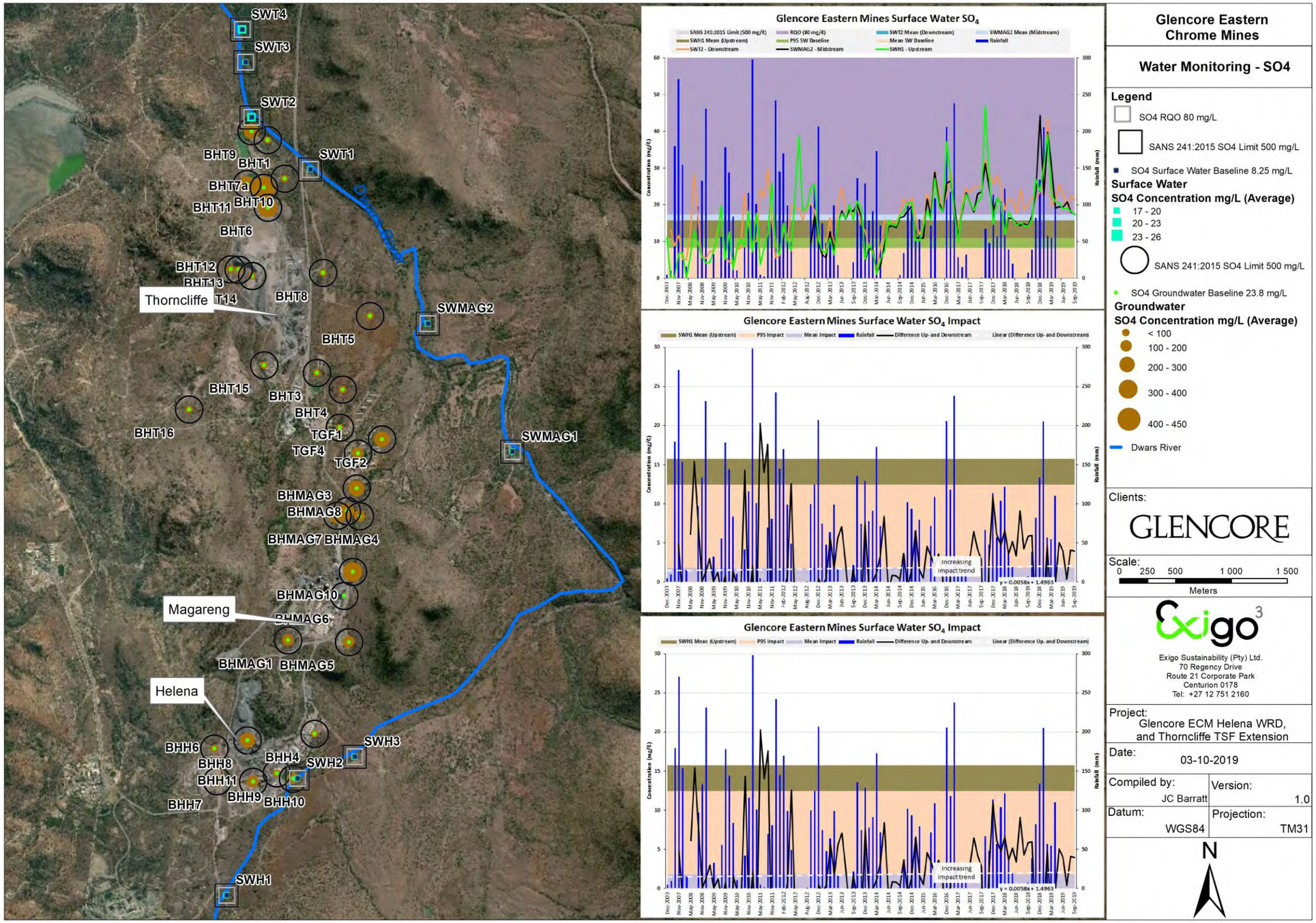

Figure 3-3 Sulphate spatial and time-series analysis at all three mines

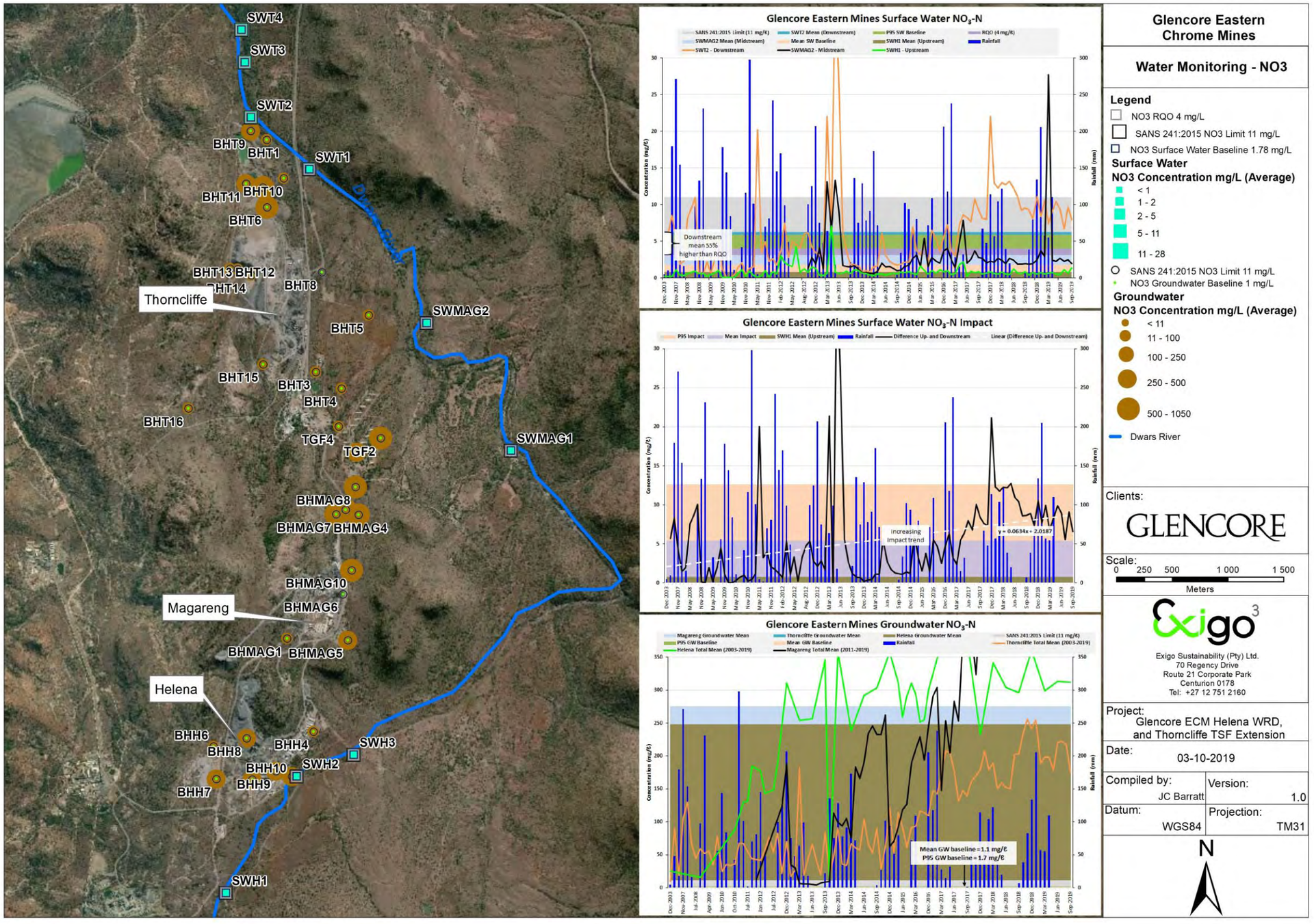

Figure 3-4 Nitrate spatial and time-series analysis at all three mines

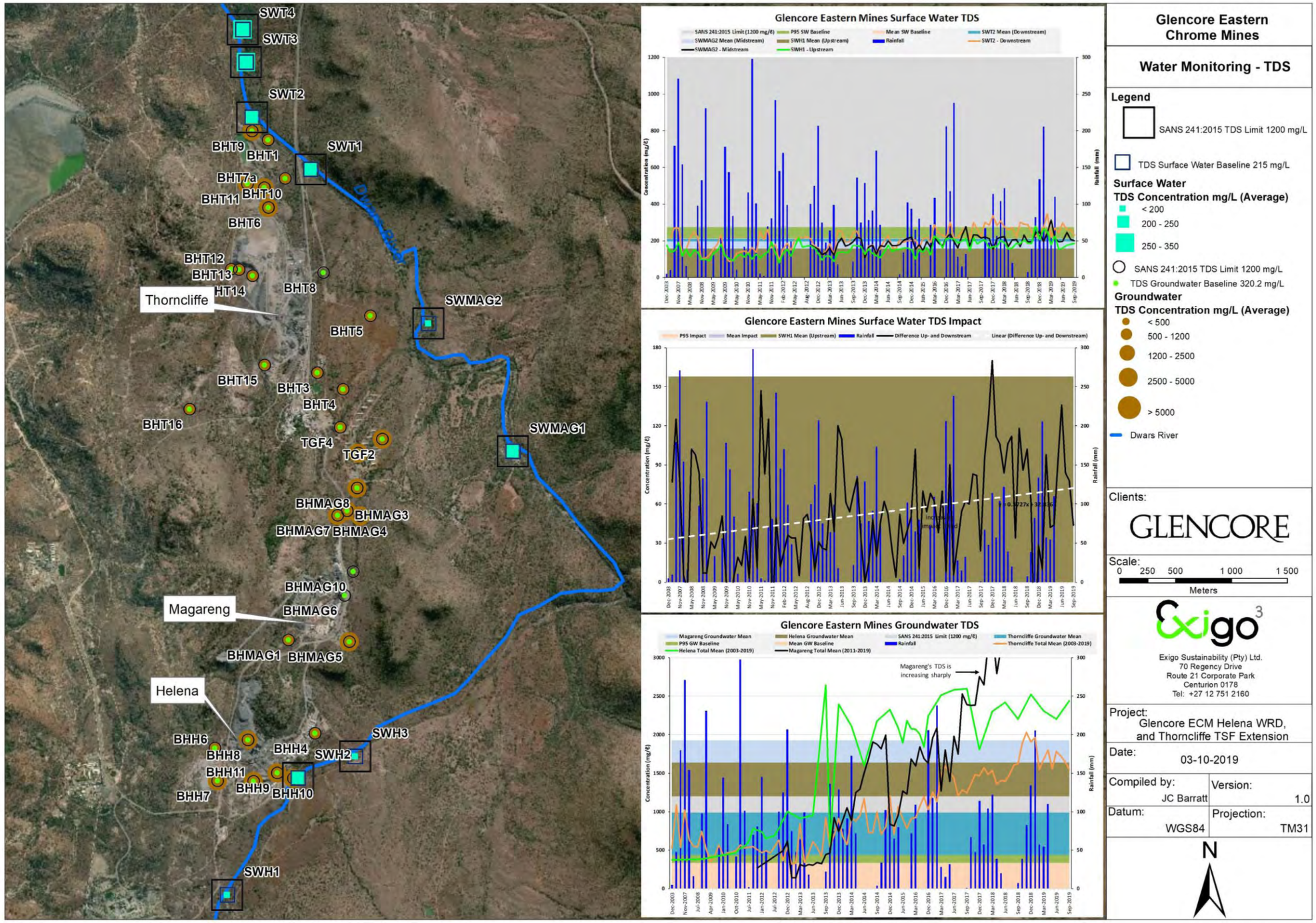

Figure 3-5 TDS spatial and time-series analysis at all three mines

4 SITE CHARACTERIZATION

During the 2017 – 2018 Hydrogeological Specialist Investigation, hydrogeological site characterisations were carried out for the Co-Disposal and WRD designs at both Thorncliffe and Helena mine operations with a view to determine hydrogeological parameters for the groundwater numerical flow and mass transport modelling. The results obtained are presented below.

4.1 Thorncliffe

The proposed new Co-Disposal Facility (CDPF) and waste rock dump (WRD) at Thorncliffe mine required detailed site assessments to evaluate the weathered profile and possible shallow aquifer systems underlying the CDPF and waste rock dump (WRD) footprint areas. The field characterization included the following:

1. Geophysical surveys conducted in a grid orientation over the CDPF and WRD footprint according to the electrical resistivity and magnetic methods to determine preferential pathways and the weathered zone geometry.
2. Double ring infiltration tests at selected sites over the TSF and WRD footprint to evaluate the surface seepage potential of the weathered overburden with specific reference to the vertical hydraulic conductivity (K_v).
3. Drilling of additional monitoring and seepage capturing boreholes to monitor and mitigate any suspected mass migration during the operational phase of the TSF and WRD. These boreholes consisted of percussion water holes to test the weathered aquifer hydraulic conductivity and core boreholes to do packer tests to determine depth specific hydraulic conductivity values.
4. Conduct falling head tests on new and existing boreholes to determine permeability of the aquifer systems and be implemented as input to the numerical groundwater model.

4.1.1 Geophysical field survey

The geophysical field survey was conducted in a grid orientation over the TFS and WRD footprint as mentioned above. At least 13 geophysical traverses were conducted in a north-south as well as east-west orientation and the data were analysed by employing 3D interpolation methods which indicated the approximate depth of the weathered profile and subsequent geological structures that might influence the groundwater flow regime (Figure 4-4). The detailed geophysical profiles and 3D slice view are indicated in Appendix A: Geophysical survey results.

The 3D Voxler model (Appendix A: Geophysical survey results: 3D Interpretation electrical resistivity results) indicated that the weathered profile is more pronounced towards the north where it reaches a maximum depth of 18 m – 20 m with basement rock expected closer to surface

at 1 m depth towards the southern sections of the tailings and waste rock facilities (See Figure 15-1 to Figure 15-5 for geological logs of the area). This observation implies increased seepage and possible flow in the subsurface in mostly a northern direction.

4.1.2 Double ring infiltration tests

Double ring infiltration tests were conducted at selected sites over the footprint of the proposed developments at Thorncliffe to evaluate the near surface seepage potential for the weathered profile which could serve as input data for the numerical groundwater flow model. The results showed that the average hydraulic conductivity was ±1.7 m/d with a low of ±0.3 m/d in the low-lying areas of the TSF footprint where clayey material occurs. A high of ±5.2 m/d in the sandy soil material in the high lying areas upstream of the TSF was obtained (Table 4-1, Figure 4-4).

The permeability values were plotted to evaluate the spatial orientation and comparison with the expected increase in weathered profile towards the north. The results are spatially represented in Figure 4-4. From the results, it seems that the surface seepage decreases to the north and east which would indicate that the weathered zone would be less permeable as suppose to the fractured harder near surface basement rocks. This observation would be favourable for the shallow aquifer system in the weathered profile as ingress would be slow from the proposed TSF, however, it does not eliminate seepage to the aquifer completely. Saturation over time would cause a positive flux from the TSF with development and subsequent increased seepage into the weathered aquifer system.

Table 4-1 DRIT tests results

Sit ID	Latitude	Longitude	Average Hydraulic Conductivity (m/d)	Test Depth (m)
DT 01	-24.97403	30.11946	5.26	Surface
DT 02	-24.96768	30.12007	1.11	0.4
DT 03	-24.96585	30.12031	1.54	0.4
DT 04	-24.96444	30.12296	0.26	0.35
DT 05	-24.96671	30.12324	0.67	0.4
DT 06	-24.97178	30.12364	5.12	0.4
DT 07	-24.97069	30.12121	0.97	0.5
DT 08	-24.969629	30.123935	0.11	Surface
DT 09	-24.97386	30.12311	0.31	0.15
DT 10	-24.96879	30.12076	2.28	0.4
Minimum			**0.11**	**0.15**
Maximum			**5.26**	**0.5**
Average			**1.76**	**0.38**

4.1.3 Drilling of monitoring boreholes

The geophysical survey results were used to position five (5) site characterization boreholes that could serve a dual purpose as either monitoring/seepage capture boreholes. The drilling focus was to monitor up- and down-gradient of the TSF and WRD facility as well as to target the expected subsurface flow zones that might act as pathways for increased groundwater flow. The drilling positions are indicated in Figure 4-4, with drilling information presented in Table 4-2. The water levels indicated that the weathered profile increases towards the north and east with GT04 having the deepest water level. The blow yields indicate that possible seepage capturing could be conducted at GT02 and GT03. Notable water strikes of > 0.5 L/s were obtained in 2 of the 5 boreholes, both located north of the TSF footprint. Water intersections and seepage were obtained from 14 m to 20 m below surface.

Table 4-2 New monitoring boreholes information

ID[1]	Future name to be authorised in WUL	Latitude	Longitude	Water strike (mbgl)	Blow yield (l/s)	Depth (m)	Water level (mbgl)
GT01	BHT13	-24.96354	30.12304	20	0.7	30	14.34
GT02	BHT12	-24.96348	30.1223	15	1.5	29	8.78
GT03	BHT14	-24.96394	30.12411	18	0.1 (seepage)	30	10.54
GT04	BHT16	-24.97375	30.11906	-	0.05 (seepage)	40	37.2
GT05	BHT15	-24.970795	30.12539	14	0.1 (seepage)	40	10.16

4.1.4 Aquifer testing: Falling head tests

After the completion of the drilling program, the newly drilled boreholes were subjected to falling head aquifer testing to obtain preliminary aquifer parameters for modelling input purposes. From this information, pumping tests could be planned for seepage capturing (Section 4.1.5).

Historically, no pumping tests were performed on the boreholes drilled at the Helena and Magareng mining operations due to low yields and minor seepage zones experienced during drilling. Falling-head tests were conducted on as many boreholes as practically possible for the Helena, Magareng and Thorncliffe mining operations. The results presented in Table 4-3. A more detailed table is provided in Table 18-2 for reference. The average hydraulic conductivity 1.5 m/d at Thorncliffe, 0.4 m/d at Helena and 0.5 m/d at Magareng. Higher permeability values were observed at BHT09, GT01 and GT02 at Thorncliffe which are boreholes drilled in or close to old backfilled open pits. The same applies for the spatial distribution of permeability values are indicated in Figure 18-1. Mean transmissivity values are relatively low at 5 -10 m^2/d, with backfill transmissivity values at 30-50 m^2/d (Table 18-1).

[1] Note the GT no. was given to the initial site of the borehole and therefore used in this report. The boreholes were subsequently renamed to fit into the mines monitoring programme and will forward be referred with a BHT no.

Table 4-3 Falling head tests

Mine area	Name	Easting	Northing	Depth (mbgl)	SWL (mbgl)	b - Thickness (m)	early K (m/d)	Late K (m/d)	Early T (m^2/d)	Late T (m^2/d)	Average T value (m^2/d)
Thorncliffe	GT01	24.96354	30.12304	30	14.28	15	1.052	0.098	15.78	1.47	8.63
	GT02	-24.96348	30.1223	29	9.04	20	2.4	0.39	48	7.8	27.9
	GT03	-24.96394	30.12411	30	10.76	20	0.063	0.063	1.26	1.26	1.26
	GT04	-24.97375	30.11906	40	36.46	4	0.002	0.002	0.008	0.008	0.008
	GT05	-24.970795	30.12539	40	10.14	30	0.029	0.018	0.87	0.54	0.71
	BHT09	-24.95338	30.12399	5.2	2	3	7.75	0.25	23.25	0.75	12
	BHT08	-24.9638	30.12987	48.72	8.2	30	0.072	0.018	2.17	0.54	1.36
	BHT10	-24.95663	30.12852	35.78	7.68	30	0.273	0.088	8.18	2.63	5.41
Average				**32.3**	**12.3**	**19**	**1.5**	**0.1**	**12.4**	**1.9**	**7.2**
Maximum				**48.7**	**36.5**	**30**	**7.8**	**0.4**	**48**	**7.8**	**27.9**
Minimum				**5.2**	**2**	**3**	**0.002**	**0.002**	**0.008**	**0.008**	**0.008**
Helena	BHH04	-24.99735	30.12919	14.8	5.44	10	1.213	0.266	12.13	2.66	7.4
	BHH06	-24.99853	30.12109	36.08	11.31	25	0.023	0.02	0.59	0.49	0.54
	BHH07	-25.0008	30.12127	45.12	11.73	30	0.162	0.074	4.85	2.22	3.53
	BHH12	-25.0015	30.12084	43.71	11.41	30	0.381	0.096	11.44	2.88	7.16
Average				**34.9**	**10**	**23.8**	**0.4**	**0.1**	**7.2**	**2.1**	**4.7**
Maximum				**45.1**	**11.7**	**30**	**1.2**	**0.3**	**12.1**	**2.9**	**7.4**
Minimum				**14.8**	**5.4**	**10**	**0.02**	**0.02**	**0.59**	**0.49**	**0.54**
Magareng	BHMAG04	-24.9815	30.13278	70	12.76	30	0.537	0.133	16.1	4	10.05
	BHMAG07	-24.98143	30.13097	33.94	1.54	30	0.361	0.124	10.83	3.71	13
	BHMAG08	-24.97945	30.13251	46.99	4.97	30	0.571	0.134	17.14	4.02	10.58
	BHMAG10	-24.98553	30.13223	48.68	6.5	30	0.453	0.032	13.59	0.95	7.27
Average				**49.9**	**6.4**	**30**	**0.5**	**0.1**	**14.4**	**3.2**	**10.2**
Maximum				**70**	**12.8**	**30**	**0.6**	**0.1**	**17.1**	**4**	**13**
Minimum				**33.9**	**1.5**	**30**	**0.36**	**0.03**	**10.83**	**0.95**	**7.27**
Average all mines				**39.1**	**9.6**	**24.3**	**0.8**	**0.1**	**11.4**	**2.4**	**7.3**
Maximum all mine				**70**	**36.5**	**30**	**7.8**	**0.4**	**48**	**7.8**	**27.9**
Minimum all mines				**5.2**	**1.54**	**3**	**0.002**	**0.002**	**0.008**	**0.008**	**0.008**

4.1.5 Pumping tests conducted on the newly drilled boreholes

From the drilling information, at least two new monitoring boreholes could be considered for constant discharge testing. BHT12 and BHT13 were identified as possible seepage capturing boreholes and constant discharge tests were conducted on them to determine their sustainability if abstraction would take place. Table 4-4 summarizes the constant discharge test results and observations. Both tests were conducted over a period of 24-hours and in both cases only ±40% of available drawdown was reached. This observation would imply a relatively high recharge

component from the weathered zone and could be due to positive flux from the existing WRD facility north and east of the monitoring holes. Borehole BHT12 had an abstraction rate of 4 ℓ/s and BHT13 was pumped at 1.1 ℓ/s over the 24-hour period. Both boreholes recovered to 95 % in the same 24-hour period. Seepage capturing from these boreholes could be conducted at ±50 % of the tested abstraction rate over a 24-hour period for sustainable abstraction and a possible additional source of water to the mine. From the information provided, Figure 4-1 shows the locality of BHT12, BHT13 and BHT14 in relation to the updated co-disposal designs.

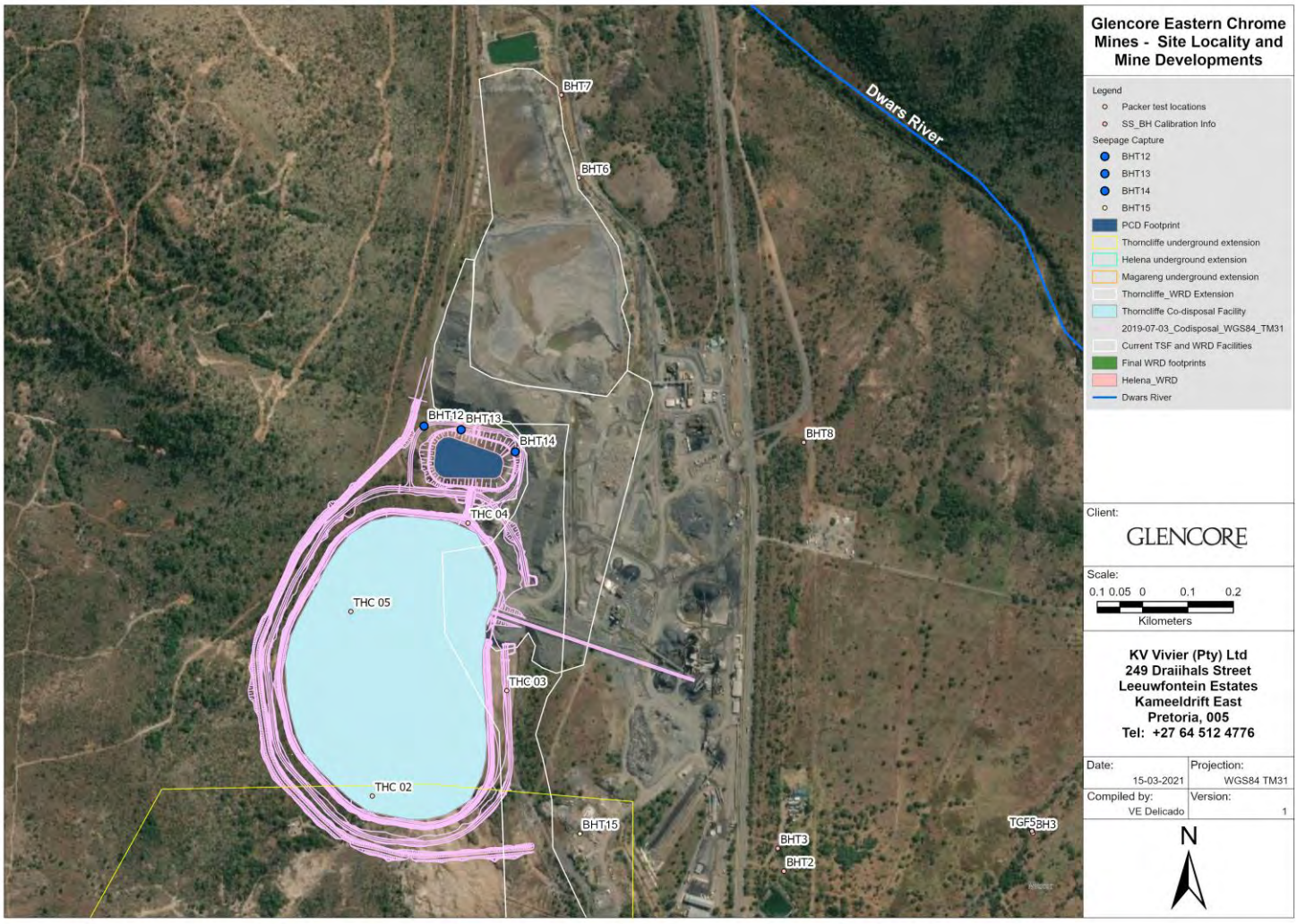

Figure 4-1 Monitoring/Seepage capture boreholes drilled in 2018

From the updated monitoring information provided (Feb 2021), all three boreholes are currently being monitored, and have been included within the numerical model as additional seepage capture boreholes to capture any fugitive seepage not intercepted by the PCD drain system downstream of the co-disposal (the model included one additional seepage capture borehole to the west of BHT12, giving a total of 4 seepage capture wells downstream of the co-disposal facility).

Table 4-4 Pump test analysis and aquifer parameters

Borehole ID	WL (mbgl)	BH Depth (m)	Test Pump Depth (mbgl)	Available drawdown	Drawdown Achieved (m)	Recovery Time (min)	% of Available Drawdwon Reached	Early T (m^2/d)	Late T (m^2/d)	Recovery (m^2/d)	Comments
BHT 12	9.4	30	29	19.6	9.1	1440	46.6	422.2	344.7	406.6	Recovery of 99%
BHT 13	13.9	30.9	29	17.1	6.9	1440	40.4	265.1	156.3	134.2	Recovery of 96%
Average	**12**	**30**	**29**	**18**	**8**	**1440**	**44**	**344**	**251**	**270**	

4.1.6 New monitoring boreholes water quality

The water quality analysis conducted for the newly drilled monitoring boreholes indicated an elevated nitrate baseline with four of the monitoring boreholes exceeding the SANS limits for NO_3 (Appendix C: Water quality of the newly drilled monitoring boreholes). These boreholes are BHT13, BHT12, BHT14 and BHT15. Increased levels of TDS and EC are also present at BHT14. This is due to the close proximity of mine residue facilities. The up-gradient monitoring borehole has elevated pH and aluminium concentrations. The poor-quality baseline up and down gradient from the new proposed CDPF facility would imply possible seepage from existing mining infrastructure as well as influences from the subsurface geological features and ore bodies.

The piper diagram (Figure 4-2) indicates that all the groundwater samples except BHT16 has a calcium-magnesium-bicarbonate signature and represent recently recharged groundwater, this observation indicates regular recharge from the existing WRD facilities near the monitoring boreholes. BHT16 has a sodium bicarbonate dominant signature and would indicate more dynamic groundwater properties.

The water quality is spatially represented in Figure 4-5 and shows that the boreholes down-gradient of the proposed new CDPF locality show a clear difference in major cations and anions compared to BHT16. The cumulative concentrations of BHT16 are less than the down-gradient monitoring boreholes and this would imply the increased recharge component from exiting mining infrastructure. Seepage capturing from BHT12 and BHT13 would take advantage of the increased recharge and reduce possible seepage from the existing/planned infrastructure whilst also supplying additional water for mining activities.

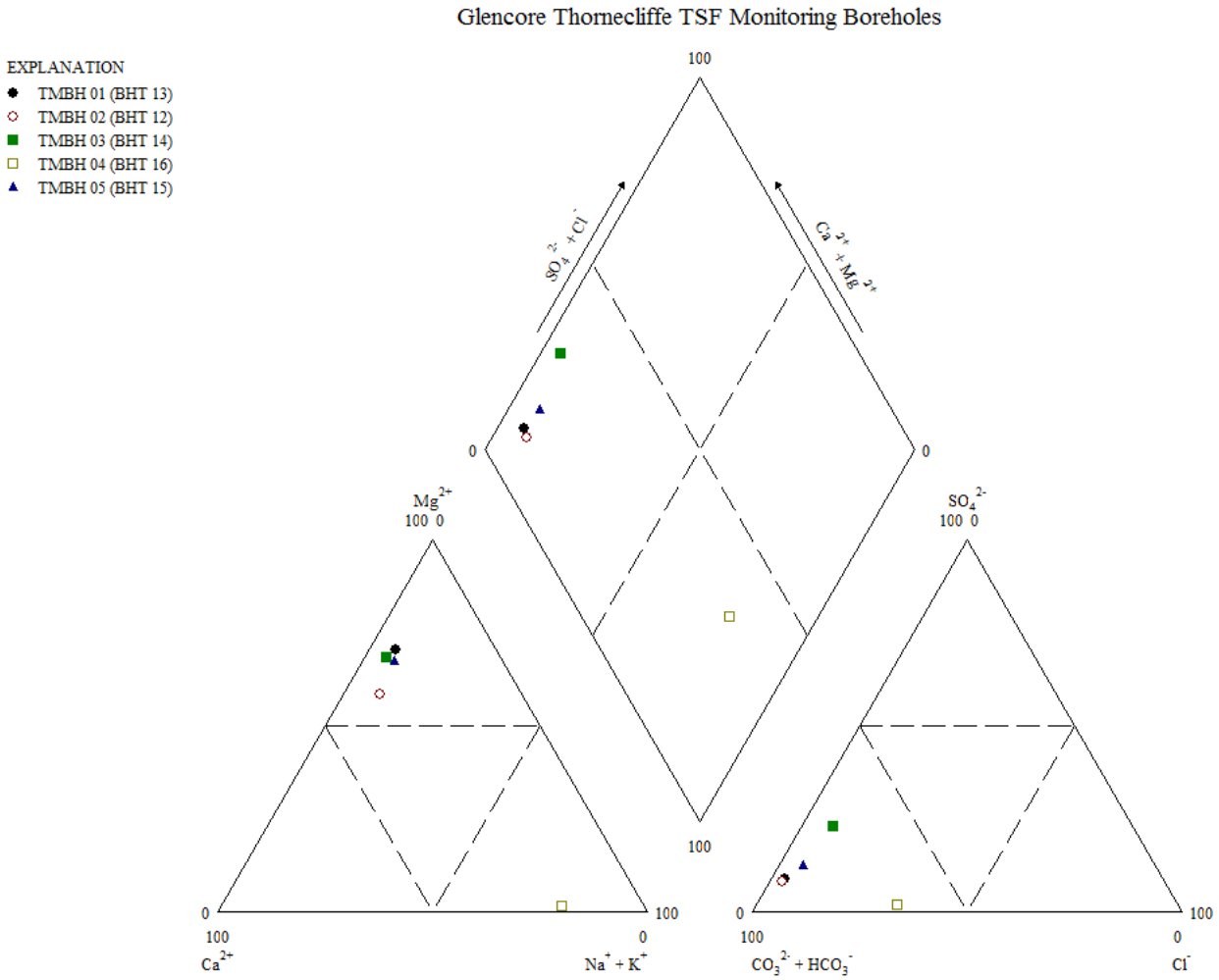

Figure 4-2 **Piper diagram of the new monitoring borehole water quality**

4.1.7 Packer (Lugeon) testing

As part of the shallow sub-surface seepage evaluation several packer tests were conducted over the original footprint of the new CDPF facility (Figure 4-1). The permeability data would aid in comparing permeability data obtained through other aquifer tests as well as confirm the accuracy of input to the numerical groundwater model.

Six diamond drilling positions were selected over the CDPF facility footprint with drilling depths up to 30 mbgl. Six packer tests were conducted on each hole at five-meter intervals. The data summary and vertical profiles with geological logs for each hole can be observed in Appendix D with the packer testing positions indicated in Figure 4-1 and Figure 4-5. The packer test results were graphed according to permeability with depth as indicated in Figure 4-3.

The graph indicates the expected low permeability up-gradient from the new TFS facility (THC1, THC2, THC3 and THC6). The geological logs also indicate less weathering from these boreholes which would imply a limited weathering profile. THC5 has the highest permeability from the weathered profile to depth and is situated more to the north of the CDPF footprint close to a possible drainage system. THC4 confirms elevated permeability in the weathered profile and low

permeability in the basement rock at depth.

The packer tests data indicated that groundwater would flow in the more permeable weathered profile on top of the less permeable basement rock towards the down gradient section north of the proposed CDPF facility footprint where seepage capturing could take place.

Figure 4-3 **Packer test results: Hydraulic Conductivity with depth**

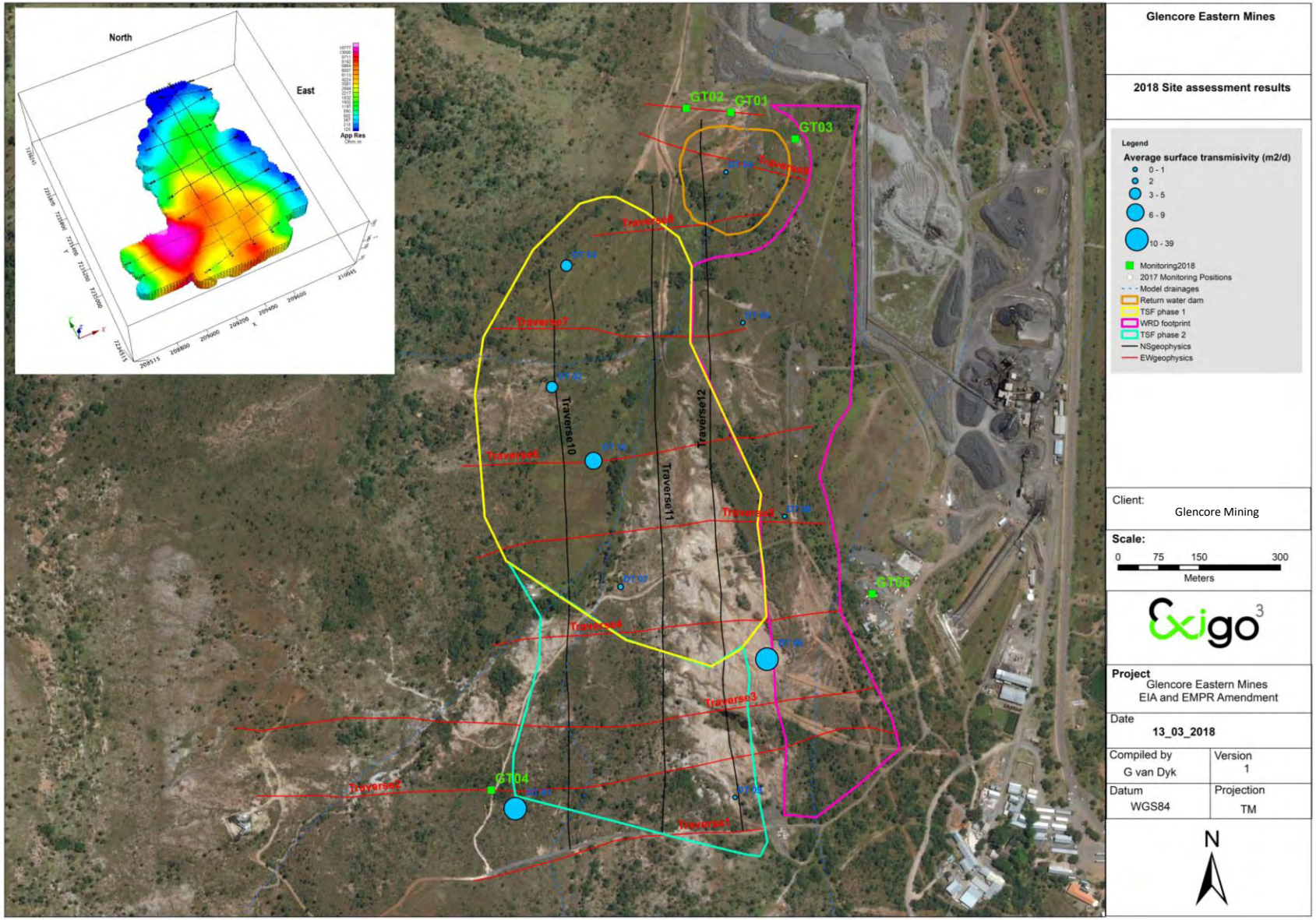

Figure 4-4 **Geophysical traverse positions and DRIT test locations at Thorncliffe new mining developments (2018)**

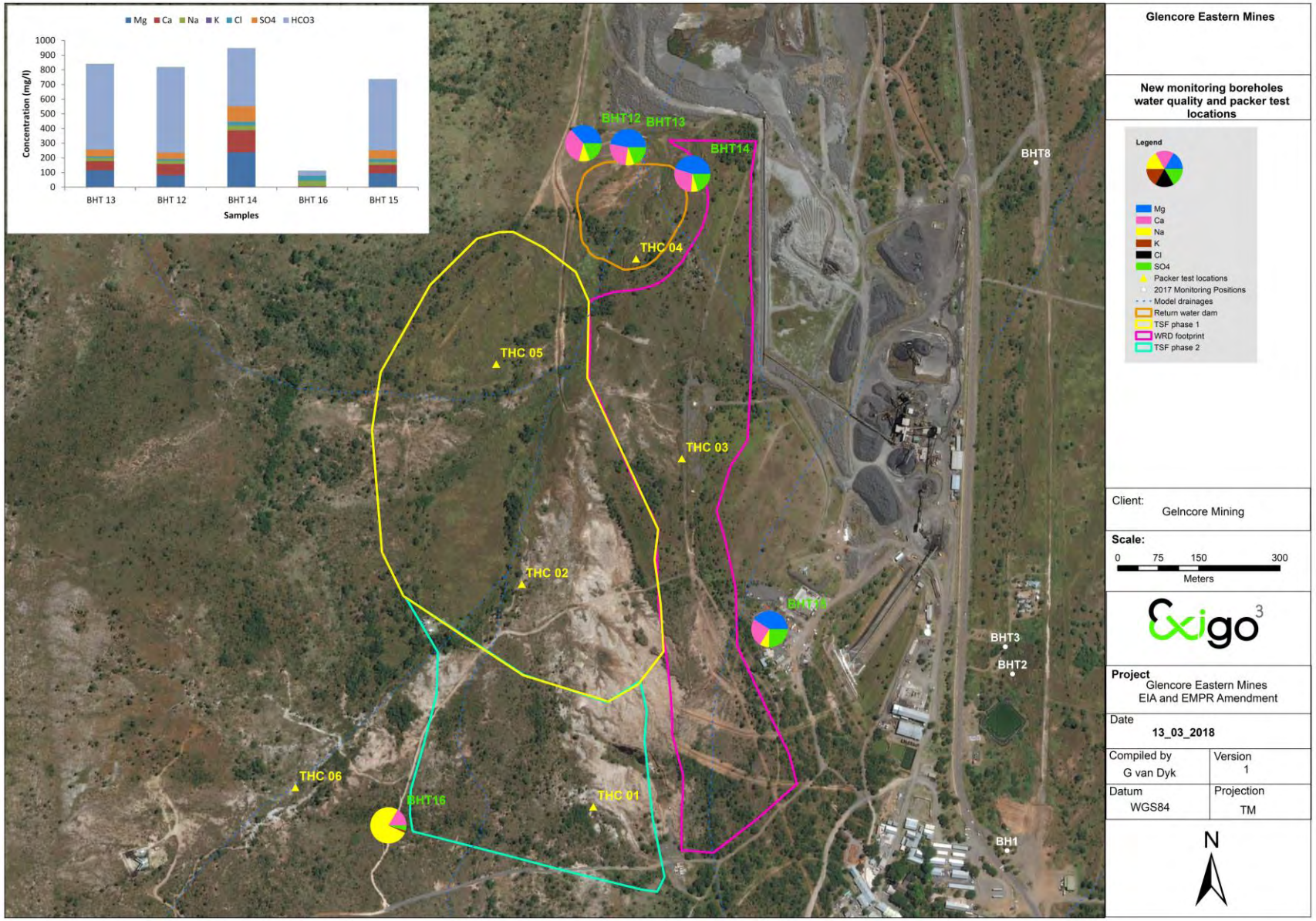

Figure 4-5 **Water quality of the new monitoring boreholes and packer test positions (2018)**

4.2 Helena

The site characterization at the Helena Mining operations included a site inspection within the area south of the proposed new developments (Figure 4-6).

Based on the tests done on the existing monitoring boreholes BHH6 and BHH7 this site is located on a low permeable zone that can be classified as a non-aquifer. Surface or toe seepage is expected to be the main pathway to the surface water zone, and the proposed trench and berm system should be effective for surface seepage capturing (East and South of the proposed WRD). From the analysis it would be beneficial to drill an additional monitoring borehole close to the southern surface drainage, downgradient of the WRD.

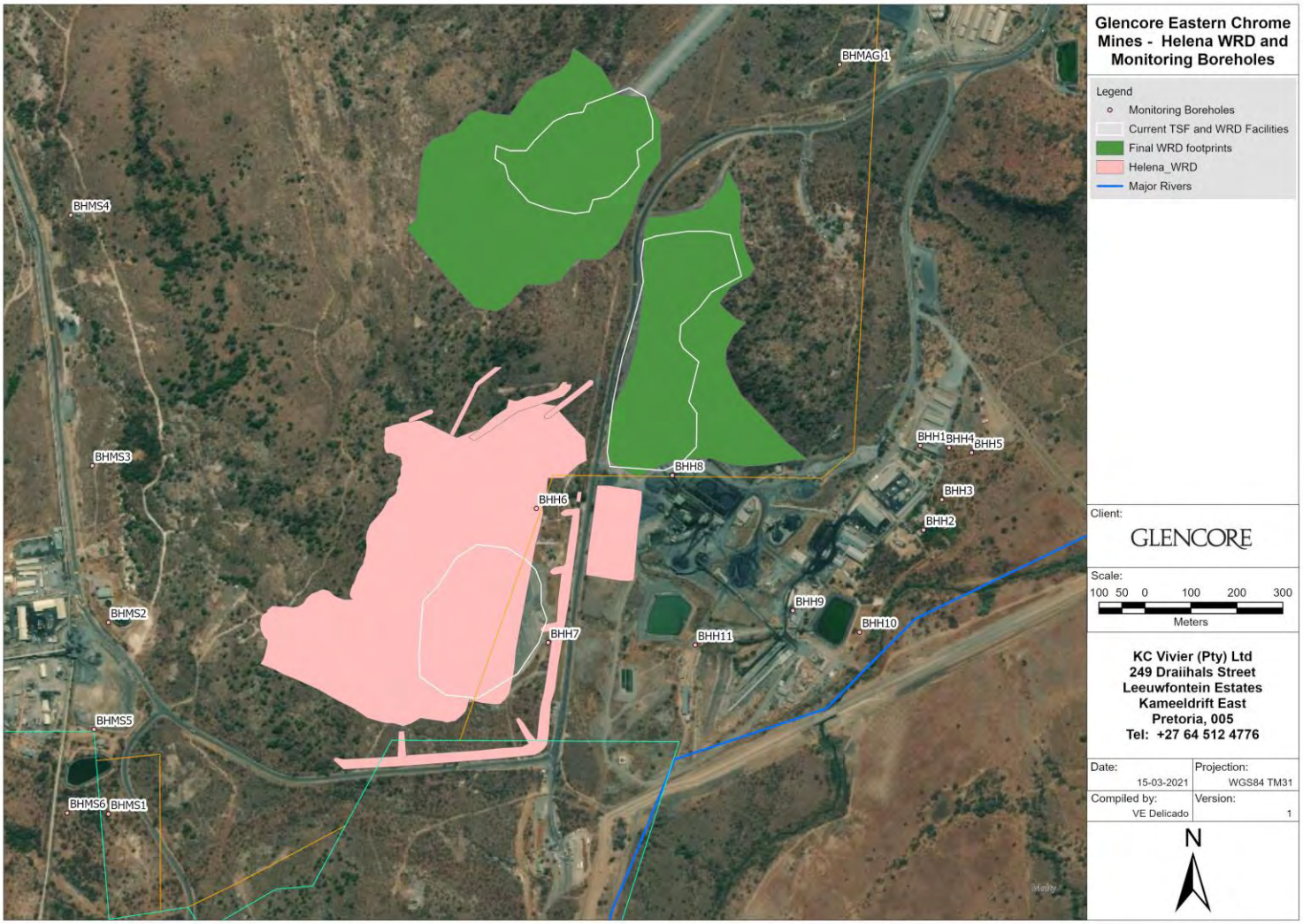

Figure 4-6 Helena mine residue disposal area

4.3 Groundwater levels

The groundwater levels were evaluated as part of the conceptual interpretation of the subsurface aquifer zones and compartmentalization of geological structures. A total of 91 groundwater levels could be measured from boreholes that include neighbouring mines over the larger mining area. In Figure 4-7 the hydraulic head is plotted against topography, and the figure shows a good correlation factor (R^2 = 0.97) exits. This points to the limited impact of dewatering considering the regional area. This implies that deep mining activities have little to no influence on the shallow aquifer systems, which also verifies that low permeable conditions are expected for the basement bedrock.

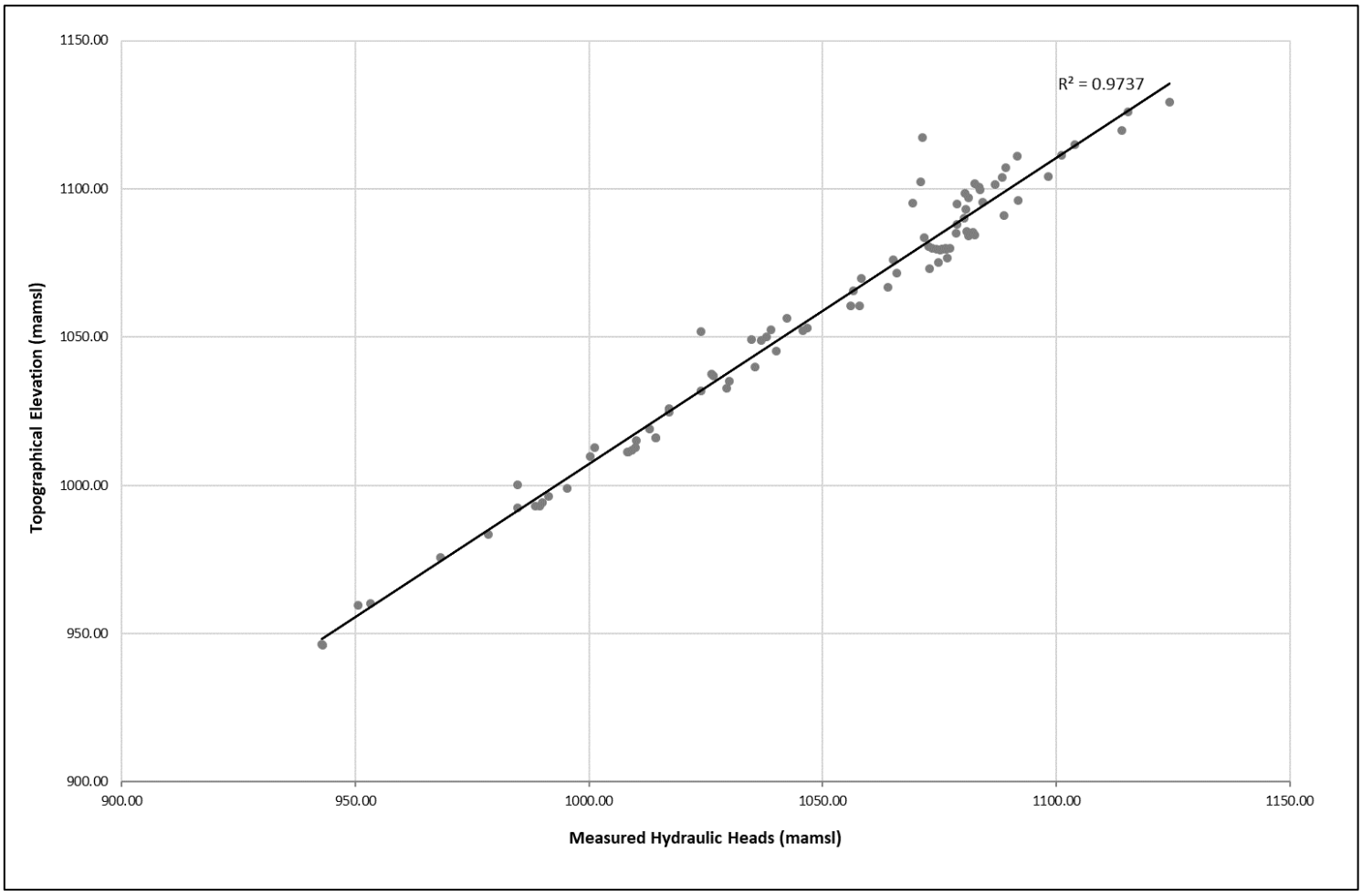

Figure 4-7 Hydraulic head measurements in relation to topography

4.4 Conceptual model: Helena Mining Operations

A section as seen from the south extending from west to east through the Helena mining area which includes the new waste facility is indicated in Figure 4-6. The groundwater movement is downgradient, towards the east in the direction of the Dwars River. An increased nitrate concentration is observed from monitoring positions at up- and down-gradient groundwater positions from the mining operations. Possible dilution also occurs as the up-gradient position (BHH7) indicating a mean nitrate source concentration of 483 mg/ℓ and the down-gradient position (BHH10) with a mean nitrate concentration of 360 mg/ℓ.

The new WRD design is proposed to be situated over the footprint of the historic TSF. The up-gradient sections of the waste facility are likely to be located on basement rocks which suggest increased surface seepage due to increased runoff and limited seepage to the saturated profile. (Figure 4-8).

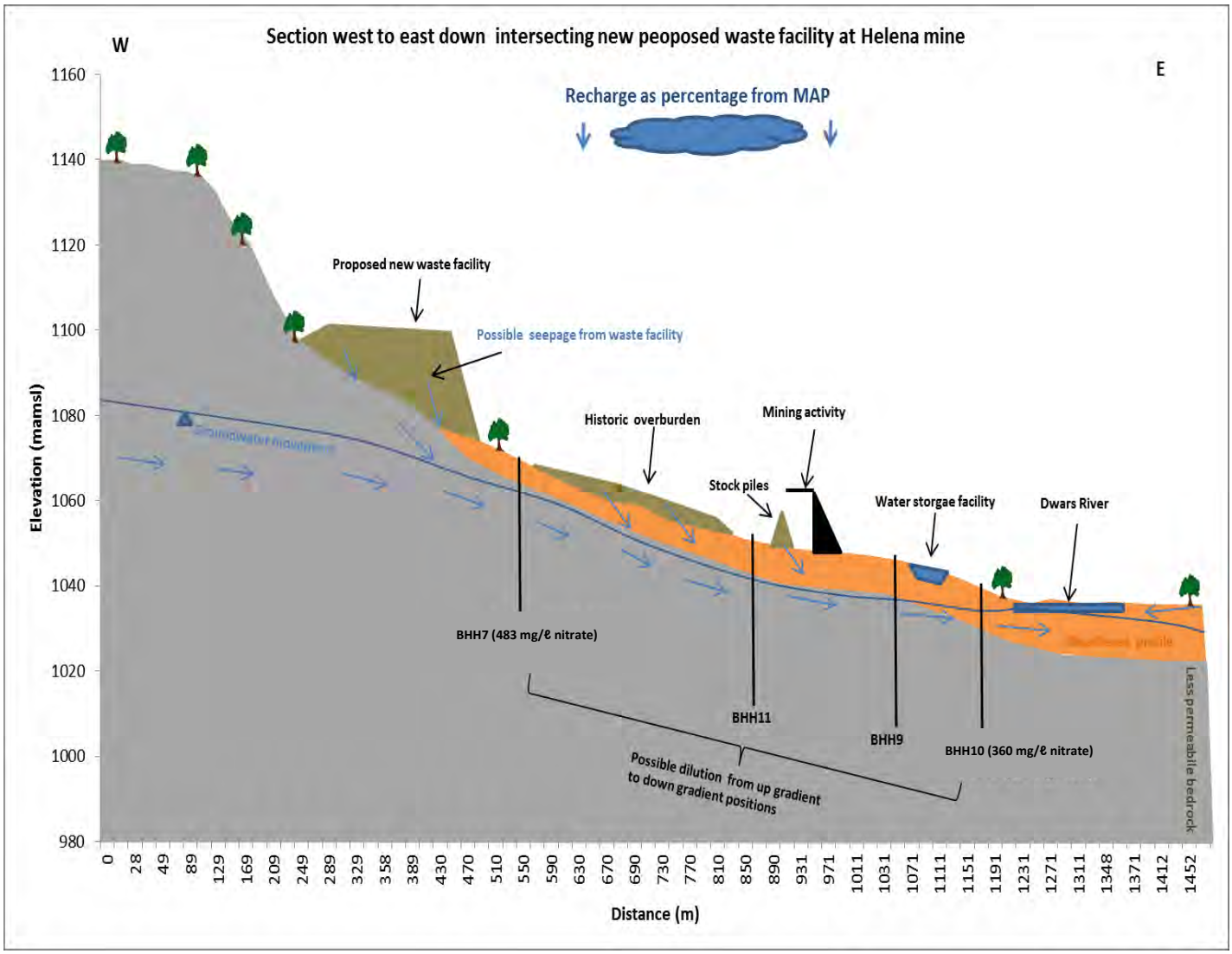

Figure 4-8 Conceptual model representing waste facility at Helena

4.5 Conceptual model: Thorncliffe Mining Operations

The conceptual section through the proposed new waste facility at Thorncliffe Mine (). and cross-sections are shown in Figure 4-9 and Figure 4-10.

Figure 4-9 Thorncliffe cross-section locations

Section A indicates the groundwater movement would flow eastward towards the Dwars River along the topographical gradient. The De Groote Boom pit area acts as a sink as evaporation and abstraction draw water from the pit. Seepage capture boreholes were drilled directly upstream (south) of the De Groote Boom pit, which is included in the model scenarios.

The **Section B** intersect indicates the possibility of groundwater flowing away from the current mining infrastructure towards the drainage line west of the current waste facilities as well as to the east towards the down-gradient areas in the direction of the Dwars River. The co-disposal will also be constructed with a surrounding trench and berm system to capture any toe seepage which might occur.

Section C indicates the groundwater movement is northwards and assumed to flow through an

extended weathered profile underlying the new proposed residue facilities. The proposed co-disposal PCD will be constructed within the topographical low (stream), downstream (north) of the co-disposal with the addition of basal drains (±4 m deep) which should capture the bulk of the co-disposal shallow seepage. Any remaining deeper fugitive seepage will be captured via the use of seepage capturing boreholes (BHT12, BHT13 and BHT14 already drilled and being monitored). Both these seepage containment/barrier systems are evaluated within the modelling scenarios.

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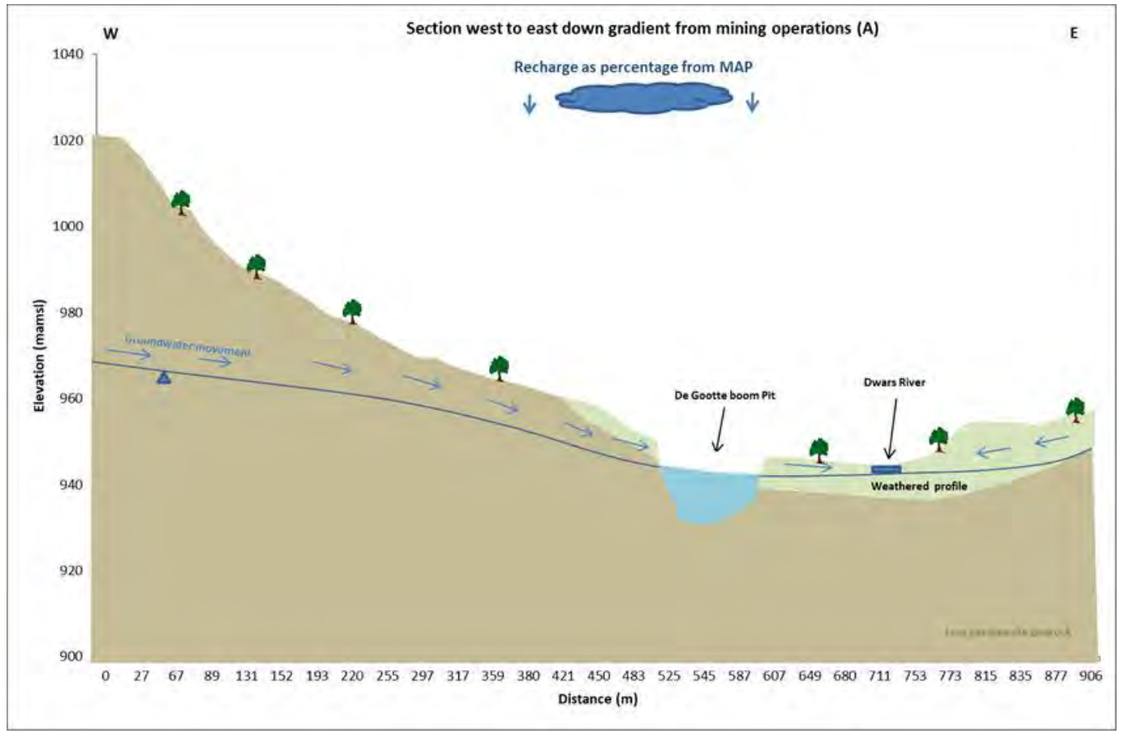
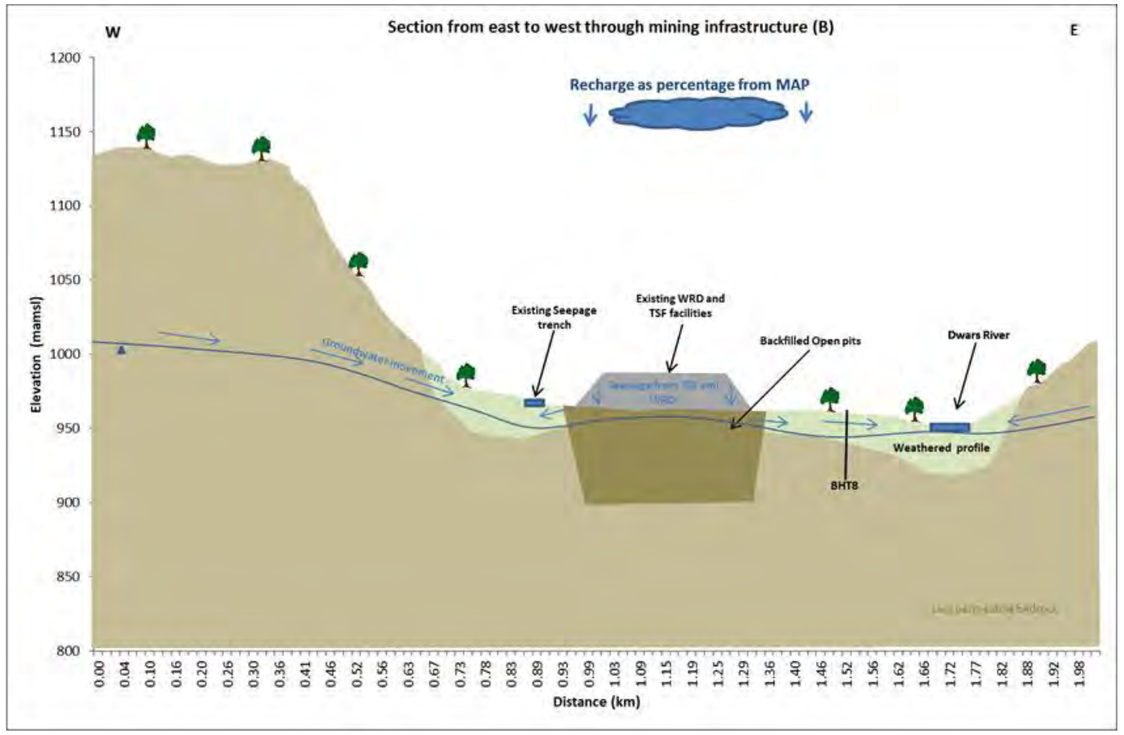
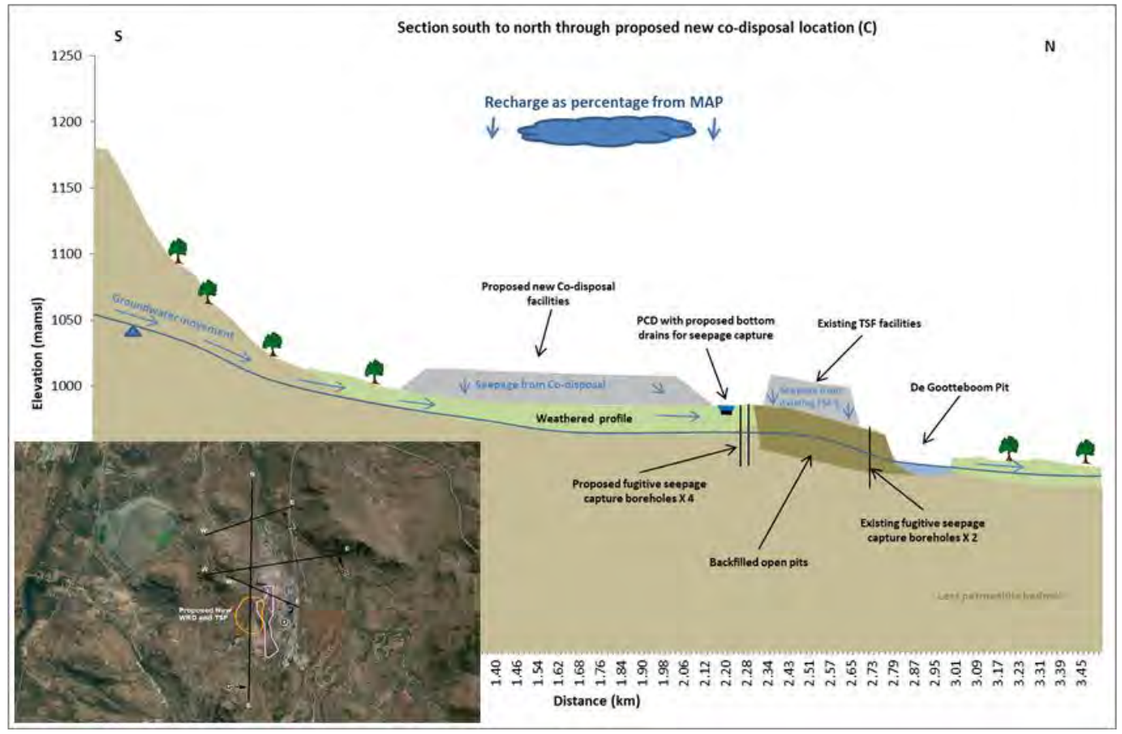






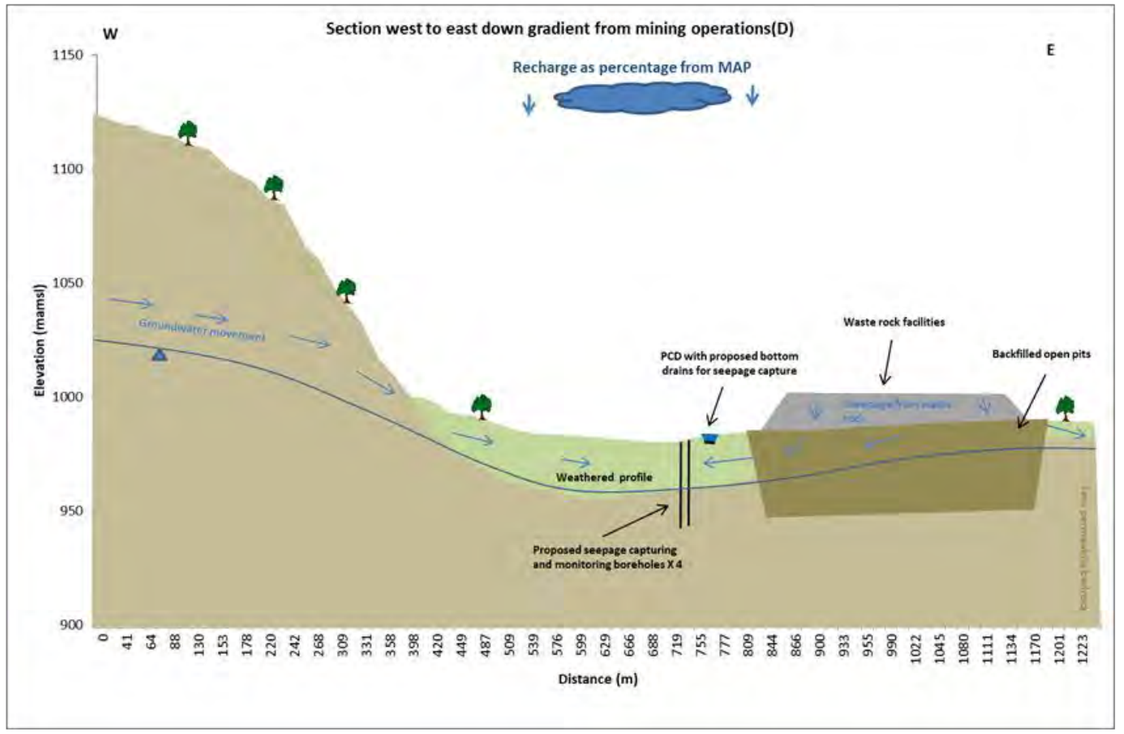


Figure 4-10 Conceptual model representing the new Thorncliffe waste facilities

5 GEOCHEMISTRY AND SOURCE TERM ANALYSIS

During 2017, Exigo Sustainability (Pty) Ltd) conducted a geochemical specialist investigation to determine the leachate potential and waste classification of the Eastern Chrome Mining operations' mine residue. The objective of the study was to conduct a hydro-geochemical leaching potential assessment, verification with monitoring data and waste classification on the mine residue material.

This study primarily follows a risk assessment approach (DEA, 2018, USEPA, 2020, Chang, 1999, Smith, 1996). The GNR 635 analysis parameters were used for the geochemical leach tests. It indicated that the results of both the leachate assessment and the total (solid) assessment need to be considered. Although the waste assessment for the samples were done according to GNR 635, it is our opinion that this regulation was not developed for industrial waste residues and is not applicable to mine wastes without an understanding of the source-pathway-receptor risks. Decision-making regarding management and mitigation measures requires a risk-based approach, which is international best practise that takes the environmental system and dynamics into account and cannot be done on a simplistic waste assessment.

It is important that the laboratory scale leach tests are not as accurate as the 12 years' water monitoring data that should be used for risk analysis and environmental decision-making (see Section 3).

5.1 Materials and methodology

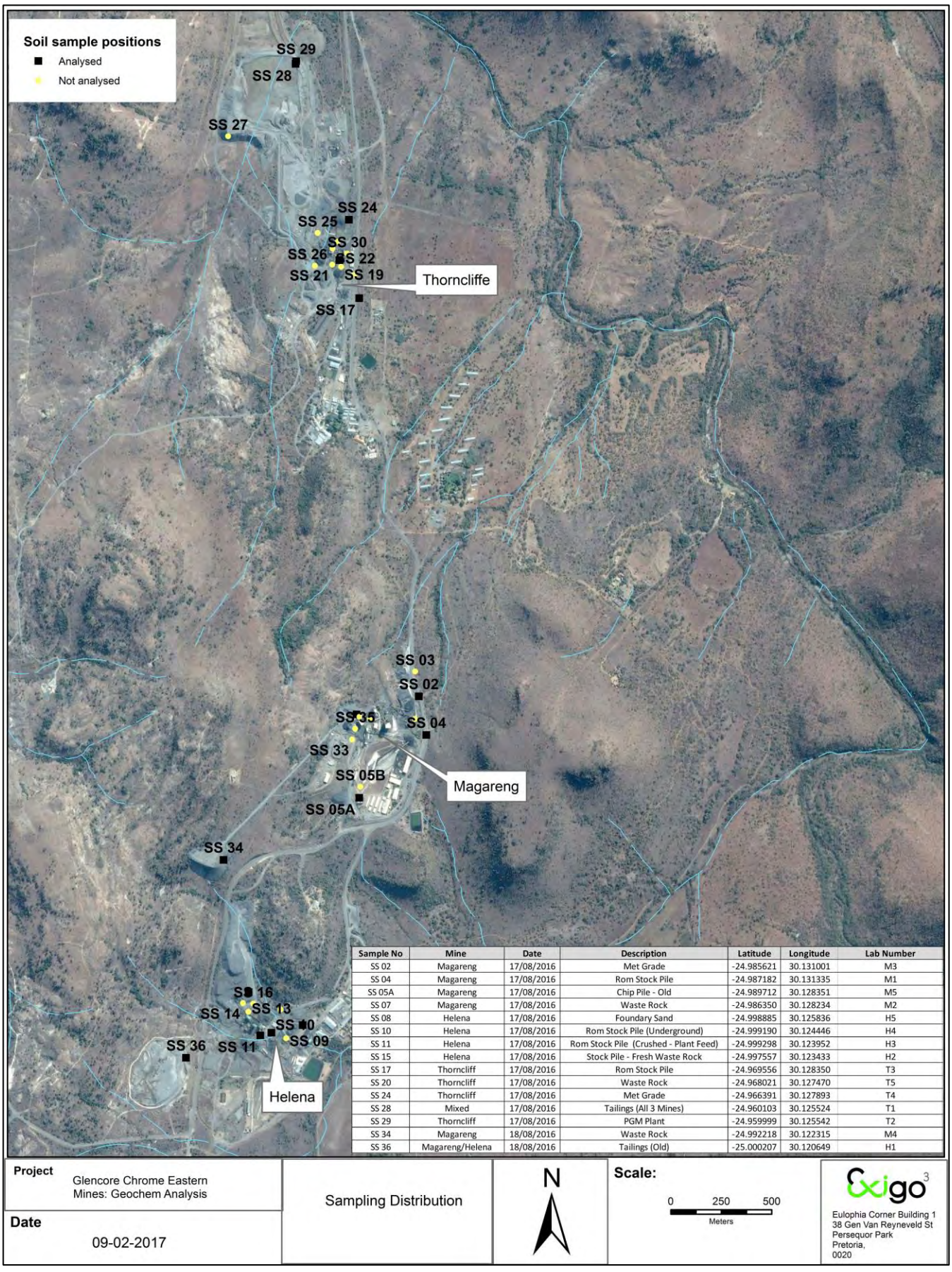
A total of 37 samples of 1 kg each were taken from mine residue and stockpile facilities as follows (Figure 5-1):

1. Helena: 10 samples were composited and 4 were sent for lab analyses.
2. Magareng: 14 samples were composited and 5 were sent for lab analyses.
3. Thorncliffe: 13 samples taken and composited of which 5 were sent to the lab.
4. One composite sample from Helena, Magareng and Thorncliffe tailings were taken as these 3 mine sections tailings are deposited on the same facility at Thorncliffe.

The composite samples were sent to Waterlab for the following analyses:

- XRD analysis for mineralogical composition.
- Aqua regia whole rock digest and ICP-MS analysis of the leachate to determine the metal and macro-chemical composition.
- A distilled water leach was done to simulate leaching potential from rainfall.

A waste classification on the mine residues were conducted in line with Regulation 635 (GNR 635), pertaining to NEMWA on the samples send to the laboratory for analysis. Reagent water leach tests, in accordance with the GNR 635, were used to determine the leachate composition.



Sample No	Mine	Date	Description	Latitude	Longitude	Lab Number
SS 02	Magareng	17/08/2016	Met Grade	-24.985621	30.131001	M3
SS 04	Magareng	17/08/2016	Rom Stock Pile	-24.987182	30.131335	M1
SS 05A	Magareng	17/08/2016	Chip Pile - Old	-24.989712	30.128351	M5
SS 07	Magareng	17/08/2016	Waste Rock	-24.986350	30.128234	M2
SS 08	Helena	17/08/2016	Foundary Sand	-24.998885	30.125836	H5
SS 10	Helena	17/08/2016	Rom Stock Pile (Underground)	-24.999190	30.124446	H4
SS 11	Helena	17/08/2016	Rom Stock Pile (Crushed - Plant Feed)	-24.999298	30.123952	H3
SS 15	Helena	17/08/2016	Stock Pile - Fresh Waste Rock	-24.997557	30.123433	H2
SS 17	Thorncliff	17/08/2016	Rom Stock Pile	-24.969556	30.128350	T3
SS 20	Thorncliff	17/08/2016	Waste Rock	-24.968021	30.127470	T5
SS 24	Thorncliff	17/08/2016	Met Grade	-24.966391	30.127893	T4
SS 28	Mixed	17/08/2016	Tailings (All 3 Mines)	-24.960103	30.125524	T1
SS 29	Thorncliff	17/08/2016	PGM Plant	-24.959999	30.125542	T2
SS 34	Magareng	18/08/2016	Waste Rock	-24.992218	30.122315	M4
SS 36	Magareng/Helena	18/08/2016	Tailings (Old)	-25.000207	30.120649	H1

Figure 5-1 **Helena, Magareng & Thorncliffe sections stockpile and mine residue sampling sites.**

5.2 XRD mineralogy analysis: Helena, Magareng and Thorncliffe

The XRD analysis indicated that the mineralogical chemical composition consists mainly of oxide minerals with chromite (48%), enstatite (28%), Talc (8.8%), plagioclase feldspar (7.4%) and biotite (4.8%) that constitutes more than 95% of the samples (Table 5-2). The mineral chemistry is dominated by Cr, Fe, Al, Mg, SiO_2 and Na (Table 5-1).

Table 5-1 Helena, Magareng, Thorncliffe mineral composition.

Mineral	Chemical composition
Actinolite	$Ca_2(Mg,Fe)5Si_8O_{22}(OH)$
Chromite	$FeCr_2O_4$
Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(OH)_2$
Enstatite	$MgSiO_3$
Kaolinite	$Al_4(OH)_8(Si_4O_{10})$
Plagioclase	$(Na,Ca)(Si,Al)_4O_8$
Talc	$Mg_3(Si_2O_5)_2(OH)_2$
Augite	$(Ca,Na)(Mg,Fe,Al)(Al,Si)_2O_6$
Smectite	$(Na,Ca)0,_3(Al,Mg)_2Si_4O_{10}(OH)_2 \bullet n(H_2O)$

Table 5-2 Helena, Magareng, Thorncliffe Chrome Mines residue XRD analysis results.

Sample number	Site	Mine	Chromite (%)	Enstatite (%)	Biotite (%)	Actinolite (%)	Plagio-clase (%)	Kao-linite (%)	Augite (%)	Talc (%)	Smec-tite (%)	Total
SS 08	Foundary Sand	Helena	100	0	0	0	0	0	0	0	0	100.00
SS 10	Rom Stockpile (UG)		49.7	25.23	4.07	0.03	7.67	1.02	0.73	10.02	1.53	100.00
SS 11	Rom Stockpile (Crushed-Plant Feed)		48.59	21.78	6.47	1.8	6.44	1.33	0.72	10.85	2.02	100.00
SS 15	Stockpile - Fresh Waste Rock		9.49	48.23	5.61	1.35	17.64	2.96	0.45	11.19	3.08	100.00
SS 36	Tailings (Old)		43.52	16.62	3.51	0.7	11.21	2.04	0.4	18.94	3.06	100.00
SS 02	Met Grade	Magareng	90.02	3.99	0	0	4.96	0	1.03	0	0	100.00
SS 04	Rom Stockpile		50.13	25.16	8.3	0.92	8.84	0.25	0.79	5.6	0	99.99
SS 05A	Chip Pile - Old		58.9	25.57	6.23	0.73	3.9	0	0.32	4.35	0	100.00
SS 34	Waste Rock		11.32	69.96	2.73	1.172	5.02	1.74	0.38	7.73	0	100.05
SS 07	Waste Rock		13.57	66.78	6.27	0.55	5.33	2.29	0.49	4.71	0	99.99
SS 17	Rom Stockpile	Thorncliffe	53.06	31.39	6.94	0.22	3.03	0.51	0.33	3.74	0.78	100.00
SS 20	Waste Rock		21.02	57.95	4.58	1.5	3.27	0.99	0.54	9.13	1.02	100.00
SS 24	Met Grade		89.41	3.91	0	0	5.84	0	0.84	0	0	100.00
SS 29	PGM Plant		33.15	17.1	7.61	0.05	14	1.93	0.26	22	3.91	100.01
SS 28	Tails (MG,H & TC)		34.49	16.27	7.61	0	13.45	1.54	0.43	23.11	3.1	100.00
	Average		**47.09**	**28.66**	**4.66**	**0.60**	**7.37**	**1.11**	**0.51**	**8.76**	**1.23**	
	Stdev		**28.65**	**22.30**	**2.87**	**0.63**	**4.81**	**0.96**	**0.26**	**7.56**	**1.44**	
	95th percentile		**93.01**	**67.73**	**7.82**	**1.59**	**15.09**	**2.49**	**0.90**	**22.33**	**3.34**	
	5th percentile		**10.77**	**2.74**	**0.00**	**0.00**	**2.12**	**0.00**	**0.18**	**0.00**	**0.00**	

5.3 Hydro-geochemical leach test analysis

In general, elevated metal contents are expected due to the geology associated with chrome and platinum mines. Mafic to ultramafic igneous rocks generally weather to clay minerals, which have significant adsorption potential for metals and metalloids. There is therefore no risk for acid rock drainage (ARD) as sulphide content is insignificantly low.

5.3.1 Helena Mining Operations

The macro-chemical leachate analysis indicated the following (Table 5-3):

1. The foundry sand leachate pH is acidic at 5.8, but all the other samples have a neutral (7.2 to 7.5) leachate pH.
2. The TDS at the stockpiles is low and range from 80 mg/ℓ to 116 mg/ℓ. The TDS at the paste tailings facility is elevated at 1681 mg/ℓ. This concentration exceeds the SANS 241-2015 drinking water quality standard.
3. The sulphate of the paste tailings facility is moderate to high at 209 mg/ℓ, with the concentration still below the SANS 241-2015 drinking water quality standard.
4. Nitrate (as N) concentrations are moderate at the stockpiles, ranging between 4 mg/ℓ to 11 mg/ℓ and exceedingly high at the paste tailings facility at 243 mg/ℓ (these high concentrations are expected at tailings facilities due to blasting). The SANS 241-2015 drinking water quality standards is 11 mg/ℓ.

Except for the foundry sand stockpile, no significant leaching of metals is expected as the pH is neutral. Metalloids such as Cr could be mobile under neutral to alkaline conditions. The metal leach analysis confirmed that the foundry sand has the potential to leach low levels of Cr. The Cr is derived from the ore and low concentrations are present in the surface and groundwater. There is no risk for acid rock drainage (ARD) as the sulphate mineral content is far exceeded by the alkaline buffer capacity. NO_3-N has the potential to leach from the ROM stockpiles, but as concluded from the long-term monitoring data, is a naturally decaying element (half-life calculated at ±300 days). The nitrate originates from explosives as the XRD analyses confirmed that there is no nitrate bearing minerals in the mine material.

Table 5-3 Helena mine residue chemical and distilled water leach test results (macro-parameters).

Helena	SS 08	SS 10	SS 11	SS 15	SS 36
Sample Number	**17211**	**17212***	**17213**	**17214**	**17215***
TCLP / Acid Rain / Distilled Water / H_2O_2	**Distilled Water**	**Distilled Water**	**Distilled Water**	**Distilled Water**	**Distilled Water**
Dry Mass Used (g)	**50**	**50**	**50**	**50**	**50**
Volume Used (mℓ)	**1000**	**1000**	**1000**	**1000**	**1000**
pH-Value at 25˚C	5.8	7.2	7.5	7.5	7.2
Electrical Conductivity in mS/m at 25˚C	1.5	12.3	14.2	9.0	208
Inorganic Anions	**mg/ℓ**	**mg/ℓ**	**mg/ℓ**	**mg/ℓ**	**mg/ℓ**
Total Dissolved Solids at 180 ˚C	12	79	116	56	1681
Total Alkalinity as $CaCO_3$	12	28	24	16	24
Bicarbonate Alkalinity as CaCO3 (calc)	12	28	24	16	24
Phenolphthalein Alkalinity as $CaCO_3$	<5	<5	<5	<5	<5
Carbonate as CO_3 (calc)	<5	<5	<5	<5	<5
Chloride as Cl	<2	<2	<2	<2	10
Sulphate as SO_4	<2	<2	<2	<2	209
Nitrate as N	0.9	10	11	4.1	243

5.3.2 Magareng Mining Operations

The macro-chemical leachate analysis indicated the following (Table 5-4):

1. The leachate pH for the waste rock sample (SS 07) is alkaline (8.7) and close to neutral (6.2 to 7.5) for all the other samples.
2. The TDS concentrations of the waste rock range from 14-53 mg/ℓ, with the stockpile concentrations ranging from 48 mg/ℓ to 70 mg/ℓ.
3. The sulphate concentrations are low at <2 mg/ℓ.
4. Nitrate (as N) concentrations are slightly elevated at the stockpiles (7 mg/ℓ), but still below the SANS 241-2015 drinking water quality standard.

The metal leach analysis confirmed that the met grade, chip pile and waste rock have the potential to leach low levels of Cr (Table 5-7). The pH is almost neutral and hence no significant leaching of metals is expected (Table 5-7). There is no risk for acid rock drainage (ARD) as the sulphide content is far exceeded by the alkaline buffer capacity. The nitrate originates from explosives as the XRD analyses confirmed that there is no nitrate bearing minerals in the mined material.

Table 5-4 Magareng mine residue chemical and distilled water leach test results (macro-parameters).

Magareng	**SS 02**	**SS 04**	**SS 05A**	**SS 34**	**SS 07**
Sample Number	**17206**	**17207**	**17208**	**17209**	**17210***
TCLP / Acid Rain / Distilled Water / H_2O_2	**Distilled Water**	**Distilled Water**	**Distilled Water**	**Distilled Water**	**Distilled Water**
Dry Mass Used (g)	**50**	**50**	**50**	**50**	**50**
Volume Used (mℓ)	**1000**	**1000**	**1000**	**1000**	**1000**
pH-Value at 25˚C	6.2	7.5	7.5	7.4	8.7
Electrical Conductivity in mS/m at 25˚C	7.4	10.5	3.8	4.3	9.5
Inorganic Anions	**mg/ℓ**	**mg/ℓ**	**mg/ℓ**	**mg/ℓ**	**mg/ℓ**
Total Dissolved Solids at 180 ˚C	48	70	14	28	53
Total Alkalinity as $CaCO_3$	<5	28	12	20	52
Bicarbonate Alkalinity as $CaCO_3$ (calc)	<5	28	12	20	36
Phenolphthalein Alkalinity as $CaCO_3$	<5	<5	<5	<5	8
Carbonate as CO_3 (calc)	<5	<5	<5	<5	10
Chloride as Cl	<2	<2	<2	<2	<2
Sulphate as SO_4	2	<2	<2	<2	<2
Nitrate as N	7	6.9	<0.1	0.4	0.9

5.3.3 Review of composite sample of Helena and Magareng tailings facilities

The macro leachate results indicated the following:

1. The leachate pH is close to neutral at 7.2.
2. The TDS concentration is elevated at 1681 mg/ℓ and exceeds the SANS 241-2015 drinking water quality standard.
3. Chloride is low at 10 mg/ℓ.
4. The sulphate concentration is moderate (209 mg/ℓ) but below the SANS drinking water standard.
5. The nitrate concentration is high at 243mg/ℓ. This signifcantly exceeds the SANS 241-2015 drinking water quality standard at the source.

The metal leach analysis confirmed that no metals will leach out, but that metalloids such as Cr could potentially leach as they are mobile under neutral to alkaline conditions. The organic anions indicated that TDS and NO_3-N has the potential to leach out. The nitrate originates from explosives as the XRD analyses confirmed that there is no nitrate bearing minerals in the mined material. Nitrate naturally decays as it moves through the sub surface, with a calculated half-life of ±300 days (Section 3.2.2).

5.3.4 Thorncliffe Mining Operations

The macro-chemical leachate (LCT) analysis indicated the following (Table 5-5):

1. The leachate pH is close to neutral at 7.1 to 7.7 for all samples.
2. The TDS for the waste rock and stockpile areas is low, ranging from 22 mg/ℓ to 166 mg/ℓ (the SANS 241-2015 drinking water quality standard for TDS is 1200 mg/ℓ).
3. The sulphate concentrations are low, ranging from 2 mg/ℓ to 14 mg/ℓ.
4. Nitrate (as N) concentrations are moderate to elevated at the stockpiles and range between 7 mg/ℓ to 12 mg/ℓ and elevated above at the SANS 241-2015 drinking water quality standard at the PGM plant (17 mg/ℓ).

The metal leach analysis confirmed that the waste rock and PGM plant has the potential to leach low levels of Cr, which is not mobile in the groundwater as confirmed by the monitoring data (Exigo, 2019). Due to the neutral pH, no leaching of metals is expected (Table 5-5). There is no risk for acid rock drainage (ARD) as the sulphide content is far exceeded by the alkaline buffer capacity. The nitrate originates from explosives as the XRD analyses confirmed that there is no nitrate bearing minerals in the mined material.

Table 5-5 Thorncliffe mine residue chemical and distilled water leach test results (macro-parameters).

Thorncliffe	SS 17	SS 20	SS 24	SS 29	SS 28
Sample Number	**17216**	**17217**	**17218**	**17219**	**17220**
TCLP / Acid Rain / Distilled Water / H_2O_2	**Distilled Water**	**Distilled Water**	**Distilled Water**	**Distilled Water**	**Distilled Water**
Dry Mass Used (g)	**50**	**50**	**50**	**50**	**50**
Volume Used (mℓ)	**1000**	**1000**	**1000**	**1000**	**1000**
pH-Value at 25˚C	7.7	7.5	7.1	7.6	7.6
Electrical Conductivity in mS/m at 25˚C	15.5	3.9	7.7	24.0	130.3
Inorganic Anions	**mg/ℓ**	**mg/ℓ**	**mg/ℓ**	**mg/ℓ**	**mg/ℓ**
Total Dissolved Solids at 180 ˚C	130	22	62	166	1158
Total Alkalinity as $CaCO_3$	20	8	28	28	28
Bicarbonate Alkalinity as $CaCO_3$ (calc)	20	8	28	28	28
Phenolphthalein Alkalinity as $CaCO_3$	<5	<5	<5	<5	<5
Carbonate as CO_3 (calc)	<5	<5	<5	<5	<5
Chloride as Cl	<2	<2	<2	2	26
Sulphate as SO_4	2	<2	2	14	49
Nitrate as N	12	0.3	6.8	17	137

5.3.5 Review of the composite sample of all 3 tailings facilities (SS 28)

The macro leachate results indicated the following:

1. The leachate pH is close to neutral at 7.6.
2. The TDS concentration is elevated at 1158 mg/ℓ, but still below the SANS 241-2015 drinking water quality standards.
3. Chloride concentrations are moderate at 26 mg/ℓ.
4. The sulphate is low (49 mg/ℓ).
5. The nitrate concentration is high at 137 mg/ℓ. This far exceeds the SANS 241-2015 drinking water quality standard but is expected due to blasting of the ore.

The leach analysis confirmed that the inorganic anions such as NO_3-N have the potential leach out.

5.4 Waste assessment

Although the waste assessment was done according to regulation GNR635, it is our opinion that the regulation was not developed for mine residues and is therefore not applicable. Decision-making with regards to management and mitigation measures requires a risk-based approach that takes the system dynamics into account, which cannot be done with the simplistic waste classification regulations.

5.4.1 Total concentration assessment

The assessment of the total concentration values according to GNR 635 requires analysis of the total (solid) concentration of specific chemical constituents in the waste rock solid phase. The results are compared to the Total Concentration Threshold (TCT) values stipulated in GNR 635.

The whole rock total concentration (TCT) analyses indicated B, Ba, Co, Cr, Cu, Ni, Mn, V, Zn and Total fluoride exceeds the threshold values for TCT0. The TCT concentrations are irrelevant for the water pathways.

5.4.2 Leachate assessment

The leach assessment according to Regulation 635 (GNR 635) requires a distilled water leach for non-putrescible waste. After the leach test is completed, the leachate, i.e., the fluid phase, is analysed for its chemical composition and the results compared to the Leach Concentration Threshold (LCT) values stipulated in GNR 635. The regulation has four categories (LCT0 to LCT3), with each category corresponding to higher concentrations of chemical constituents, and therefore also corresponds to a higher hazard rating for the specific waste.

The leachable concentration (LCT) analyses showed that Cr, TDS and NO_3-N exceed the threshold values for LCT0 (Table 5-6, Table 5-7 and Table 5-8).

Table 5-6 Helena mine whole rock and distilled water leach test results (metals and micro-parameters).

Parameter	R635 Total Concentration Threshold Values			R635 Leach Concentration Threshold Values				SS08		SS10		SS11		SS15		SS36	
	Helena =H, Magareng= M, Thorncliffe=T							H	Foundary Sand	H	Rom Stockpile (underground)	H	Rom Stockpile (crushed plant feed)	H	Stockpile (fresh waste rock)	M and H	Tailings
	TCT0	TCT1	TCT2	LCT0	LCT1	LCT2	LCT3	TCT	LCT	TCT	LCT	TCT	LCT	TCT	LCT	TCT	LCT
Sample no								17211	17211	17212	17212	17213	17213	17214	17214	17215	17215
Unit	mg/kg	mg/kg	mg/kg	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ
Metal ions																	
Al								18400	0.171	18000	0.223	14400	<0.100	22000	0.245	39200	<0.100
As	5.8	500	2 000	0.01	0.5	1	4	<4	<0.001	<4	<0.001	<4	<0.001	<4	0.001	<4	0.001
B	150	15 000	60 000	0.5	25	50	200	159	<0.001	105	0.004	134	0.003	39	<0.001	<4	0.012
Ba	62.5	6 250	25 000	0.7	35	70	280	<4	0.028	16	0.011	13	0.006	33	0.004	46	0.066
Ca								<400	1	7200	13	6400	14	20000	8	18400	235
Cd	7.5	260	1 040	0.003	0.15	0.3	1.2	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001
Co	50	5 000	20 000	0.5	25	50	200	116	<0.001	76	<0.001	64	<0.001	56	<0.001	136	<0.001
Cr	46 000	800 000	n.a	0.1	5	10	40	133200	0.24	63200	0.081	52800	0.003	6400	0.035	122800	0.005
Cu	16	19 500	78 000	2	100	200	800	<4	<0.001	16	<0.001	25	<0.001	49	0.001	51	0.002
Fe								65600	0.382	43600	0.377	38800	<0.025	38800	0.43	66800	<0.025
Hg	0.93	160	640	0.006	0.3	0.6	2.4	<4		<4		<4		<4		<4	
K								<200	<0.5	700	0.8	727	<0.5	1450	0.5	2378	22
Mg								14400	<1	31200	2	26800	1	55200	1	50400	68
Mn	1 000	25 000	100 000	0.5	25	50	200	717	<0.025	782	<0.025	722	<0.025	1170	<0.025	1104	<0.025
Mo	40	1 000	4 000	0.07	3.5	7	28	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	0.007
Na								<400	<1	1200	2	1200	2	4400	2	3600	46
Ni	91	10 600	42 400	0.07	3.5	7	28	863	0.003	670	0.007	597	<0.001	683	0.006	1195	0.016
Pb	20	1 900	7 600	0.01	0.5	1	4	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	12	<0.001
Sb	10	75	300	0.02	1.0	2	8	<4	<0.001	<4	0.002	<4	<0.001	<4	<0.001	<4	<0.001
Se	10	50	200	0.01	0.5	1	4	<4	<0.001	<4	<0.001	<4	<0.001	<4	0.007	<4	0.004
Si								2587	0.8	77600	3.0	74000	0.4	186800	3.7	118800	1.2
Te									<0.001		<0.001		<0.001		<0.001		<0.001
Th								<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	0.004
U								<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001
V	150	2 680	10 720	0.2	10	20	80	777	0.002	414	0.002	347	<0.001	141	0.003	862	<0.001
Zn	240	160 000	640 000	5	250	500	2 000	292	0.004	161	0.095	133	<0.001	56	<0.001	303	<0.001
Inorganic Anions																	
TDS				1000	12500	25000	100000		**12**		**79**		**116**		**56**		**1681**
Cl				300	15000	30000	120 000		**<2**		**<2**		**<2**		**<2**		**10**
Total F	100	1 000	40 000	1.5	75	150	600	116		130		125		142		141	
SO_4				250	12500	25000	100000		**<2**		**<2**		**<2**		**<2**		**209**
NO_3-N				11	550	1100	4400		**0.9**		**10**		**11**		**4.1**		**243**
Total CN^-	14	10 500	42 000	0.07	3.5	7	28	<0.05		<0.05		<0.05		<0.05		<0.05	

Table 5-7 Magareng mine whole rock and distilled water leach test results (metals and micro-parameters).

Parameter	R635 Total Concentration Threshold Values			R635 Leach Concentration Threshold Values				SS02		SS04		SS05		SS34		SS07		SS36	
	Helena =H, Magareng= M, Thorncliffe=T							M	Met Grade	M	Rom Stockpile	M	Chip pile	M	Waste Rock	M	Waste Rock	M and H	Tailings
	TCT0	TCT1	TCT2	LCT0	LCT1	LCT2	LCT3	TCT	LCT	TCT	LCT	TCT	LCT	TCT	LCT	TCT	LCT	TCT	LCT
Sample no								17206	17206	17207	17207	17208	17208	17209	17209	17210	17210	17215	17215
Unit	mg/kg	mg/kg	mg/kg	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ
Metal ions																			
Al								18400	0.138	15200	<0.100	14800	0.273	14400	1.090	18800	0.156	39200	<0.100
As	5.8	500	2 000	0.01	0.5	1	4	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	0.001
B	150	15 000	60 000	0.5	25	50	200	73	<0.001	139	<0.001	202	0.001	<4	<0.001	13	<0.001	<4	0.012
Ba	62.5	6 250	25 000	0.7	35	70	280	<4	0.001	18	0.009	13	0.007	27	0.007	32	0.005	46	0.066
Ca								800	5	6000	10	6000	3	12400	5	19200	8	18400	235
Cd	7.5	260	1 040	0.003	0.15	0.3	1.2	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001
Co	50	5 000	20 000	0.5	25	50	200	136	<0.001	55	<0.001	62	<0.001	68	0.002	67	<0.001	136	<0.001
Cr	46 000	800 000	n.a	0.1	5	10	40	140800	0.11	48400	0.008	52400	0.217	16400	0.472	14400	0.004	122800	0.005
Cu	16	19 500	78 000	2	100	200	800	12	<0.001	10	<0.001	10	<0.001	16	0.002	23	<0.001	51	0.002
Fe								64800	0.143	34400	<0.025	37200	0.323	36000	2.73	49600	0.043	66800	<0.025
Hg	0.93	160	640	0.006	0.3	0.6	2.4	<4		<4		<4		<4		<4		<4	
K								<200	<0.5	972	<0.5	645	0.6	1084	0.6	1508	3.6	2378	22
Mg								15200	3	26400	3	29600	1	57200	3	77600	4	50400	68
Mn	1 000	25 000	100 000	0.5	25	50	200	813	<0.025	601	<0.025	678	<0.025	1236	0.056	1271	<0.025	1104	<0.025
Mo	40	1 000	4 000	0.07	3.5	7	28	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	0.007
Na								<400	1	800	1	800	<1	1600	<1	3200	2	3600	46
Ni	91	10 600	42 400	0.07	3.5	7	28	988	0.003	514	<0.001	592	0.005	763	0.039	789	<0.001	1195	0.016
Pb	20	1 900	7 600	0.01	0.5	1	4	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	12	<0.001
Sb	10	75	300	0.02	1.0	2	8	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001
Se	10	50	200	0.01	0.5	1	4	<4	0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	0.004
Si								12400	0.8	60800	0.7	75200	2.5	176400	19.3	189200	3.6	118800	1.2
Te									<0.001		<0.001		<0.001		<0.001		<0.001		<0.001
Th								<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	0.004
U								<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001
V	150	2 680	10 720	0.2	10	20	80	904	0.001	301	<0.001	338	0.003	148	0.008	159	0.003	862	<0.001
Zn	240	160 000	640 000	5	250	500	2 000	336	<0.001	114	<0.001	125	<0.001	67	<0.001	69	<0.001	303	<0.001
Inorganic Anions																			
TDS				1000	12500	25000	100000		**48**		**70**		**14**		**28**		**53**		**1681**
Cl				300	15000	30000	120 000		**<2**		**<2**		**<2**		**<2**		**<2**		**10**
Total F	100	1 000	40 000	1.5	75	150	600	107		121		121		136		136		141	
SO_4				250	12500	25000	100000		**2**		**<2**	<40	**<2**		**<2**		**<2**		**209**
NO_3-N				11	550	1100	4400		**7**		**6.9**	<2	**<0.1**		**0.4**		**0.9**		**243**
Total CN^-	14	10 500	42 000	0.07	3.5	7	28	<0.05		<0.05		<0.05		<0.05		<0.05		<0.05	

Table 5-8 Thorncliffe mine whole rock and distilled water leach test results (metals and micro-parameters).

Parameter	R635 Total Concentration Threshold Values			R635 Leach Concentration Threshold Values				SS17		SS20		SS24		SS29		SS28	
	Helena =H, Magareng= M, Thorncliffe=T							T	Rom Stockpile	T	Waste Rock	T	Met grade	T	PGM plant	Mixed	Tailings (all 3)
	TCT0	TCT1	TCT2	LCT0	LCT1	LCT2	LCT3	TCT	LCT	TCT	LCT	TCT	LCT	TCT	LCT	TCT	LCT
Sample no								17216	17216	17217	17217	17218	17218	17219	17219	17220	17220
Unit	mg/kg	mg/kg	mg/kg	mg/ℓ	mg/ℓ	mg/ℓ	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ	mg/kg	mg/ℓ
Metal ions																	
Al								14000	0.103	16000	0.889	14000	<0.100	30000	0.258	46800	<0.100
As	5.8	500	2 000	0.01	0.5	1	4	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001
B	150	15 000	60 000	0.5	25	50	200	<4	0.002	<4	<0.001	<4	<0.001	<4	0.009	<4	0.050
Ba	62.5	6 250	25 000	0.7	35	70	280	14	0.008	27	0.004	<4	0.001	72	0.037	87	0.061
Ca								6000	15	11600	4	1200	6	16400	18	24800	84
Cd	7.5	260	1 040	0.003	0.15	0.3	1.2	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001
Co	50	5 000	20 000	0.5	25	50	200	78	<0.001	71	0.002	93	<0.001	71	<0.001	88	<0.001
Cr	46 000	800 000	n.a	0.1	5	10	40	60800	0.034	28800	0.468	99600	0.02	56000	0.159	78000	<0.001
Cu	16	19 500	78 000	2	100	200	800	12	<0.001	29	0.001	4.56	<0.001	54	<0.001	73	<0.001
Fe								38800	0.136	38400	2.48	49600	0.034	38000	0.566	58000	<0.025
Hg	0.93	160	640	0.006	0.3	0.6	2.4	<4		<4		<4		<4		<4	
K								582	0.6	1381	<0.5	218	<0.5	3018	1.2	3696	8.3
Mg								28000	2	54400	1	14000	3	40800	8	65600	44
Mn	1 000	25 000	100 000	0.5	25	50	200	788	<0.025	1172	0.055	598	<0.025	794	<0.025	893	<0.025
Mo	40	1 000	4 000	0.07	3.5	7	28	<4	<0.001	<4	<0.001	<4	<0.001	<4	0.001	<4	0.008
Na								800	3	1600	<1	<400	1	2800	6	5200	52
Ni	91	10 600	42 400	0.07	3.5	7	28	647	<0.001	785	0.033	698	<0.001	831	0.009	1017	0.013
Pb	20	1 900	7 600	0.01	0.5	1	4	<4	<0.001	<4	<0.001	<4	<0.001	8.71	<0.001	11	<0.001
Sb	10	75	300	0.02	1.0	2	8	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001
Se	10	50	200	0.01	0.5	1	4	<4	<0.001	<4	<0.001	6.9	<0.001	<4	<0.001	<4	0.001
Si								79600	1.7	168400	11.7	12800	0.7	140000	4.7	131200	0.3
Te									<0.001		<0.001		<0.001		<0.001		<0.001
Th								<4	<0.001	<4	<0.001	5.65	<0.001	<4	<0.001	<4	<0.001
U								<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001	<4	<0.001
V	150	2 680	10 720	0.2	10	20	80	408	0.001	235	0.007	599	<0.001	398	0.003	509	<0.001
Zn	240	160 000	640 000	5	250	500	2 000	139	<0.001	70	<0.001	201	<0.001	126	<0.001	166	<0.001
Inorganic Anions																	
TDS				1000	12500	25000	100000		**130**		**22**		**62**		**166**		**1158**
Cl				300	15000	30000	120 000		**<2**		**<2**		**<2**		**2**		**26**
Total F	100	1 000	40 000	1.5	75	150	600	131		137		125		173		166	
SO_4				250	12500	25000	100000		**2**		**<2**		**2**		**14**		**49**
NO_3-N				11	550	1100	4400		**12**		**0.3**		**6.8**		**17**		**137**
Total CN^-	14	10 500	42 000	0.07	3.5	7	28	<0.05		<0.05		<0.05		<0.05		<0.05	

5.5 Classification of the mine residue

To be able to anlyse the mine residue, GNR 635 indicates that the results of the Leach Concentration Threshold (LCT) assessment as well as the results from the Total Concentration Threshold (TCT) assessment need to be considered. Although the waste classification was done in accordance with GNR 635, the waste was further classified by incorporating the LCT0, long term ground- and surface water monitoring data (see Section 3: Surface- and Groundwater Monitoring and Baseline Analysis).

Table 5-9 Summary of TCT and LCT exceedances in sampled sites of Helena, Magareng and Thorncliffe

Sample site number	Site description	TCT exceedances	LCT exceedances	Waste type classification (LCT0 and TCT0)	Waste type classification (LCT0 and monitoring data)
Helena					
SS08	Foundary Sand	B, Co, Cr, Ni Ni, V, Zn and Total F	Cr	Type 3	Type 4
SS10	Rom Stockpile (underground)	Co, Cr, Ni, V, and Total F	No exceedances	Type 3	Type 4
SS11	Rom Stockpile (crushed plant feed)	Co, Cr, Ni, V, and Total F	No exceedances but NO_3-N is on the limit for LCT0	Type 3	Type 4
SS15	Stockpile (fresh waste rock)	Co, Cu, Mn, Ni, and Total F	No exceedances	Type 3	Type 4
Magareng					
SS02	Met Grade	Co, Cr, Ni, V, Zn and Total F	Cr	Type 3	Type 4
SS04	Rom Stockpile	Co, Cr, Ni, V and Total F	No exceedances	Type 3	Type 4
SS05	Chip pile	B, Co, Cr, Ni, V, and Total F	Cr	Type 3	Type 4
SS34	Waste Rock	Co, Cr, Mn, Ni, V, and Total F	Cr	Type 3	Type 4
SS07	Waste Rock	Co, Cr, Cu, Mn, Ni and Total F	No exceedances	Type 3	Type 4
Helena and Magareng Composite					
SS36	Tailings (Helena and Magareng composite)	Co, Cr, Cu, Mn, Ni, V, Zn and Total F	TDS and NO_3-N	Type 3	Type 4
Thorncliffe					
SS17	Rom Stockpile	Co, Cr, Ni, V and Total F	NO_3-N	Type 3	Type 3
SS20	Waste Rock	Co, Cu, Mn, Ni, V and Total F	Cr	Type 3	Type 4
SS24	Met grade	Co, Cr, Ni, V and Total F	No exceedances	Type 3	Type 4
SS29	PGM plant	Ba, Co, Cr, Cu, Ni, V and Total F	Cr and NO_3-N	Type 3	Type 4
Helena, Magareng and Thorncliffe Composite					
SS28	Tailings (all 3 composite)	Ba, Co, Cr, Cu, Ni, V and Total F	TDS and NO_3-N	Type 3	Type 4

5.5.1 Helena waste classification

The exceedance the TCT0 and LCT0 for samples are listed in Table 5-9. The following conclusions were made from the Helene mine residue classification:

- In terms of the exceedances of the TCT0 the Foundry sands (SS08), Rom Stockpile-underground (SS10), Rom stockpile-crushed plant feed (SS11) and Rom stockpile-fresh waste rock (SS15) classifies as a Type 3 waste in accordance with GNR 635.
- In terms of the leachate assessment, i.e., the liquid phase, the results indicated that the RoM Stockpile-underground (SS10), RoM stockpile-crushed plant feed (SS11) and RoM stockpile-fresh waste rock (SS15) classifies as a Type 4 waste in accordance with GNR 635 as none of the chemical constituents exceeded the LCT0 regulatory limit.
- The leachate assessment of the Foundry sands (SS08) indicated that the lowest regulatory (LCT0) value was exceeded for Cr. The long-term monitoring data and hydro-geochemical analysis indicated that Cr (due to the adsorption potential of clays weathered from mafic and ultramafic igneous rocks for metals and metalloids.) does not exceed the SANS 241-2015 drinking water quality standard in either groundwater or surface water monitoring and therefore the sample site re-classifies as inert, as a Type 4 waste.

5.5.2 Magareng waste classification

The exceedance of both the TCT0 and LCT0 for each sample site is listed in Table 5-9. The following conclusions were made from the Magareng mine residue classification:

- The lowest regulatory value for the total concentration (TCT0) was exceeded in all the sample sites at Magareng. In term of GNR 635 the Met grade (SS02), Rom Stockpile (SS04), Chip pile (SS05), waste rock (SS34) and Waste rock (SS07) classifies as Type 3 waste. The TCT values are irrelevant for the water pathways.
- The leachate assessment indicated that the lowest regulatory (LCT0) value for Cr was exceeded in the met grade (SS04), chip pile (SS05) and waste rock (SS07). In accordance with Regulation 635 these sample sites classify as Type 3 waste.
- Further investigation of the long-term ground- and surface-water monitoring data indicated that Cr (adsorption potential of clay minerals) is detected at concentrations far below the SANS 241-2015 drinking water quality standard, and therefore the sample site was re-classified as inert or Type 4.

5.5.3 Magreng and Helena Composite tailings (SS36) waste classification

Refer to Table 5-9 for the exceedances of the TCT and LCT. The following conclusions were derived from the analysis of the composite tailings sample of Magareng and Helena:

- Total concentration assessment indicates that the TCT0 regulatory value was exceeded for numerous chemical constituents (refer to Table 5-9). Therefore, based on the total concentration the sample classifies as a Type 3. The TCT values are irrelevant for the water pathways.
- From the detailed analysis conducted on the long-term surface- and groundwater, TDS and NO_3-N was detected at moderate to high concentrations exceeding the baseline and SANS 2015 drinking water quality standard. These exceedances are however localised around mining activities, and additionally nitrate decays naturally as it moves through the sub surface with passing time. A half-life of ± 300 days was calculated considering the long-term monitoring data (2007 to 2021).
- The monitoring data provides the basis for re-classifying the waste as a Type 4 waste, as a source. The risk-based modelling approach incorporates an analysis of a multi barrier approach as to ensure the main downstream receptor (Dwars River) is not notably affected/impacted.

5.5.4 Thorncliffe waste classification

Refer to Table 5-9 for the exceedances of the TCT and LCT. The following conclusions were derived from the analysis of the mine residue of Thorncliffe.

- The whole rock total concentration threshold (TCT) the analyses indicated that the Rom stockpile (SS17), waste rock (SS20), met grade (SS24) and PGM plant (SS29) classify as a Type 3 waste based on the exceedance of the TCT0 of numerous chemical constituents (refer to Table 5-9).
- **Note that the total concentration is not applicable for determination of the barrier system. Only the leachable constituents should be taken into consideration.**
- The leachate assessment of the mine residue indicated that the Rom stockpile (SS17), met grade (SS24) and the PGM plant (SS29) exceeded the lowest regulatory (LCT0). In accordance with GNR 635 the sample sites classify as Type 3 waste.
- From the monitoring data no Cr (IV) and Cr (III) are present in the ground- or surface water. This is most likely due to the adsorption potential of clays weathered from mafic and ultramafic igneous rocks for metals and metalloids. Considering the available data, the waste rock (SS20) and Met grade (SS24) samples thus re-classified as inert or as a Type 4 waste (no liner requirement).

5.5.5 Composite Tailings for all three sites (SS28)

A composite sample of all three the tailings facilities were sent to the laboratory the exceedance of the TCT0 and LCT0 are listed in Table 5-9.

- The whole rock total concentration threshold (TCT) for all the analyses indicated the threshold values for TCT0 was exceeded. Note that the total concentration is no applicable for determination of the barrier system.
- In terms of the leachate assessment, i.e., the liquid phase, the results show that TDS and NO_3-N exceeds the leachable concentration threshold (LCT0).
- From the detailed analysis conducted on the long-term surface- and groundwater, TDS and NO_3-N was detected at moderate to high concentrations exceeding the baseline and SANS 2015 drinking water quality standard. These exceedances are however localised around mining activities, and additionally nitrate decays naturally as it moves through the sub surface with passing time. A half-life of ± 300 days was calculated considering the long-term monitoring data (2007 to 2021).
- The monitoring data provides the basis for re-classifying the waste as a Type 4 waste, as a source. The risk-based modelling approach incorporates an analysis of a multi barrier approach as to ensure the main downstream receptor (Dwars River) is not notably affected/impacted.

6 MASS TRANSPORT SOURCE TERMS FOR NUMERICAL GROUNDWATER MODELLING AND RISK ASSESSMENT

From the review conducted on the geochemical waste assessment (Exigo, 2017), it was evident that the main parameters which have leachate potential exceeding the GNR 365 LCT0 threshold values were TDS, NO_3-N and Cr. SO_4 concentrations also show to have an increasing trend considering the baseline water quality data analysis.

6.1.1 Parameter Selection Process

In review of the geochemical analysis results and long-term surface- and groundwater monitoring data (2007 – 2021), the following source term parameters were identified:

1. Even though Cr concentrations exceed the LCT0 for some samples, the concentrations are low to non-existent in both the groundwater and surface water timeseries data, which is due to the adsorption potential of clays weathered from mafic and ultramafic igneous rocks for metals and metalloids. Modelling of this parameter is therefore not required.
2. None of the samples analysed geochemically exceed the SO_4 SANS Drinking Water Standard. The SO_4 concentrations of both groundwater and surface water are below the SANS 241 drinking water standard for most sampling points. The exceedances are situated onsite, near mining residue facilities. The risk is insignificant, and no modelling is currently required for

this parameter.

3. NO_3-N leachate concentrations exceeds the LCT0 values for both the composite tailings material samples, as well as the PGM plant material at Thorncliffe. As nitrate exceedances in the CDPF and WRF sources are high, this constituent will be modelled.

4. TDS leachate concentrations exceed the LCT0 value for both the composite tailings material samples. The long-term groundwater monitoring data shows no exceedances above the SANS 214:2015 drinking water limit for surface water (Dwars River). All the groundwater monitoring exceedances occur onsite around the mining activities (Figure 3-5). Process water circulation is also evident at the Thorncliffe site as concentration build-up from the return water dam (RWD) timeseries data is observed as water is circulated from plant to RWD. With the build-up of TDS concentrations evident, this constituent was also selected to be modelled. It must be noted that the high TDS concentrations are due to elevated concentrations of Ca, Mg, SO_4, NO_3-N and HCO_3, which are natural soil and rock forming minerals.

6.1.2 Source Term Determination

From the waste assessment results (Section 5) and supporting long term surface and groundwater monitoring data analysis (Section 3), NO_3-N and TDS are potential sources to be modelled to determine the Life of Mine (LoM) and post closure risks and impacts associated with the updated designs for the Helena WRD and Thorncliffe Co-disposal facilities on local receptors (Groot Dwars River) downstream of the relevant mining operations.

A source term for each of the relevant mining infrastructures (WRD, TSF and co-disposal) need to be determined. The provided data was utilised conservatively to calculate the relevant source terms.

The TDS leachate concentrations for the relevant composite tailings material were 1158 - 1681 mg/ℓ. The TDS source term concentrations for the relevant waste streams are set out below:

1. Tailings Storage Facility - As long-term borehole monitoring data was available from a borehole directly downstream of the existing TSF's (BHT6 and BHT7/7a), the TDS concentrations with time data was utilised as a representative source term as the monitoring data represents a *long-term leach test*. The source term was modelled in accordance with the timeseries data, but conservatively not below 1200 mg/ℓ, as depicted by the geochemical leach test results for the tailings material.

2. Waste Rock Dumps – as the WRD leachate concentrations were extremely low (22 – 53 mg/ℓ), long term groundwater monitoring data was utilised from boreholes situated directly downstream of WRD facilities to obtain representative source terms (BHT9, BHH8 was not seen as a representative downstream monitoring location due to influence of ore processing near the borehole and WRD at the Helena operations). A constant concentration of 560 mg/ℓ

was used as the source term for all WRD facilities, which is considered conservative.

3. Co-disposal – As the proposed design involves mixing of 3 different waste material streams (Figure 6-1), and deposition of the composite material as a moist to dry slurry, calculation of a representative source term is essential. Figure 6-1 represents the conceptual model for how the co-disposal material will interact with the environment (mining processes and rainfall) to form leachate.

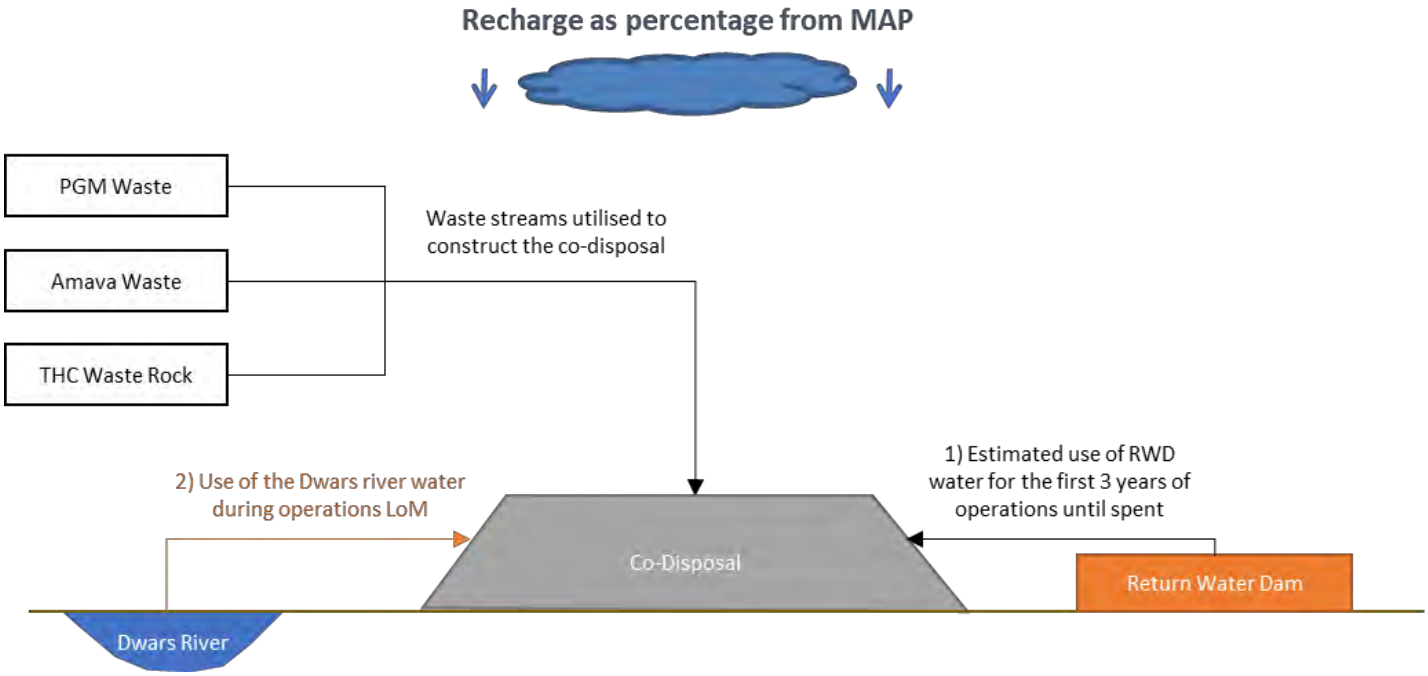


Figure 6-1 Conceptual model representing co disposal source term determination

For the purpose of this modelling update, a decision was made to follow a conservative approach for co-disposal source term calculation. The calculations were based on the supposition that the tailings material would interact with the RDW circulation water for a period of 3 years as the old TSF's are closed and rehabilitated. Once the RWD circulation water is spent, more Dwars River water would be utilised during the processing of ore, and therefore the TDS concentrations for the co-disposal waste would be greatly reduced (the combined calculated source term TDS concentration for the co-disposal, taking the ratios into consideration, is ±1170 mg/ℓ). The TDS concentrations of the co-disposal waste was conservatively assumed to be above a minimum concentration of 1200 mg/ℓ.

The source terms of each of the relevant mining infrastructure used within the numerical mass transport modelling is depicted in Figure 6-2 below.

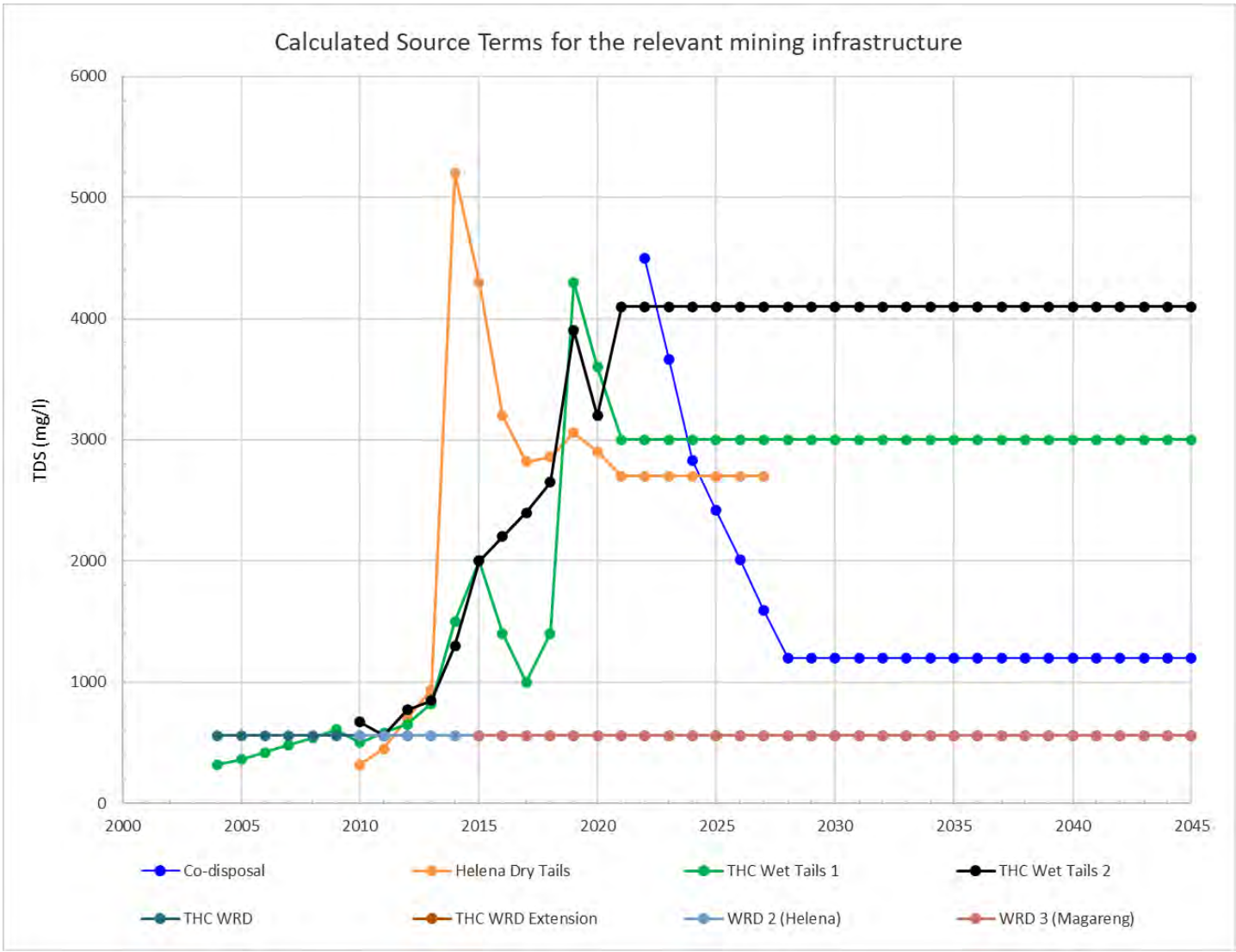


Figure 6-2 Calculated source terms for the relevant mining infrastructure

For the Nitrate source term calculations, a worst-case, constant source term concentration was utilised to evaluate the potential environmental risks and impacts.

From evaluation of the geochemical results for Nitrate from the relevant mining waste materials, it is evident that the waste rock does not possess significant nitrate leaching potential. Considering the composite tailings material results, Nitrate leachate concentrations of 243 mg/ℓ (composite of Helena and Magareng Tailings) and 147 mg/ℓ (composite of all three mining operations' tailings) was obtained. This aligns with the long-term monitoring data for the process water. The nitrate concentrations within the circuit water build's up with time and shows to have an average concentration of around 600 – 650 mg/ℓ since January 2017. As mentioned, a decay component for Nitrates is proven on site with a decay rate was applied during modelling (conservative 500–600-day de-nitrification process as indicated by measured concentrations at BHT8, Section 3.2.2)

1. From the mentioned information for Nitrate, a constant source term concentration of 650 mg/ℓ was used as the basis for modelling old TSF (wet tailings) and new CDPF (dry tailings) infrastructure.
2. As the WRD Nitrate leachate concentrations were exceptionally low (below or just above the LCT0 threshold), a decision was made to conservatively model all WRD facilities using a constant source term of 150 mg/ℓ (worst-case approach).

7 NUMERICAL GROUNDWATER MODEL

7.1 Model development

7.1.1 Model objectives

The purpose of the groundwater flow model update was to simulate the possible impact of the mine dewatering caused by the underground extension of all three chrome mines Helena, Magareng and Thorncliffe as well as mass transport associated with the new co-disposal facility design and Waste Rock Dumps (WRD) at Thorncliffe and new WRD development at Helena. Specifically, the modelling objectives were:

1. Quantify dewatering rates considering temporal and spatial factors such as the mining operational phases through Life of Mine (LoM).
2. Determine the radius of influence and volumetric impacts of dewatering on water users and the environment with specific reference to the Groot Dwars River.
3. Quantify the potential for seepage plumes and mass transport from the existing TSF's, new co-disposal facility and WRD's with specific reference to risks and impacts on the Groot Dwars River receptor.

7.1.2 Model Setup

For the numerical flow and mass transport model, an update on the 2018 numerical groundwater flow model was conducted using the modelling package FEFLOW 7.1. Details of this software are provided at www.FEFLOW.info.

7.1.3 Model Domain and Finite Element Network

The model domain covers an area of 68km², differentiated into a finite element network with 157 959 elements and 107 064 nodes (Figure 7-2). The 3D configuration incorporated a three-layer system with the top layer representing the weathered profile which pinched out at the mountain edges (owing to the conceptual model). The two deeper layers represented the basement rock and the regional dyke systems as the dykes would propagate through where the mountainous areas intersect the top layer. The dyke zones were explicitly included as linear less permeable zones in the Finite Element network. The total volume of the 3D domain is 47 350 Mm³. Refinement around specific features were done during mesh generation to conduct the model calibration process more accurately.

7.1.4 Model limitations and assumptions

The following assumptions were made with listed limitations:

1. Prior to development, the system is in equilibrium and therefore in steady state (Jan

2003).

2. The accuracy and scale of the assessment will result in deviations at specific points e.g., on the boundaries of mine layout areas, however this effect is minimal and the selected mesh elements would represent the footprint of specific infrastructure.
3. When modelling assumptions were made or reference values used, a conservative approach was followed such that the tendency was to overestimate groundwater impacts and mine inflows if compared to the actual case.

When assumptions were made or reference values used, a conservative approach was followed aligned with the precautionary principle (NEMA, 1998).

7.1.5 Aquifer Parameters and Recharge calculation

The aquifer parameters used in the calibration process is presented in Table 7-1 and the data used are:

1. Recorded hydrocensus data i.e., coordinates and water levels.
2. Aquifer test data which include historic pump test on boreholes at Thorncliffe and Mototolo mines as well as falling head tests on the newly drilled monitoring boreholes at Thorncliffe and selected holes at Magareng and Helena. These are currently part of the monitoring program. The historic data as well as newly acquired data is presented in Appendix E: Aquifer test parameters incorporated into the groundwater model. This information is also discussed in detail in Section 4: Site characterization.

Table 7-1 Material input parameters incorporated within the numerical model per geological unit

Model geology	Hydraulic conductivity (m/d)	Transmissivity (m^2/d)	Storativity (2D)	Specific Storage (Ss)	Porosity (%)	Recharge (%)	Recharge (m/d)
Layer one (m)							**30**
Alluvium	1.30E-01	3.90	5.00E-03	1.67E-04	5%	6.13%	1.00E-04
Norite/Anorthosite South (higher recharge)	4.00E-02	1.20	1.00E-03	3.33E-05	2%	3.68%	6.00E-05
Norite/Anorthosite Lower K Zone	6.00E-03	0.18	1.00E-03	3.33E-05	2%	2.58%	4.20E-05
Gabbro Anorthosite	8.00E-03	0.24	1.00E-03	3.33E-05	2%	2.77%	4.52E-05
Groot Dwars Weathering	1.20E-01	3.60	5.00E-03	1.67E-04	5%	3.99%	6.50E-05
River weathering	5.00E-02	1.50	5.00E-03	1.67E-04	5%	3.99%	6.50E-05
Backfilled open pits	4.00E+00	120.00	1.00E-01	3.33E-03	20%	10.43%	1.70E-04
Layer two (m)							**300**
Norite/Anorthosite South (higher recharge)	2.00E-03	0.60	5.00E-04	1.67E-06	1%		
Norite/Anorthosite Lower K Zone	7.00E-04	0.21	5.00E-04	1.67E-06	1%		
Gabbro Anorthosite	5.00E-04	0.15	5.00E-04	1.67E-06	1%		
Dykes	5.00E-04	0.15	5.00E-04	1.67E-06	1%		
Fractured Dyke sections	1.00E-02	3.00	5.00E-04	1.67E-06	1%		
Layer three (m)							**500**
Norite/Anorthosite	4.50E-04	0.23	5.00E-04	1.00E-06	1%		
Gabbro Anorthosite	3.00E-04	0.15	5.00E-04	1.00E-06	1%		
Dykes	3.00E-04	0.15	5.00E-04	1.00E-06	1%		
Fractured Dyke sections	5.00E-03	2.50	5.00E-04	1.00E-06	1%		

The recharge values were based on rainfall data collected from the mine for the mining area from 2002 to 2016 (Figure 19-1, Appendix F). Recharge percentages for the geological units were determined with the chloride method and compared with previous groundwater models, as well as current dewatering potential for this area to obtain optimal recharge values.

The recharge percentages range from 2.5% to 6.2% for the geological units and up to 10.5% for the backfilled open pit sections (Table 7-1 and Table 7-2).

Additional important model inputs and conditions are indicated in Table 20-1 as part of Appendix G: Model calibration statistics and Inputs.

Table 7-2 Preliminary recharge determination using the Chloride method

Thorncliffe			Helena			Magareng		
ID	Date	Cl (mg/ℓ)	ID	Date	Cl (mg/ℓ)	ID	Date	Cl (mg/ℓ)
BHT1	06/03/2018	58	**BHH2**	2008-01-24	10.0	**BHMAG1**	2018-03-06	4.1
BHT3	06/09/2017	20.9	**BHH3**	2008-04-03	7.9	**BHMAG3**	2018-03-06	58.0
BHT4	08/03/2018	17	**BHCMO**	2014-09-30	8.3	**BHMAG4**	2018-03-06	40.8
BHT5	08/03/2018	70.4	**BHH4**	2016-12-12	8.2	**BHMAG5**	2017-11-08	22.8
BHT6	06/03/2018	37.9	**BHH6**	2018-03-08	15.9	**BHMAG6**	2014-11-17	54.7
BHT7a	06/03/2018	49.6	**BHH7**	2018-03-08	21.4	**BHMAG7**	2018-03-07	61.4
BHT8	06/03/2018	25.8	**BHH8**	2018-03-06	7.8	**BHMAG8**	2018-03-07	58.2
BHT9	06/03/2018	60.6	**BHH9**	2018-03-06	27.0	**BHMAG10**	2018-03-06	60.5
BHT10	06/03/2018	17	**BHH10**	2017-09-05	17.7			
BHT11	06/03/2018	55.9	**BHH11**	2018-03-06	25.9			
Average		**41**			**15**			**45**
Minimum		**17**			**8**			**4**
Maximum		**70**			**27**			**61**
Average Recharge Cl method	**1.7%**		**4.7%**			**1.6%**		
Maximum Recharge Cl method	**4.1%**		**17.2%**			**9.0%**		

7.2 Simulation of development stages

7.2.1 Steady state initial conditions (2003)

The model calibration process focused on obtaining steady state conditions which would represent the 2003, natural state of the aquifer system within the modelled domain. The groundwater level measurements of 91 observation points were used for the calibration assessment (See Appendix G: Model calibration statistics and Inputs, Table 20-2). The calibration process was deemed excellent with a correlation between simulated and measured hydraulic heads of approximately 99%. The mean absolute error between the measured and simulated hydraulic head was below 5 and the root mean square percentage below 5 % (Table 20-2). A correlation factor (R^2) of 0.98 was obtained between the measured versus simulated hydraulic heads as shown by below.

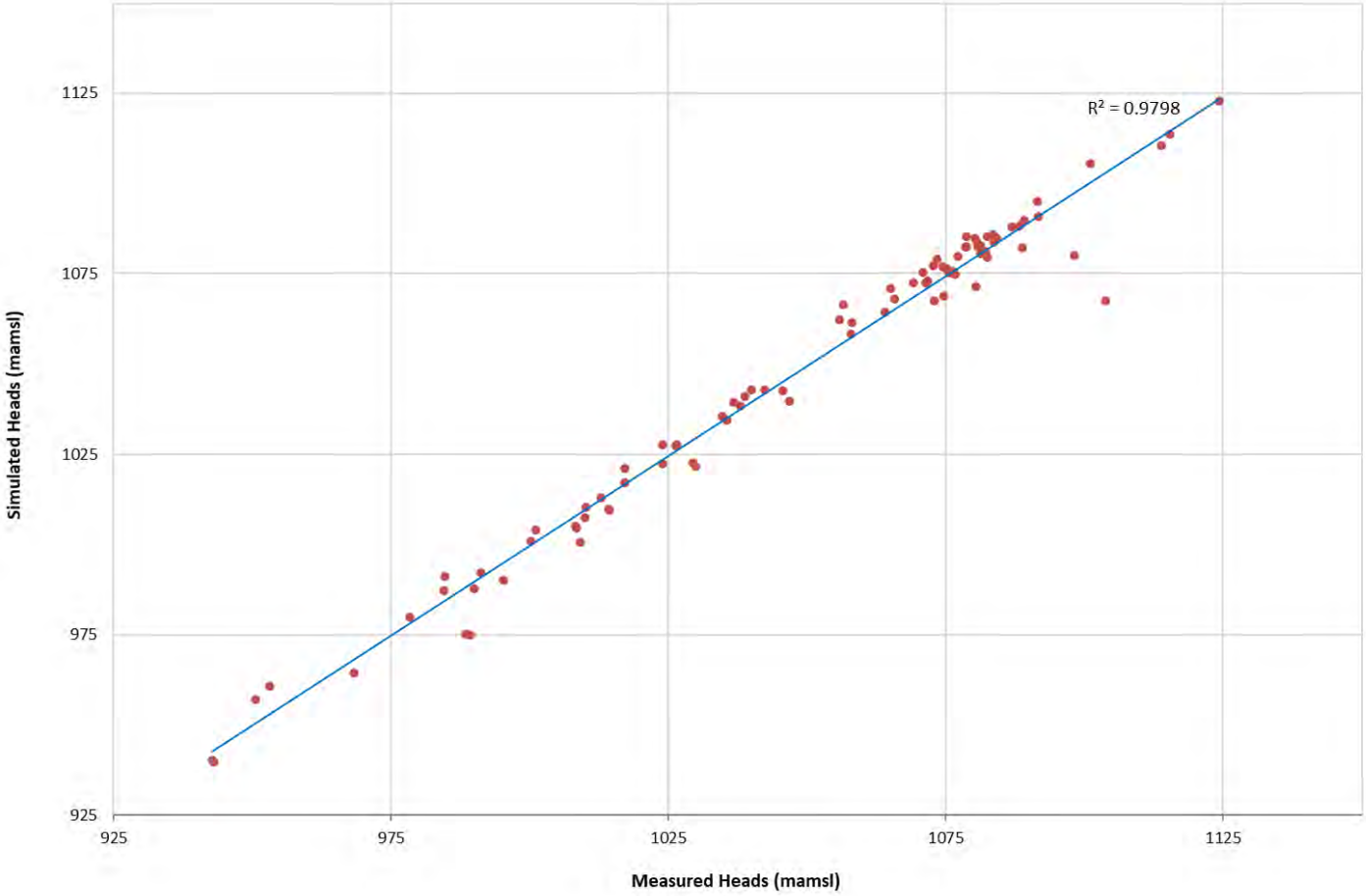


Figure 7-1 Measured vs Simulated Hydraulic Heads

The bar chart presented in Figure 20-1 implies that the simulated hydraulic head error would be slightly above the measured hydraulic head for more than half of the boreholes with an average mean error of +0.59 m. The surface to groundwater map (Figure 7-2), and the initial steady state hydraulic head for the regional groundwater regime is also indicated as contours in Figure 7-2. The

simulated steady state hydraulic head would follow topography as indicate by the measured hydraulic head and Figure 4-7. Table 7-3 indicates the steady state, 2003 baseline water balance.

Table 7-3 Initial Steady State Water Balance

Steady State Initial Conditions (2003)				
	Component	**Inflow (m^3/d)**	**Outflow (m^3/d)**	**Balance (m^3/d)**
1	Recharge from precipitation	4163	0	**4163**
2	Flux from existing TSFs and WRDs	1023	0	**1023**
3	Abstraction from boreholes	0	-139	**-139**
4	Abstraction from De Groote Boom Pit	0	-655	**-655**
5	Base flow and losses to drainages	0	-4392	**-4392**
	Total	**5186**	**-5186**	**-0.02**
			Balance Error (%)	**0.0%**

From the calibration, the model shows that around 4 163 m^3/d enters the model domain as recharge, with 4 392 m^3/d exiting the domain via base flow and losses to drainages. For steady state calibration, the underground mine operations were not included, as evidence suggests minimal dewatering from the low permeable geological units mined. This is corroborated by the small amounts of dewatering required and fissure water pumped from the underground workings (see Section 3, as well as Section 7.2.2, taken from the 2018 Exigo Sustainability EIA and EMPR Hydrogeological report). Limited to no base flow is expected from the Dwars River as the Helena Mine would have reported increased dewatering rates if any significant base flow would have occurred. The model also shows ±140 m^3/d is abstracted from the dewatering boreholes, with ± 655 m^3/d abstracted from the De Groote Boom Pit (which acts as a sink within the model). Combined borehole abstraction rates for all three mining operations were not available for 2003, but the abstraction rates compare well with the average borehole abstraction for 2006. The De Groote Boom pit modelled abstraction rates also compare well with the rates from mid-2012 to end-2013 (first available data), at an average of ± 450 m^3/d.

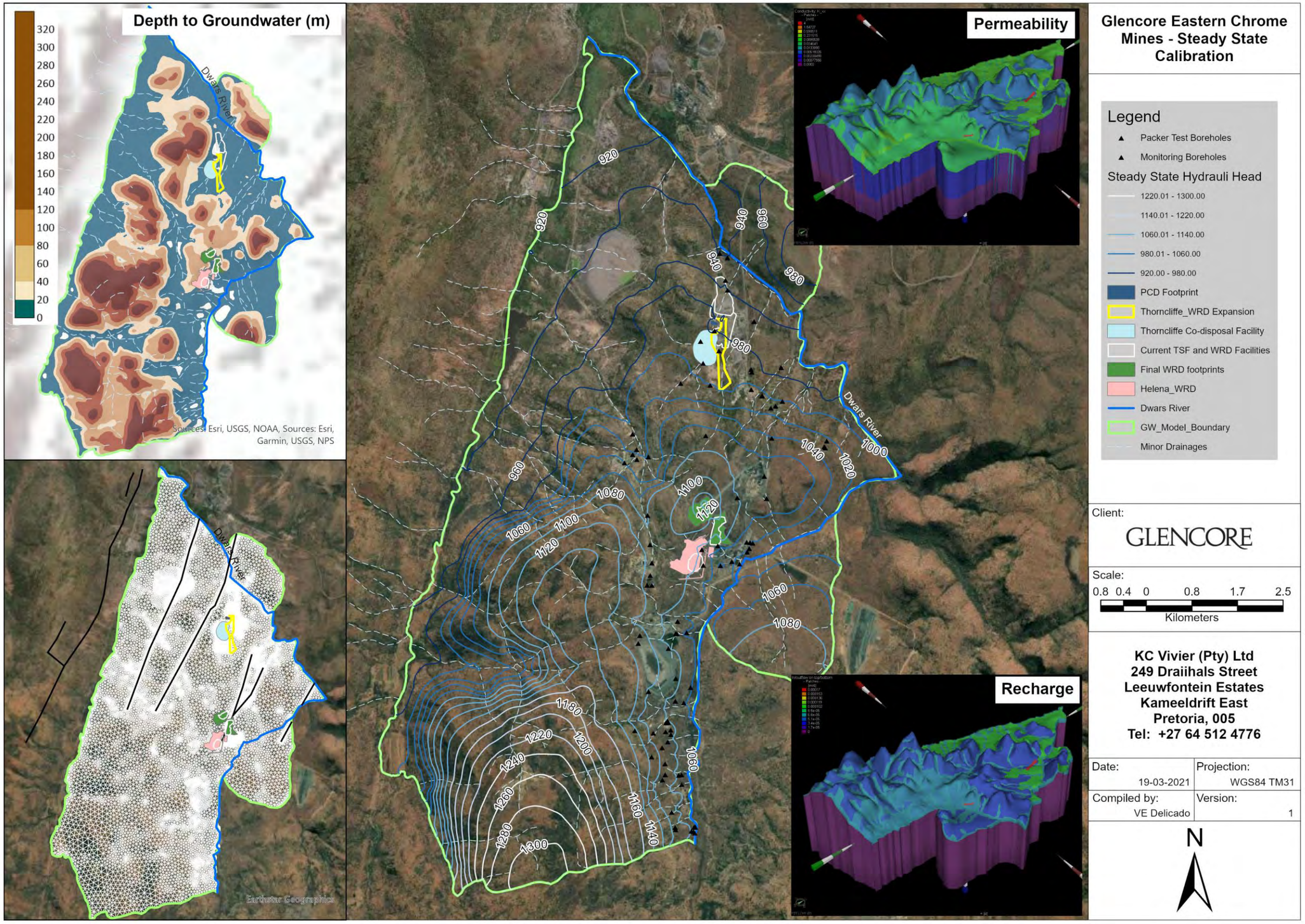


Figure 7-2 Model construction with input parameters and calibration hydraulic head

7.2.2 The underground extension of Helena, Magareng and Thorncliffe mines (2018)

Underground dewatering study was conducted by Exigo Sustainability in 2018 (Exigo, 2018). The mine is planning to extend the underground workings at all three chrome mines towards the west of the current underground workings (Figure 7-4). As mentioned previously, the impact on the shallow aquifer systems are negligible (See Section 3) and current combined underground dewatering rates are less than 600 m^3/d, which is ± 14 % of the steady state recharge of 4 163 m^3/d. The dewatering scenario was simulated using actual rainfall figures. Rainfall data can be observed in Appendix F.

The mining depth over time (as provided by Glencore Eastern Mines) can be seen in Figure 7-4 and Appendix H: Development of the underground Zone of influence with no shallow aquifer impacts. The 3D representation gives perspective of the limited influence that the underground dewatering has on the shallow hydraulic head and shallow aquifer systems. From the modelling results, both the river systems (Groot and Klein Dwars) are not expected to be influenced by the underground mining activities as an impact would already have been evident from current mining activities at the Helena operations. Figure 7-3 indicates the cumulative dewatering rates over time.

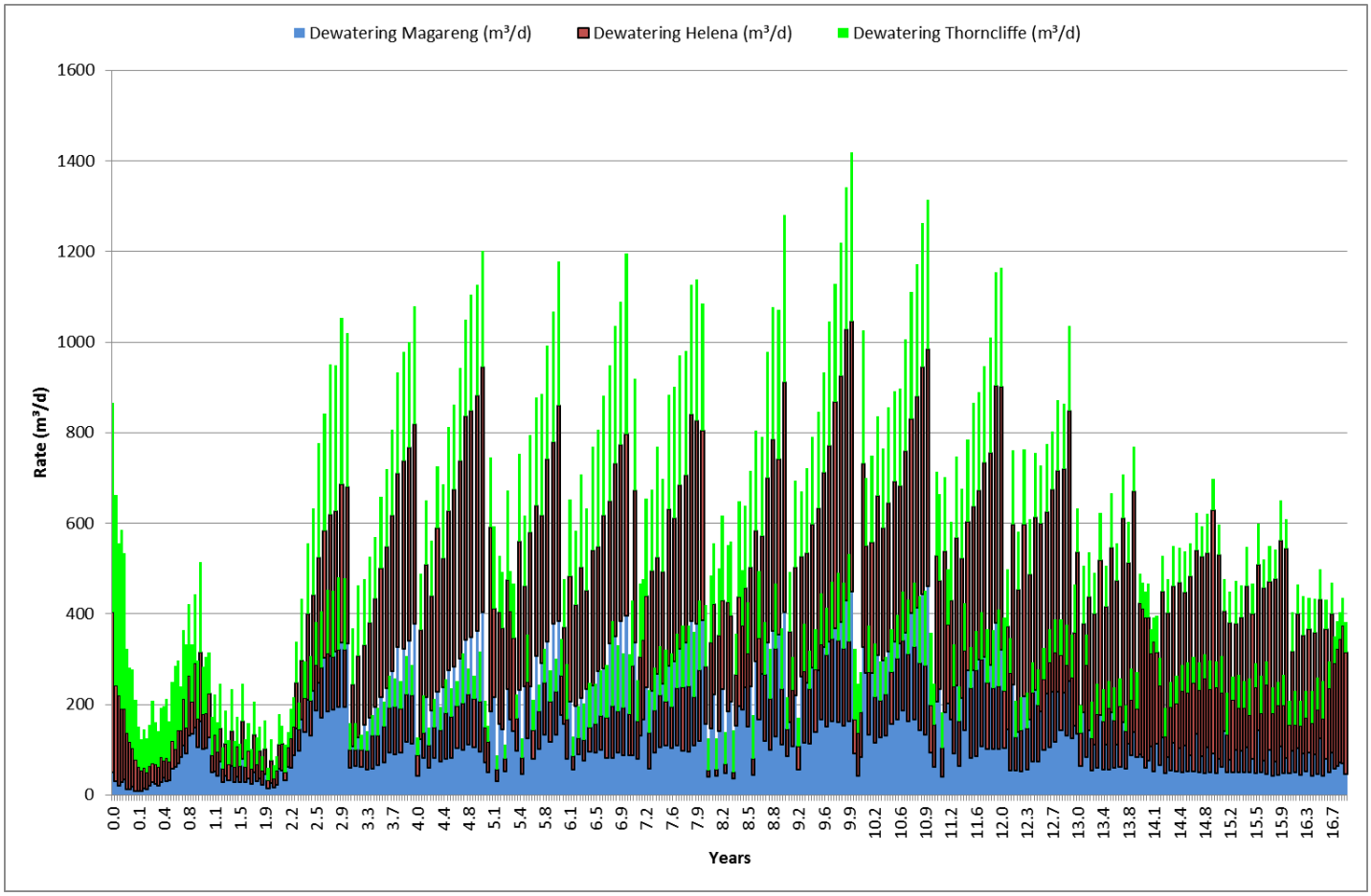


Figure 7-3 **Cumulative dewatering rates over the proposed 17-year LoM**

A maximum of approximately 1 600 m³/d could be expected to flow into the mine at peak development stage of all three shafts with depth. The groundwater balance for the transient simulation can be observed in Table 7-4 below.

Table 7-4 Water balance for the underground extension with transient recharge applied over 17-years

Transient recharge over 17 years with mine dewatering				
	Component	**Inflow (m³/d)**	**Outflow (m³/d)**	**Balance (m³/d)**
1	Recharge from precipitation	4613	0	**4613**
2	Abstraction from boreholes	0	-224	**-224**
3	**Mine Dewatering: Thorncliffe**	**0**	**-462**	**-462**
4	**Mine Dewatering: Magareng**		**-461**	**-461**
5	**Mine Dewatering: Helena**	**0**	**-598**	**-598**
6	Base flow and losses to drainages	0	-4388	**-4388**
7	From-To Storage	1512	0	**1512**
	Total	**6125**	**-6133**	**-8**
			Balance Error (%)	**-0.13%**

The table shows the potential dewatering rates for Helena mine at 600 m³/d and both Thorncliffe mine and Magareng mine at approximately 460 m³/d. The estimated groundwater abstraction as measured from monitoring data is approximately 225 m³/d. Discharge via surface drains and base flow components were estimated at approximately 4390 m³/d which leaves a storage component remaining in the aquifer system of approximately 1510 m³/d.

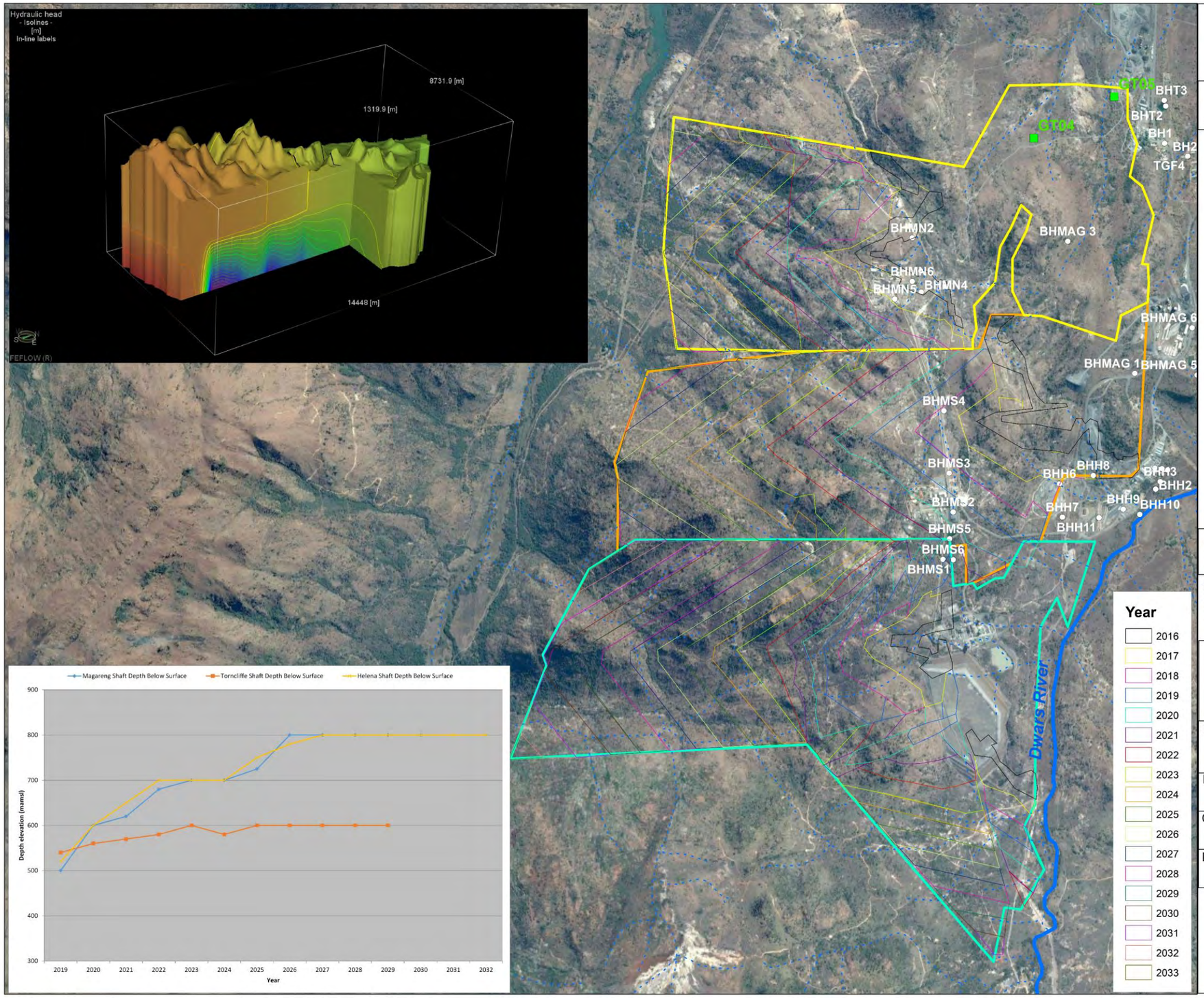


Figure 7-4 Limited zone of influence in 3D as well as the deep mine development stages

7.2.3 Mass transport of the proposed new developments at Thorncliffe and Helena

The mass transport simulations were conducted in transient flow conditions with transient mass migration potential with time. The simulations were conducted over a period of ±97 years (base date of simulations taken as 2003) to incorporate operational and post-operational migration plumes. The timing related to each of the mine infrastructural components are reflected in Table 7-5.

Table 7-5 Mine infrastructural timeframes used for modelling

Thorncliffe Mine					
Infrastructure Type	**POW From**	**POW To**	**Flux***	**Max TDS Mass (mg/l)**	**Max NO3 Mass (mg/l)**
WRD old	Jan-04	Dec-45	20%	560	150
TSF 1	Jan-04	Jun-22	-0.001	4300	650
TSF 2	Jan-10	Jun-22	-0.001	4100	650
Co-Disposal	Jan-22	Dec-36	20%	4500	650
WRD extension	Jan-22	Dec-45	20%	560	150
Magareng Mine					
Infrastructure Type	**POW From**	**POW To**	**Flux**	**Max TDS Mass (mg/l)**	**Max NO3 Mass (mg/l)**
WRD 3	Jul-15	Dec-45	20%	560	150
Helena Mine					
Infrastructure Type	**POW From**	**POW To**	**Flux**	**Max TDS Mass (mg/l)**	**Max NO3 Mass (mg/l)**
WRD 2	Jan-10	Dec-45	20%	560	150
Dry Tailings	Jan-10	Jun-27	20%	5200	650
New WRD 2023 - 2045	Jan-23	Dec-45	20%	560	150
Post Operational					
Infrastructure Type	**POW From**	**POW To**	**Flux**	**Max TDS Mass (mg/l)**	**Max NO3 Mass (mg/l)**
THC WRD old	Dec-45	Dec-00	20%	560	150
THC TSF 1	Jul-22	Dec-00	5%	4300	650
THC TSF 2	Jul-22	Dec-00	5%	4100	650
THC Co-Disposal	Jan-37	Dec-00	5%	4500	650
THC WRD extension	Dec-45	Dec-00	20%	560	150
Magareng WRD 3	Jan-45	Dec-00	20%	560	150
Helena WRD 2	Jan-45	Dec-00	20%	560	150
Helena new WRD 2023 - 2045	Dec-45	Dec-00	20%	560	150

* Percentage of linear recharge used where applicable

The numerical modelling groundwater balance results for both operational and post-operational for the model domain, Throncliffe- and Helana Sub-catchments are presented in Table 7-6.

Table 7-6 Numerical Modelling Water Balance Results

Operational Phase		Model Domain (Mean Values)			Thorncliffe (Mean Values)			Helena (Mean Values)		
No	Component	Inflow (m3/d)	Outflow (m3/d)	Balance (m3/d)	Inflow (m3/d)	Outflow (m3/d)	Balance (m3/d)	Inflow (m3/d)	Outflow (m3/d)	Balance (m3/d)
1	Recharge from precipitation	4160	0	4160	440	0	440	235	0	235
2	Abstraction from boreholes	0	-220	-220	0	0	0	0	-40	-40
3	Leakage from TSFs	540	0	540	510	0	510	30	0	30
4	Leakage from WRDs	175	0	175	75	0	75	100	0	100
5	Leakage from co-disposal	70	0	70	70	0	70	0	0	0
6	Underground Dewatering (Max Potential)	0	-1500	-1500	0	-460	-460	0	-600	-600
7	De Grootteboom Pit	0	-300	-300	0	-300	-300	0	0	0
8	De Grootteboom Pit Seepage Capture boreholes (x2)	0	-350	-350	0	-350	-350	0	0	0
9	Co-disposal Seepage Capture Boreholes (x4)	0	-20	-20	0	-20	-20	0	0	0
10	PCD Drains	0	-10	-10	0	-10	-10	0	0	0
11	Base flow and losses to drainages	0	-4030	-4030	0	-420	-420	0	-320	-320
12	From-To Storage	1500	0	1500	460	0	460	600	0	600
	Total	**6445**	**-6430**	**15**	**1555**	**-1560**	**-5**	**965**	**-960**	**5**
	Balance Error (%)			**0.23%**			**-0.32%**			**0.52%**

Post-Operational Phase		Model Domain (Mean Values)			Thorncliffe (Mean Values)			Helena (Mean Values)		
No	Component	Inflow (m3/d)	Outflow (m3/d)	Balance (m3/d)	Inflow (m3/d)	Outflow (m3/d)	Balance (m3/d)	Inflow (m3/d)	Outflow (m3/d)	Balance (m3/d)
1	Recharge from precipitation	4160	0	4160	440	0	440	235	0	235
2	Abstraction from boreholes	0	-220	-220	0	0	0	0	-40	-40
3	Leakage from TSFs	25	0	25	15	0	15	10	0	10
4	Leakage from WRDs	175	0	175	75	0	75	100	0	100
5	Leakage from co-disposal	20	0	20	20	0	20	0	0	0
6	Underground Dewatering (Max Potential)	0	0	0	0	0	0	0	0	0
7	De Grootteboom Pit	0	0	0	0	0	0	0	0	0
8	De Grootteboom Pit Seepage Capture boreholes (x2)	0	0	0	0	0	0	0	0	0
9	Co-disposal Seepage Capture Boreholes (x4)	0	0	0	0	0	0	0	0	0
10	PCD Trees - ET	0	-20	-20	0	-20	-20	0	0	0
11	Base flow and losses to drainages	0	-4160	-4160	0	-530	-530	0	-305	-305
12	From-To Storage	0	0	0	0	0	0	0	0	0
	Total	**4380**	**-4400**	**-20**	**550**	**-550**	**0**	**345**	**-345**	**0**
	Balance Error (%)			**-0.46%**			**0.00%**			**0.00%**

From the modelling output, the following are important:

1. The CDSF vs TSF leakage decreased by 20-fold from 510 m^3/d to 70 m^3/d due to the technology design.
2. The WRDs have been conservatively modelled (% recharge flux remains the same for operational and post-operational) due to the low mass concentrations.
3. The CDSF has a multiple barrier approach to mitigate potential migration to the Dwars River via the groundwater pathway. Four barriers planned as follows:
    i. PCD Bottom Drain: The modelled PCD drains abstract at an average of 10 m^3/d starting initially at 40 m^3/d. The drains are important to prevent pressure build up below the PCD to protect the liner and to capture seepage. A more detailed analysis of the PCD bottom drain is required.
    ii. Seepage capturing holes near: The additional seepage capture boreholes (x4) abstract at an additional ±20 m^3/d. Three additional seepage capturing holes should be provided for and only drilled pending reactions at the planned 4 holes monitoring in water levels and chemistry.
    iii. Seepage capturing holes distant: The seepage capture boreholes immediately upstream of the De Grootteboom Pit are effective, as some of the holes are drilled within the higher permeable backfilled open pit section, and abstract at an average of ±175 m^3/d per borehole.
    iv. The De Grootteboom pit captures and abstracts an average of 300 m^3/d for the operational phase.
4. Post-operations, the PCD drain footprint should be backfilled with permeable material and planted with trees (e.g. Rus Lancea). These trees evapo-transpirate at ±20 m^3/d, which is calculated to be more than the post-operational leakage from the rehabilitated CDPF during the post-operational phase.

7.2.3.1 Operational

The operational phase was simulated by utilising results from the source term analysis (Section 6). The input parameters used during the modelling is presented in Table 7-1, Table 7-5 and Table 20-1.

7.2.3.1.1 Thorncliffe

The TDS source terms for both TSF 1 and TSF 2 were calculated by utilising actual long term monitoring data from BHT6 and BHT7, respectively. The data shows that the first phase TSF (TSF 1) TDS concentrations steadily increased from baseline (300 mg/l) to a peak concentration of ±4 300

mg/l within 15 years, after which a decrease is observed to the current concentrations of ±3 000 mg/l. The second phase of the TSF construction commences around 2010 (TSF 2), and a steady increase in concentration is observed from 670 mg/l to 4 100 mg/l in 2021. This concentration then remains constant for the duration of the facility life (conservative approach). The WRD facilities was of the same material as that of Helena mine, and were kept at a constant concentration of 560 mg/l to model their impact in a conservative manner (see Section 6). As mentioned, due to the decay rate (denitrification) of nitrate, the source terms for the relevant mine infrastructure were modelled conservatively by applying a constant source term of 650 mg/l to all tailings facilities (wet and dry tailings) and 150 mg/l to all WRD facilities corresponding to the duration of their operating life, after which nitrate concentration fluxes are ceased for post operations.

The De Grootteboom Pit area was treated as a sink and not assigned a concentration, as the leakage concentrations observed from the bit at BHT9 and BHT1 are due to surface water runoff/ process water and is therefore a management issue which can adequately be addressed by management practices – i.e. keeping the head of the pit below that of the Dwars River to inhibit flux to the receptor.

The results indicate that the Tailings TDS mass plume would extend to the north as would be expected with regards to the groundwater flow regime (Figure 7-5). The maximum existing wet tailings operational plume extent is approximately 300 m towards the north (of which 100 m of the plume is below SANS 241 limits) and 350 m towards the east (of which 200m is below the SANS 241 standard for TDS). The northern extent would follow the backfilled open pits direction leading to the De Grootteboom Pit and ultimately to the Dwars River to the north. The plume however, does not reach the Dwars River during the operational phase, as the Pit and 2 seepage capture boreholes mitigate the flow of the mass flux beyond this point. The open pit and seepage capture boreholes upstream of the open pit area would draw most of the mass concentrations which would have only limited amounts diluted into the Dwars River (Figure 7-5).

The nitrate mass plumes for the wet tailings facilities at selected times are presented in Figure 7-6. The nitrate plume shows to move ±200 m north, toward the pit area, and 150 m in an easterly direction (max concentration plume, movement to the east mainly due to TSF 1 leakage). As can be seen from the figure, denitrification occurs, and the plume size and max concentrations decrease with time as the facilities enter post operations (start of the new co-disposal facility).

7.2.3.1.2 Helena

The TDS source term for the Helena TSF was calculated by utilising the long-term monitoring data from BHH7 directly downstream of the facility as the source term with time. The data shows that the concentrations steadily increase from baseline (2010) up to a maximum concentration of

5 200 mg/l within 4 years of operations, after which it decreases to 2 700 mg/l for the remaining 7 years of its operational life. Nitrate was modelled conservatively with concentrations for the TSF and WRD's similar to those used for the Thorncliffe simulations.

The TDS modelling results indicated that the mass plume would migrate to an approximate extent of 600 m towards the east (of which 300m of the plume is below the SANS 241 standard for TDS as it reaches the Dwars River) over the operational life of the facilities with increased section of migration expected at the drainages (Figure 7-7). The steep gradient towards the east could imply an increased flux component however surface infiltration is expected to be less than surface runoff. This would imply proper surface water management systems are required.

For nitrate, the mass plume is expected to just reach the Dwars River from the modelling, but below the SANS 241 limit for nitrate (Figure 7-8). As nitrates decay over time due to denitrification, the max plume adequately dissipates post operational phase.

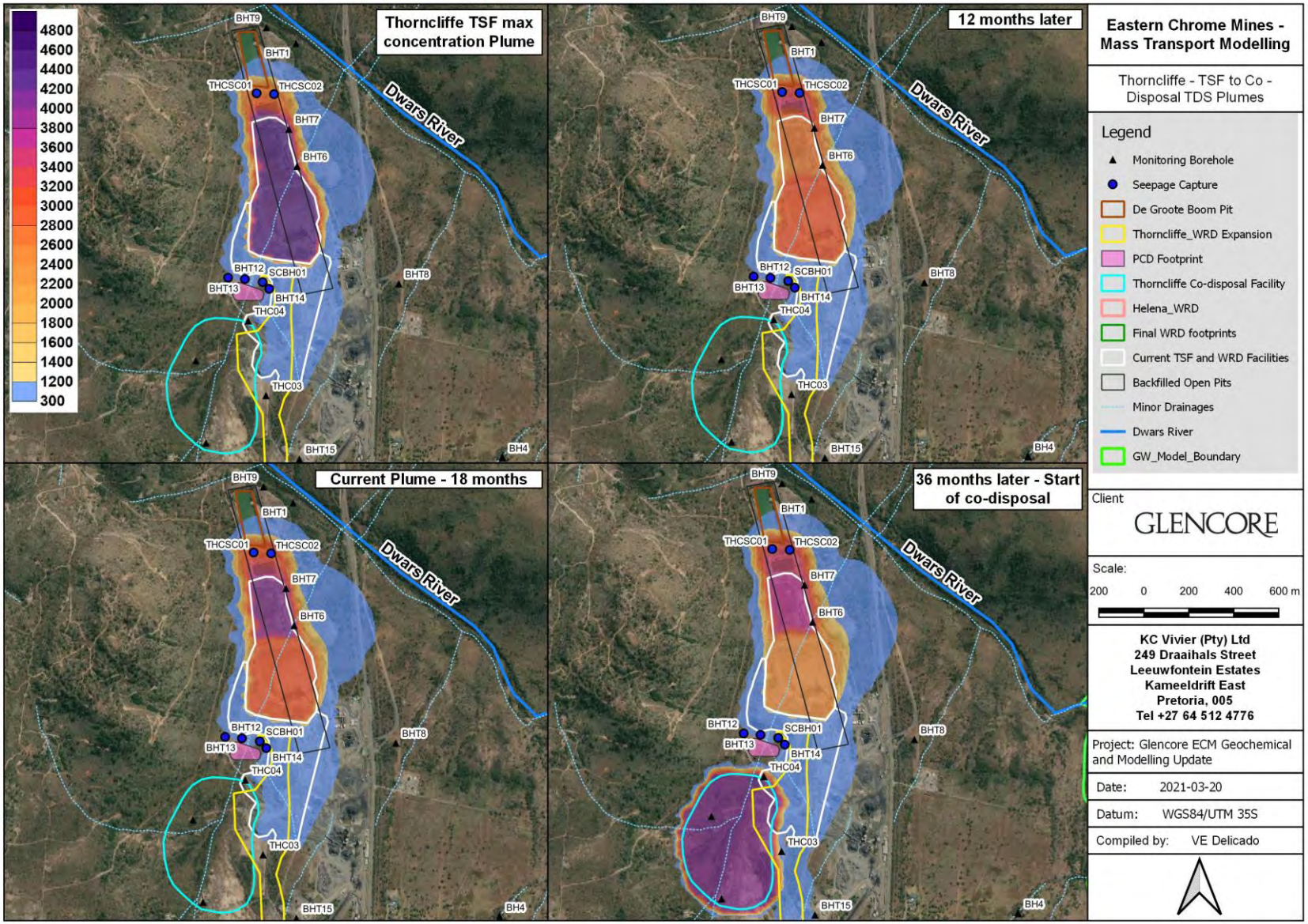


Figure 7-5 **Thorncliffe – TSF to co-disposal simulated maximum TDS plumes**

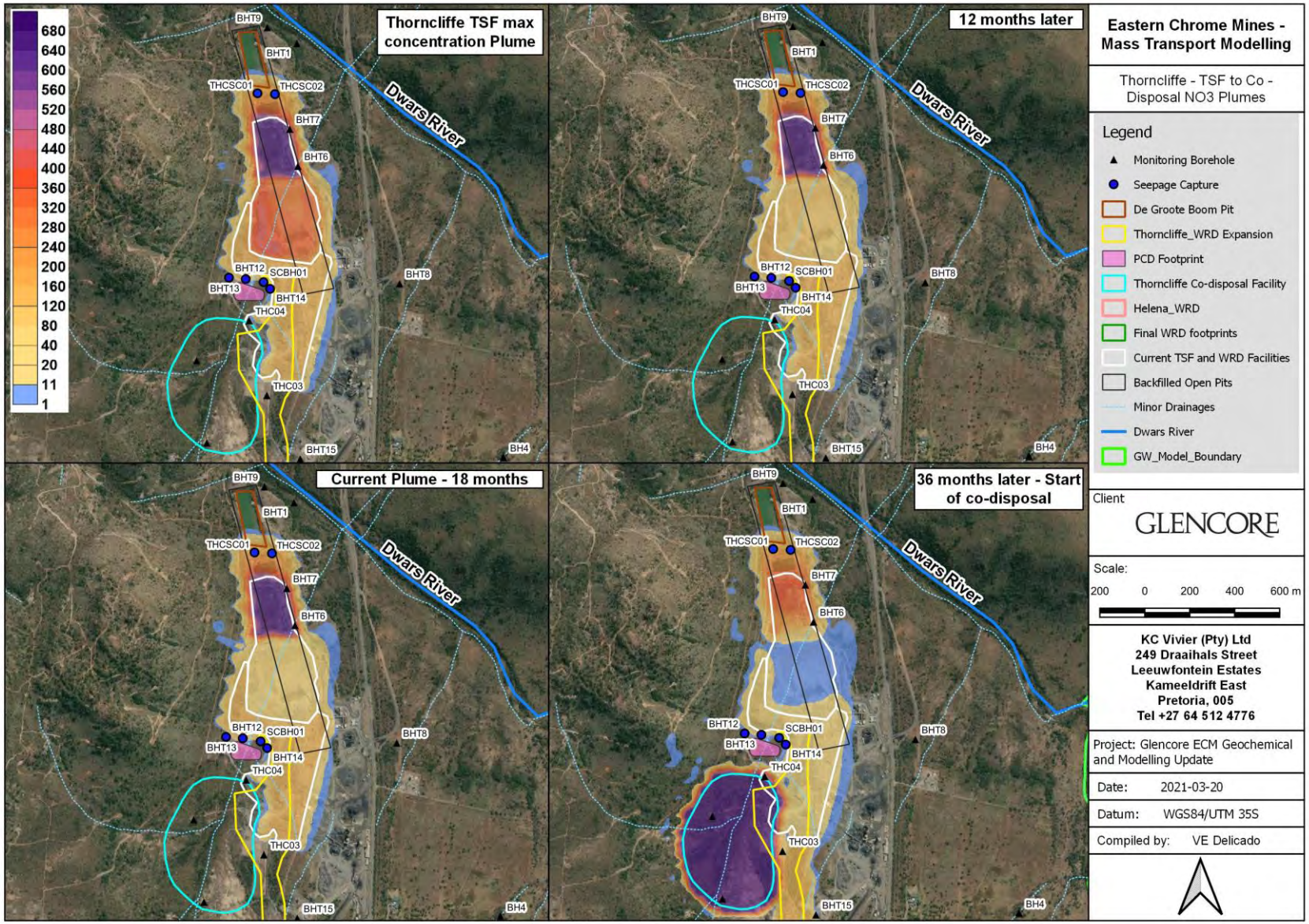


Figure 7-6 **Thorncliffe – TSF to co-disposal simulated maximum nitrate plumes**

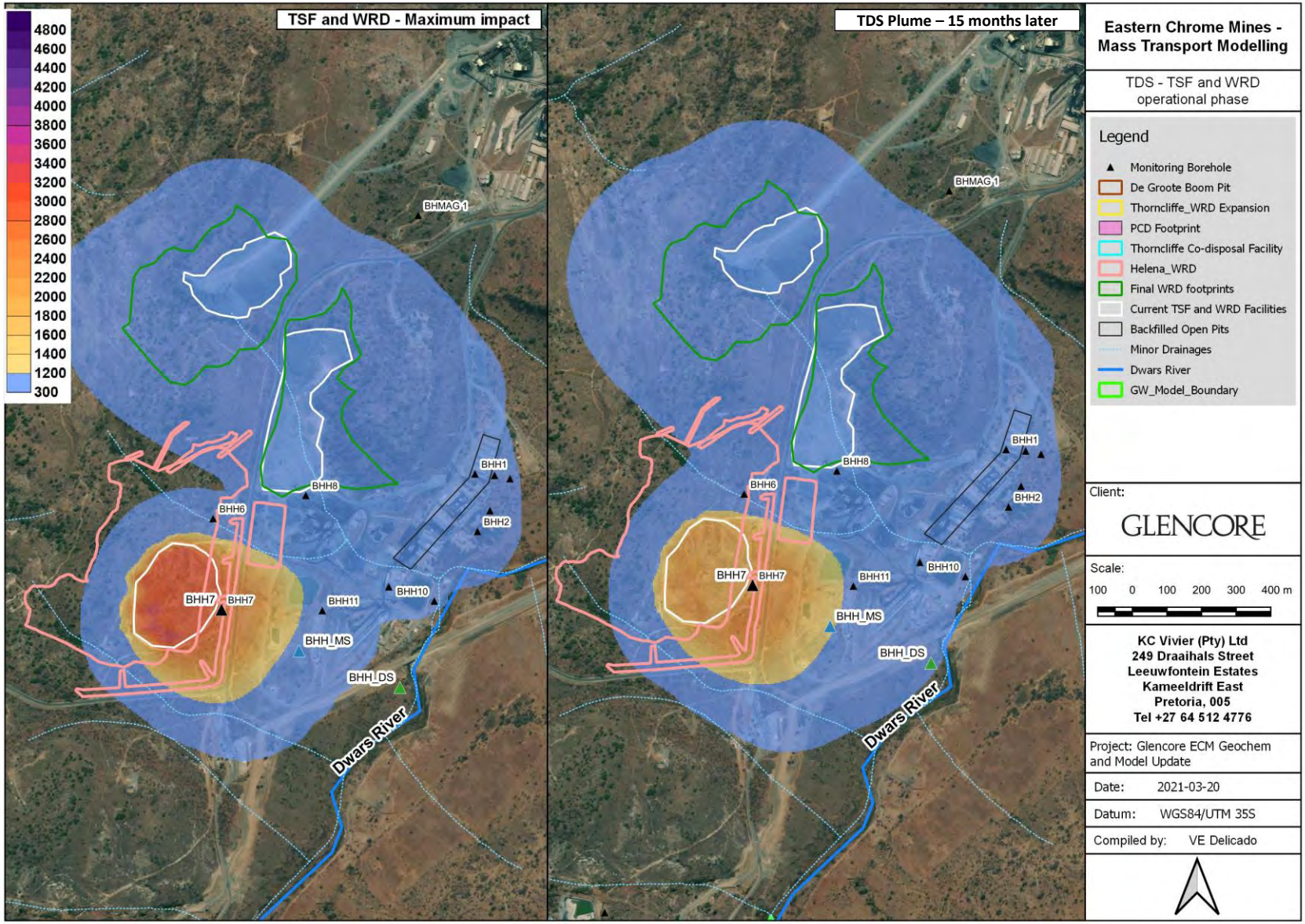


Figure 7-7 Helena – TSF and WRD LOM TDS plumes

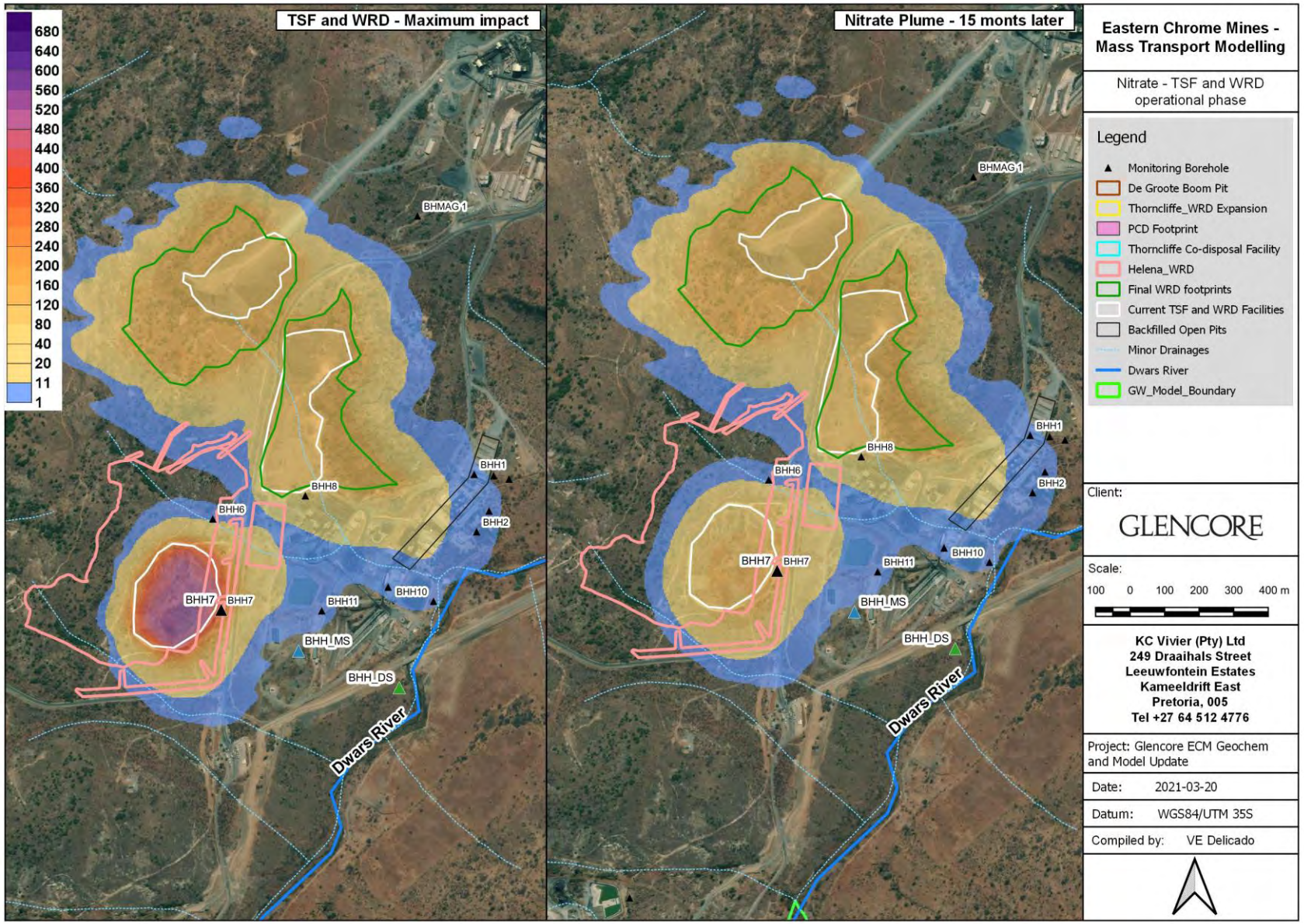


Figure 7-8 Helena – TSF and WRD LOM nitrate plumes

7.2.3.2 Operational Mitigation

7.2.3.2.1 Thorncliffe TSFs and CDSF (Figure 7-9)

Precautionary mitigation measures need to be considered regarding seepage capturing and barrier systems. Such measures are already utilised for the current wet tailings facilities i.e. De Grootteboom Pit and 2 seepage capturing boreholes upstream of the Pit (Figure 7-5 and Figure 7-6). The 2 seepage capture boreholes show to have a notable effect within the model as they are drilled within the higher permeable, backfilled open pits (modelled dewatering rates should be verified with actual rates once obtained). As some leakage is observed from the Pit (long term monitoring data from BHT9 and BHT1), correct management of the pit water level is required (as the seepage is believed to be due to surface water runoff/ process water entering the pit).

As the CDSF design employs the use of dry tailings material deposited over the footprint, this significantly reduces the facility's potential for leakage of potential harmful constituents. The main barrier system employed and evaluated within the modelling was the utilisation of the co-disposal PCD downstream of the facility as a bottom drain for seepage to accumulate. The bottom drain system below the PCD serves a dual purpose as it also ensures that the PCD liner would not be damaged due to pressure from the groundwater levels below. As indicated in previous sections, at least two boreholes can be considered for seepage capturing purposes namely BHT12 and BHT13. This would act as an additional barrier system secondary to the PCD bottom drains to capture any fugitive seepage from the co-disposal facility. Within the model, at least two additional boreholes were also included – both to the east of BHT13 (undrilled SCBH01 and drilled BHT14) to capture any fugitive seepage to the east of the PCD bottom drain system.

The results indicate that the max concentrations of the mass plume are kept upstream of the PCD bottom drains and seepage capturing boreholes, with only minor leakage to the eastern boundary of the co-disposal (concentrations below SANS 241). The PCD drain was modelled to capture water up to 4 m below surface, with the model showing that it abstracts an average of ±10 m^3/d (initially 20 m^3/d).

7.2.3.2.2 Helena WRD

From the source terms and modelling results, the TDS plumes for all the WRD facilities show to be well below SANS 241 standards (see Figure 7-7 and Figure 7-12). From historic monitoring of BHH7, only the Helena tailings facility footprint shows elevated TDS concentrations above SANS 241 limits for TDS. As the facility is already in post operations (pending site preparations for the new WRD facility, TDS concentrations have steadily decreased over time. Nitrate from Figure 7-8 show to be above the SANS 241 limit for the max impact plume (peak of Helena TSF operations - Aug 19).

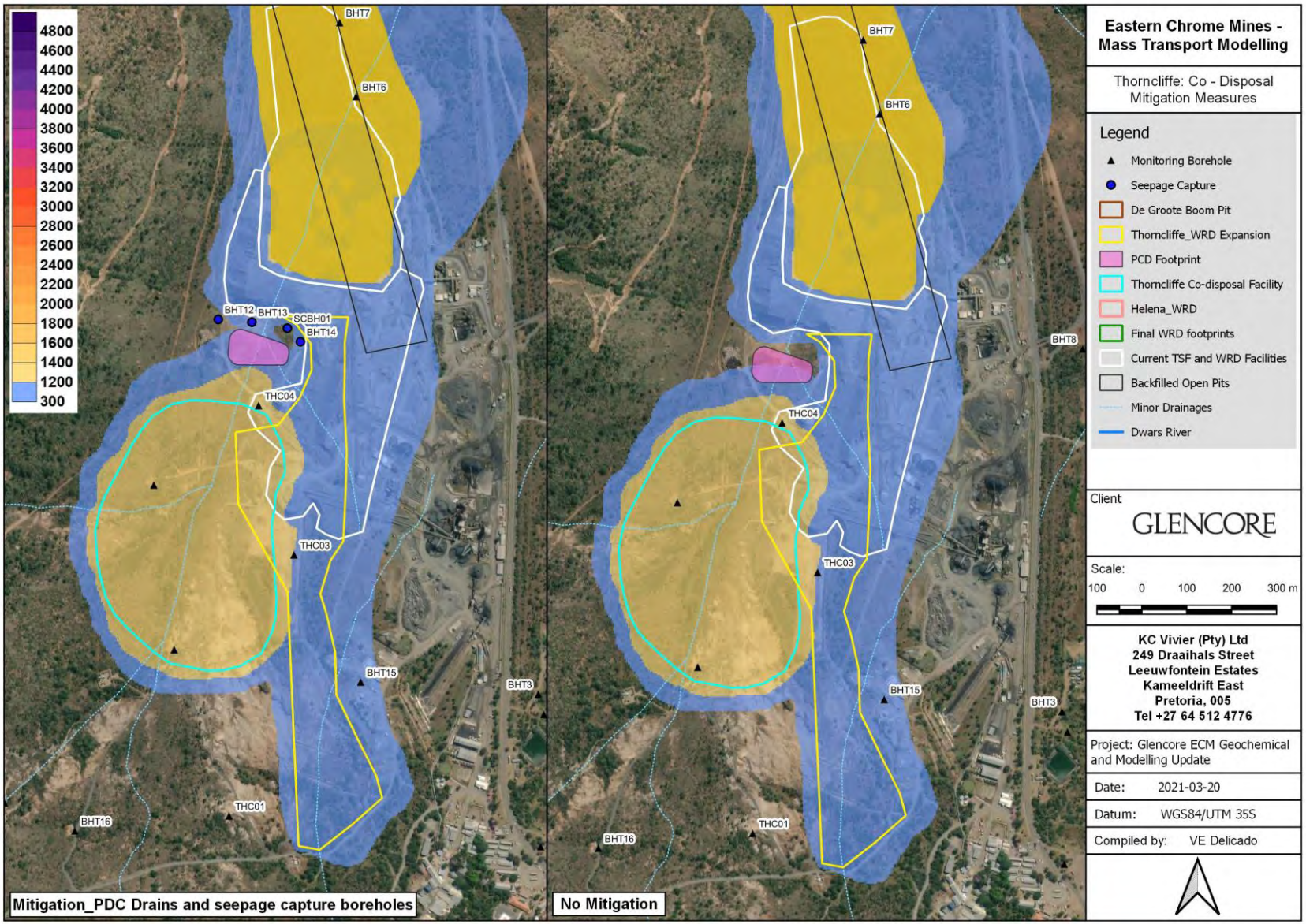


Figure 7-9 Co-disposal Mitigation measures

7.2.3.3 Post operational

7.2.3.3.1 Thorncliffe TSFs and co-disposal

The post operational phase was simulated over a 55-year period for both TDS and nitrate. Tailings facility fluxes were altered for post operational simulations in accordance with Table 7-5. Nitrate mass flux was removed from all infrastructure in relation to each of their post operational timeframes as indicated in Table 7-5.

Figure 7-10 shows the post operational TDS plume for Thorncliffe. Concentrations on the footprints of the co-disposal and TSF's remain just above the SANS 241 limit (1 200 mg/l) from the source term analysis conducted, but the majority of the plume from end of mine life to 55 years post closure that reached the Dwars River shows to be below the SANS 241 limit.

The de-nitrification process is expected to decay all the nitrates left after the operational phase, with this process observed in Figure 7-11. The figure shows that at end of co-disposal life (±14 years), the nitrates for the original tailings facilities to the north have already decayed back to the background nitrate concentrations. It further indicates that within 30 months, nitrate concentrations will decay from ±650 mg/l to around 20 – 40 mg/l on the co-disposal footprint. At 120 months post operations, nitrate concentrations would be below the SANS limit for all the facilities at Thorncliffe. From the results, it is evident that the nitrate mass plume from the co-disposal and TSF's do not reach the Dwars River.

7.2.3.3.2 Helena WRD

For the TDS mass plumes at Helena (Figure 7-12), the post operational results show that the plume concentrations are all below the SANS 241 limit for TDS. Considering the nitrate plume in Figure 7-13, the plume reaches the Dwars River receptor at end of operations for the Magareng WRD (WRD 3), but never above the SANS 241 nitrate limit. The Magareng WRD plume also decreases in size quite significantly due to the decay of nitrate and shows to have disappeared by the time the new WRD over the old tailings facility completes Phase 2 of development (2031 – 2038). The results show that 13 months post operations, the nitrate plume would be below the SANS 241 limit (Figure 7-13).

7.2.3.3.3 Breakthrough curves

Figure 7-14 and Figure 7-15 indicate the max mass plumes and breakthrough curves for TDS and nitrate, respectively. Both the TDS and nitrate mid-stream monitoring location breakthrough curves show to have a higher initial concentration at the start of simulation. This was due to leakage from the WRD facility directly upstream of the monitoring location affecting the concentrations. Modelled TDS breakthrough curves for the downstream monitoring location for

each of the mining operations show to be well below SANS 241. The upstream monitoring location nitrate concentrations for the mitigated scenario is higher, which shows the effect of the PCD bottom drains and seepage capturing boreholes. All the breakthrough curves for nitrate show to decrease below baseline around 40 years into simulation (initial modelling base date at 2003).

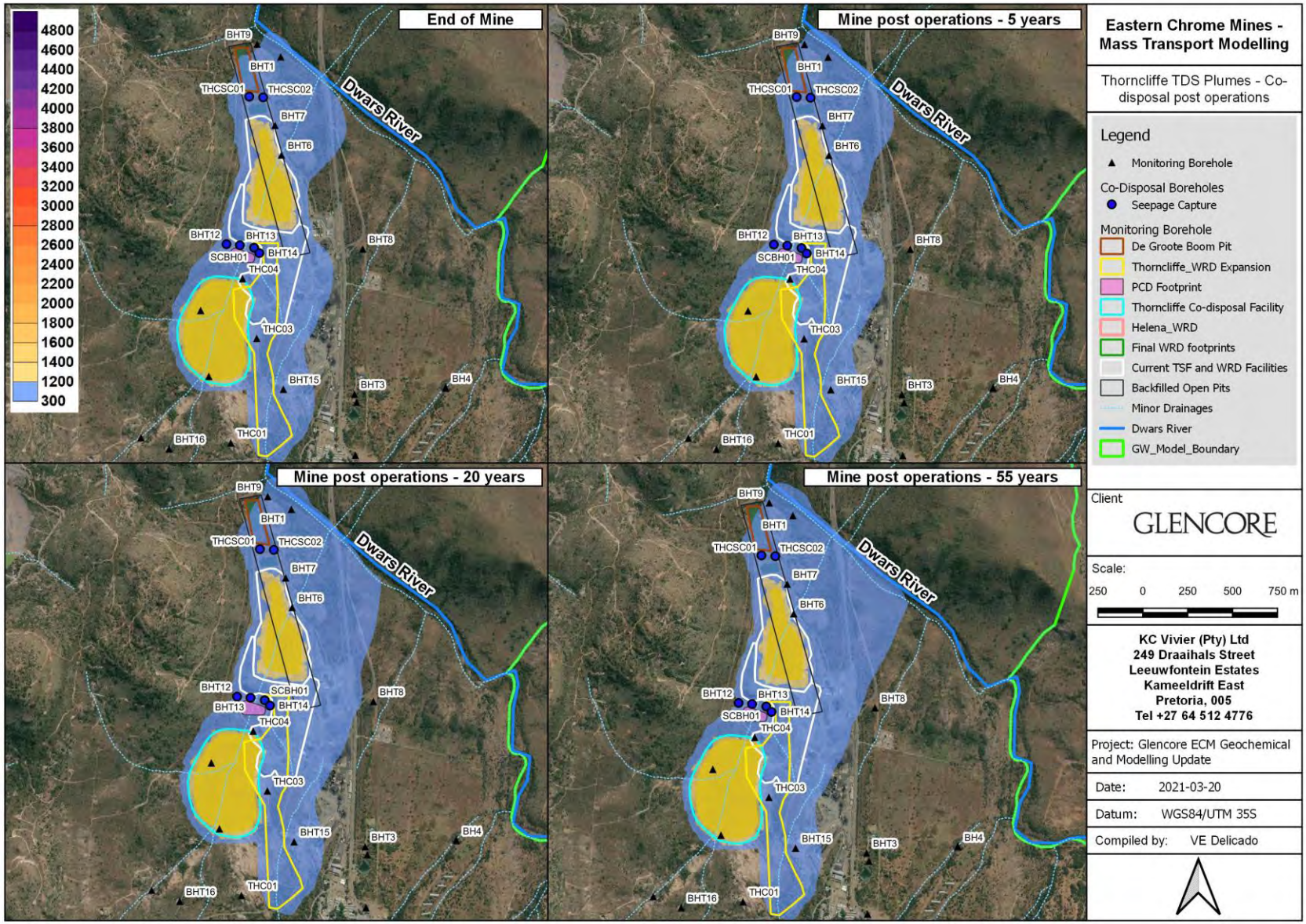


Figure 7-10 Thorncliffe TDS Plumes - Post operational phase

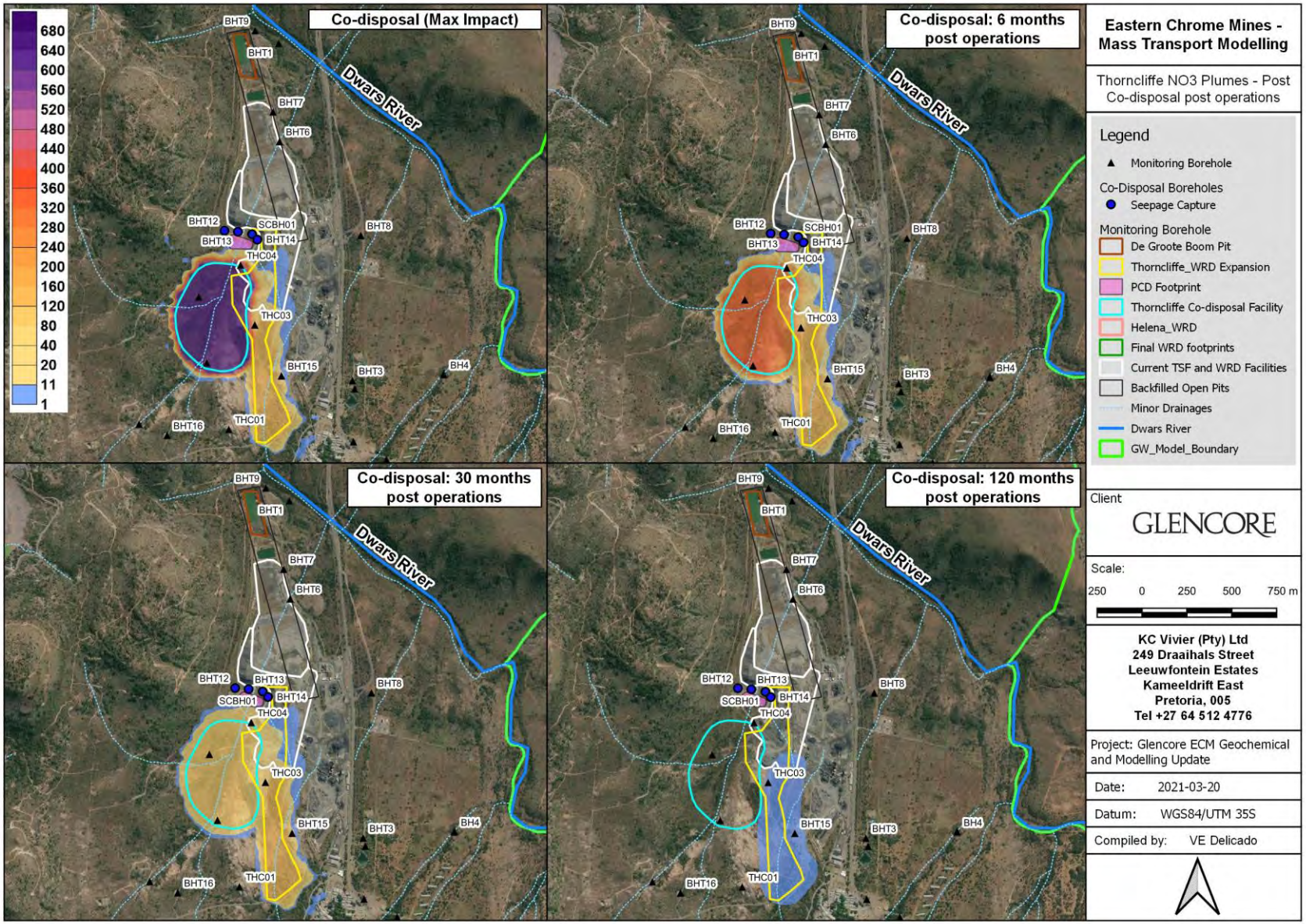


Figure 7-11 Thorncliffe Nitrate Plumes - Post operational phase

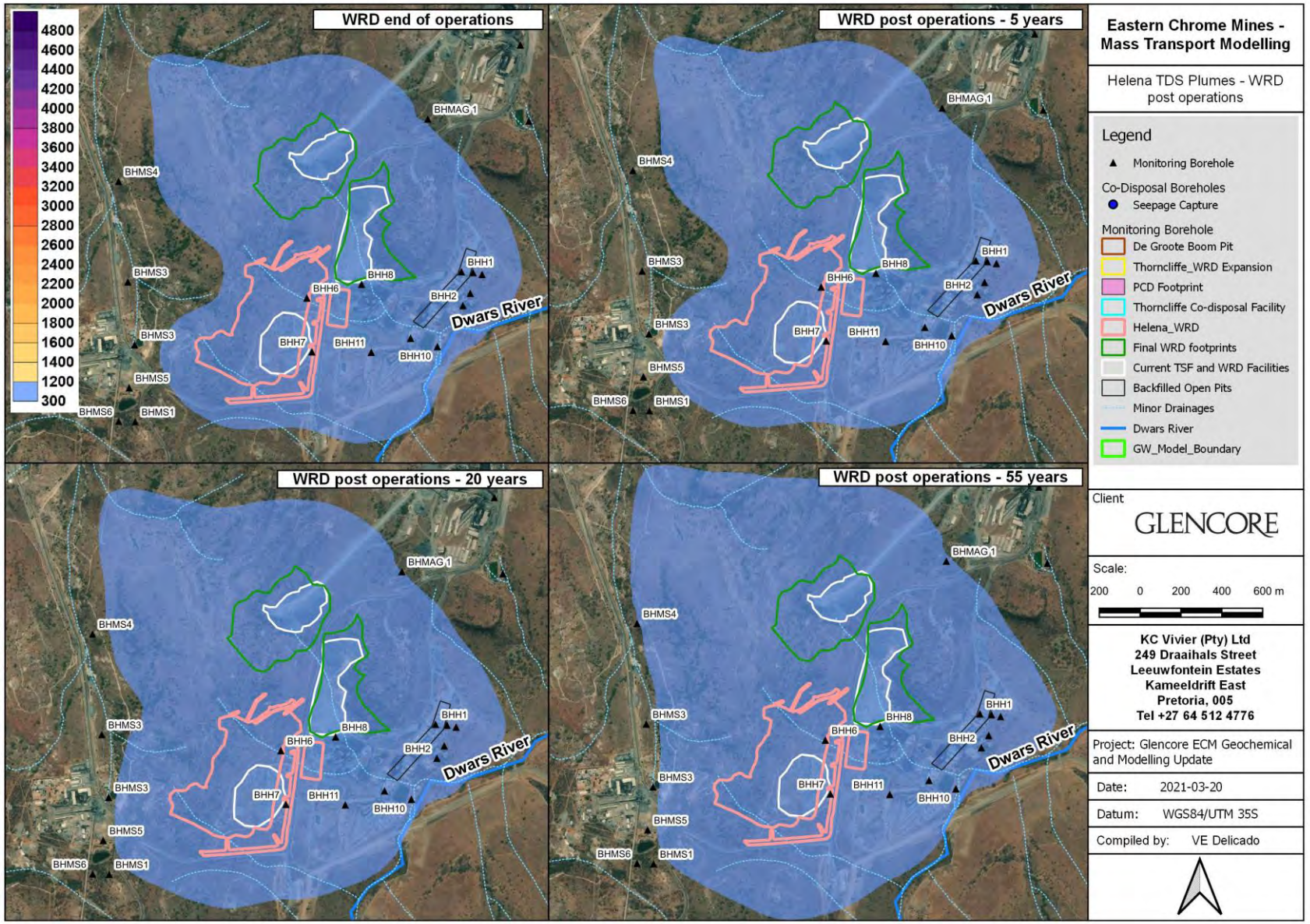


Figure 7-12 Helena TDS Plumes – WRD post operational phase

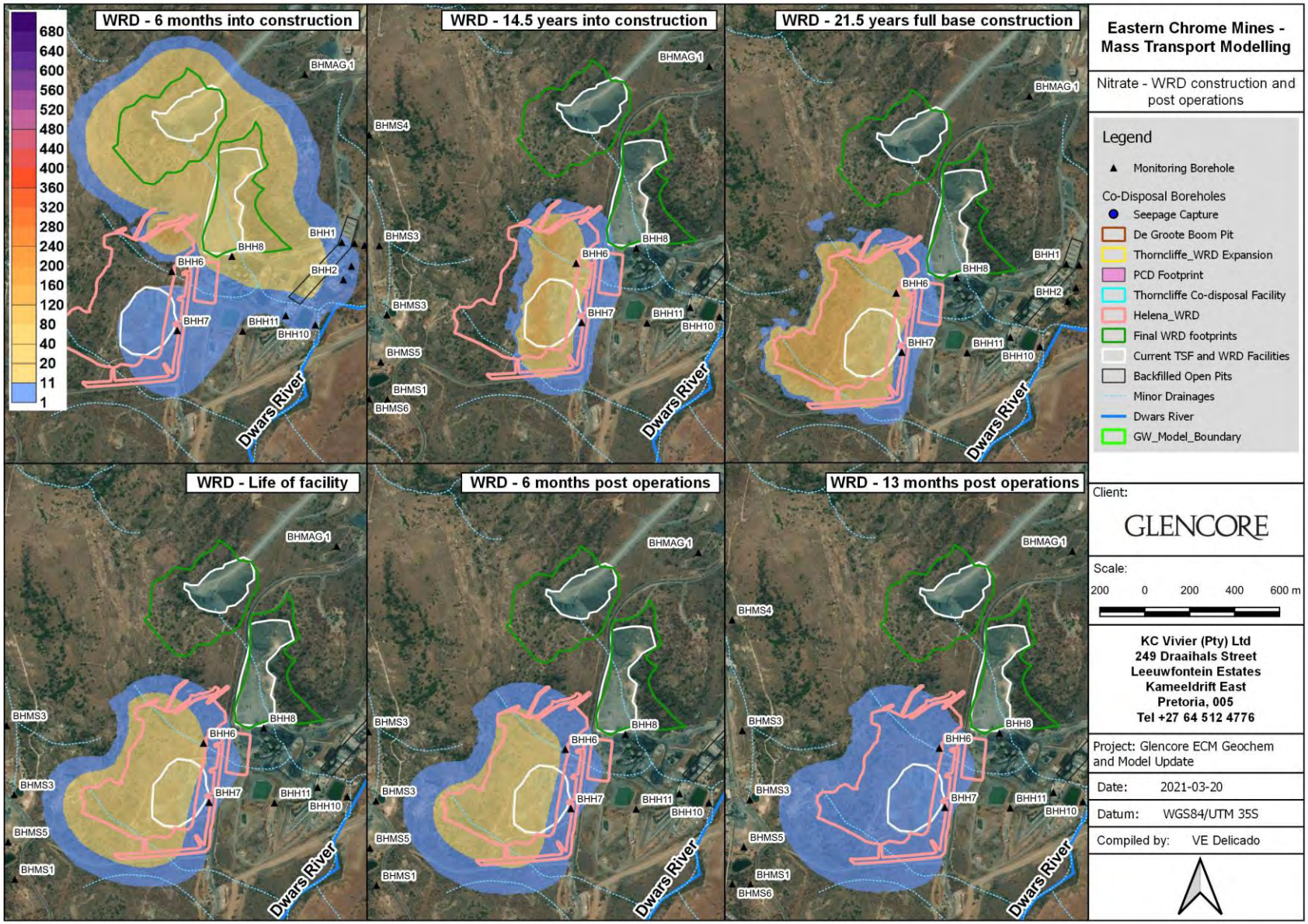


Figure 7-13 Nitrate Plumes – Helena WRD construction and post-operational phases

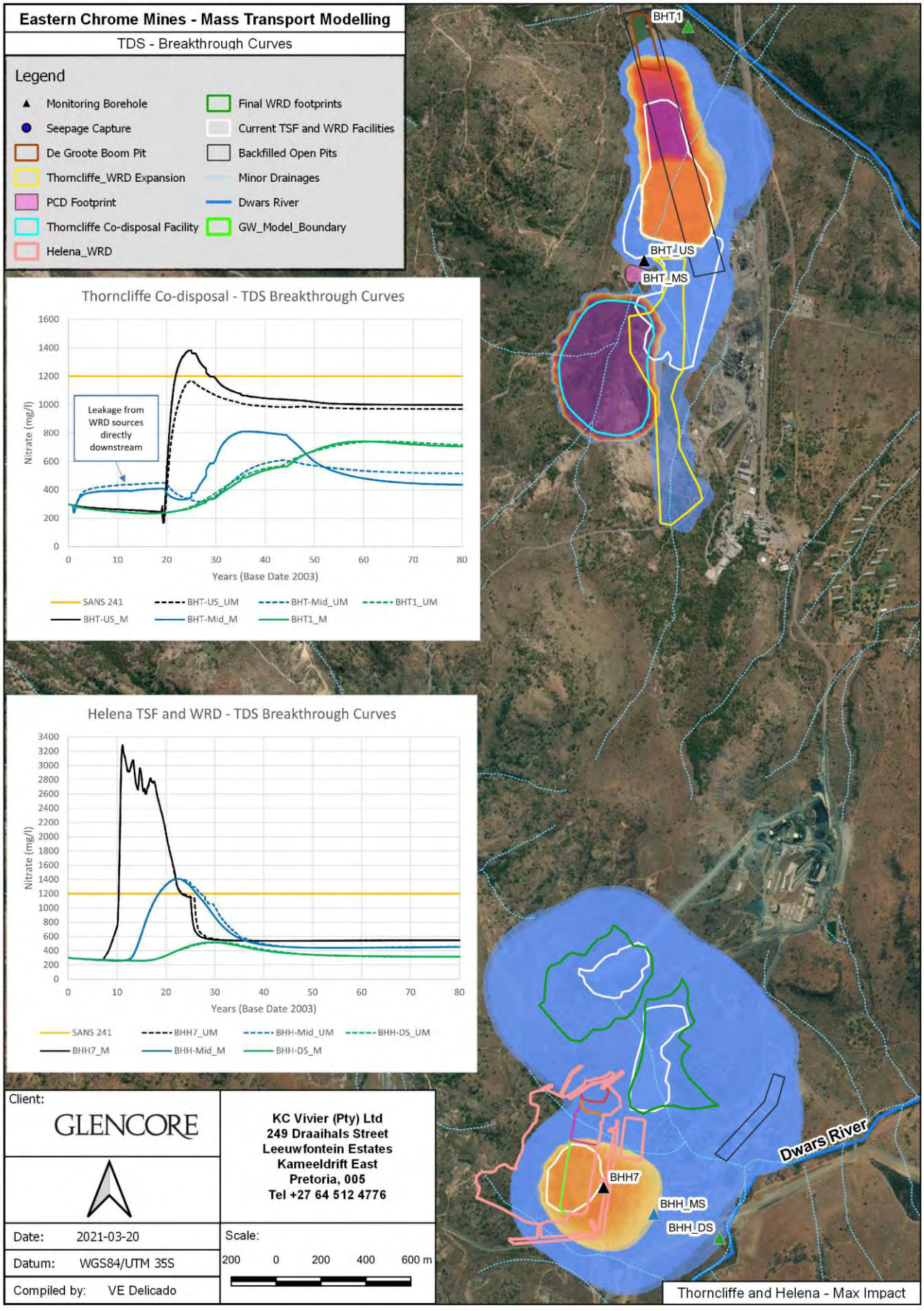


Figure 7-14 TDS Max Impact with Breakthrough curves

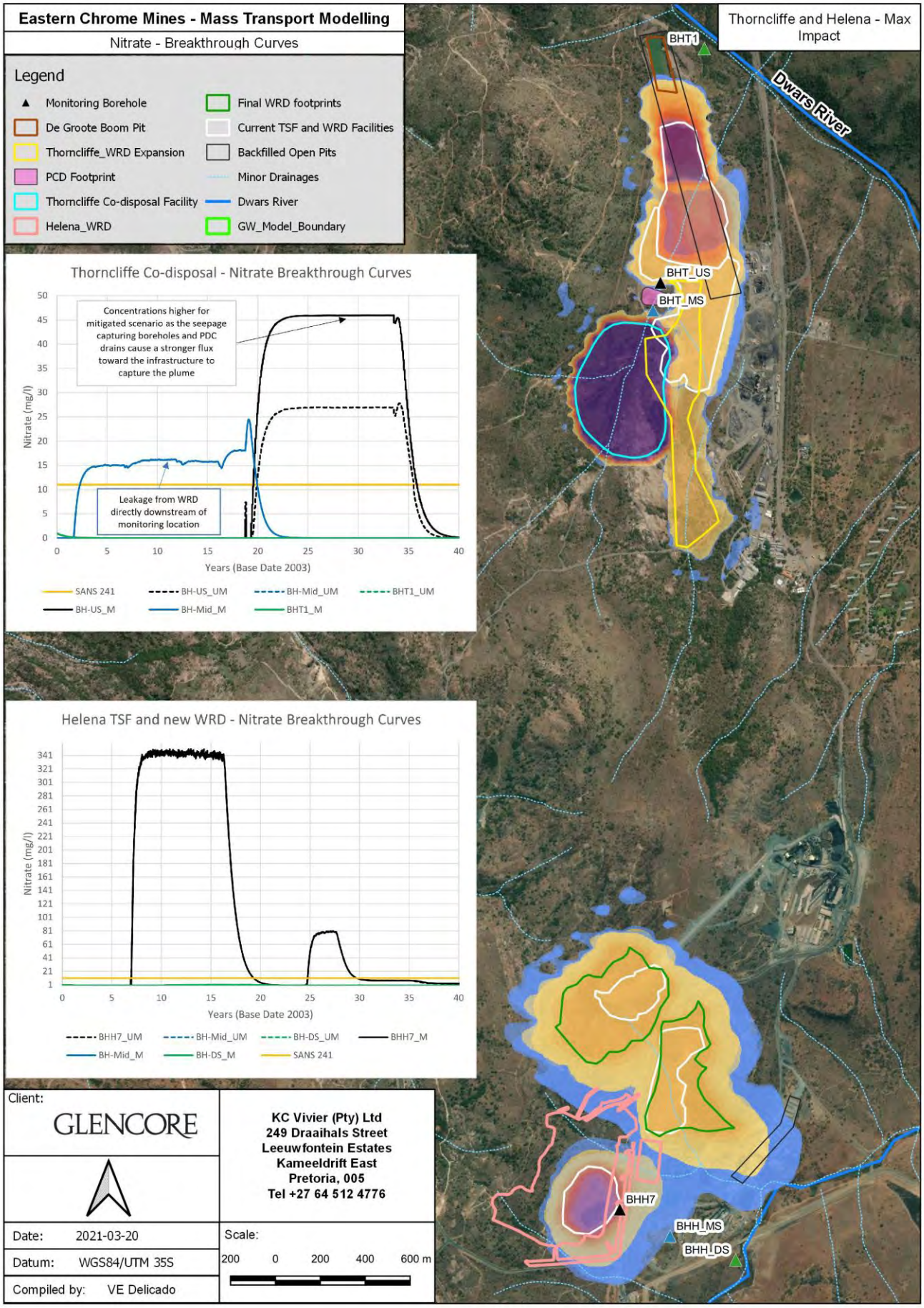


Figure 7-15 Nitrate max impact with breakthrough curves

8 IMPACT ON DWARS RIVER RECEPTOR

From the TDS modelling results, a detailed analysis of the maximum impact on the main receptor – the Dwars River, was conducted for both the Thorncliffe and Helena mining operations. To be conservative, the unmitigated, modelled TDS mass flux that reaches the Dwars River with time were used in the evaluation. Actual flow station data (Station number: B4H009PK) were used and corrected for the mean flows for the Groot Dwars River.

The calculated impact on the groundwater TDS near the Dwars River (BHT01) is given by Figure 8-1.

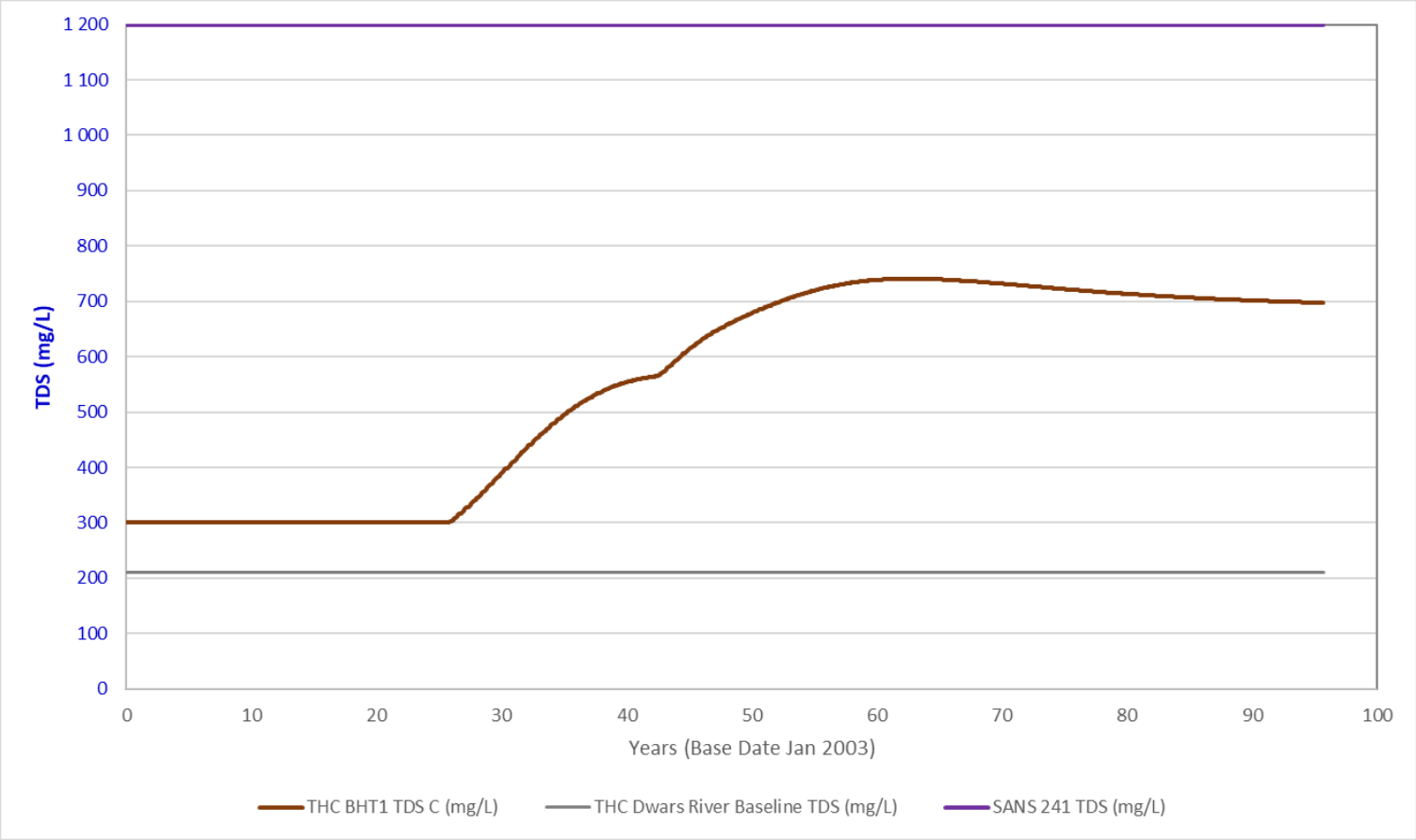


Figure 8-1 TDS impact on the groundwater upstream from the Dwars River

From the modelling, the groundwater TDS concentrations of BHT01 steadily increased to a maximum of ±750 mg/l, after which a decrease is observed. TDS concentrations will naturally decrease when higher rainfall events occur (flushing of salt build-up), or as mine infrastructure is remediated (lower flux from mine infrastructure during rainfall). The TDS concentrations are also well below the SANS 241 Drinking Water limits.

The calculated impact on the Dwars River increased in TDS concentrations is presented in Figure 8-2.

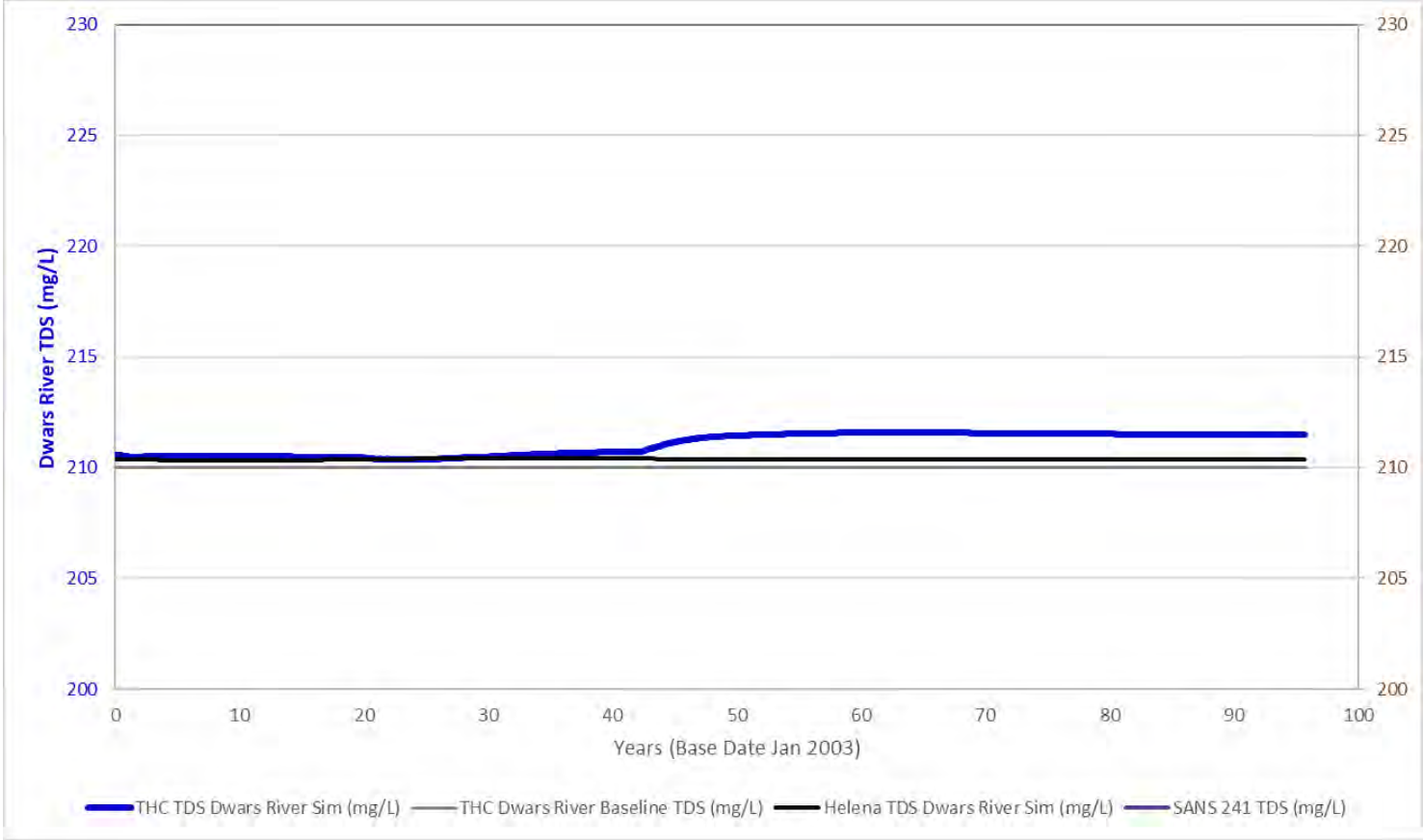


Figure 8-2 TDS impact on the Dwars River

The figure shows that from the modelling results, the physical impact on the Dwars River TDS concentrations is insignificant (<2%) for both life of mine and post operational periods, and therefore no barrier for mining infrastructure (Thorncliffe co-disposal and Helena updated WRD) is required. The groundwater management and mitigation measures accounts for a multi-barrier mitigation approach to ensure mass plumes are mitigated before the receptor is reached.

In terms of nitrate impacts, Figure 8-3 and Figure 8-4 from the Exigo long term monitoring data shows that:

1. Nitrate is the only potential contaminant of concern.
2. Spikes of nitrate load occurs after rainfall events; surface water (not groundwater) is the contributor as the spikes last only during and immediately after rain events or wet months.
3. Nitrate concentrations steadily decreased from 2017 for Thorncliffe.
4. Dry season nitrate is below base line, at <2.5 mg/L which in turn is way below the SANS 241 drinking standard of 11 mg/L any groundwater contributions is diluted, and impact is

insignificant.

5. The biomonitoring does not show deteriorating conditions at samples locations above Helena (upstream) and below Thorncliffe (downstream) (see detailed Exigo Quarterly monitoring reports, 2019, 2020).

6. The aquifer has a low transmissivity (1-10 m^2/d) and although high nitrate values are measured immediately downstream from waste rock sources the migration potential is low.

7. Nitrate has a proven half-life of 500 - 600 days and undergoes decay due to denitrification which means that nitrate plumes decay long before it reaches the Dwars River receptor.

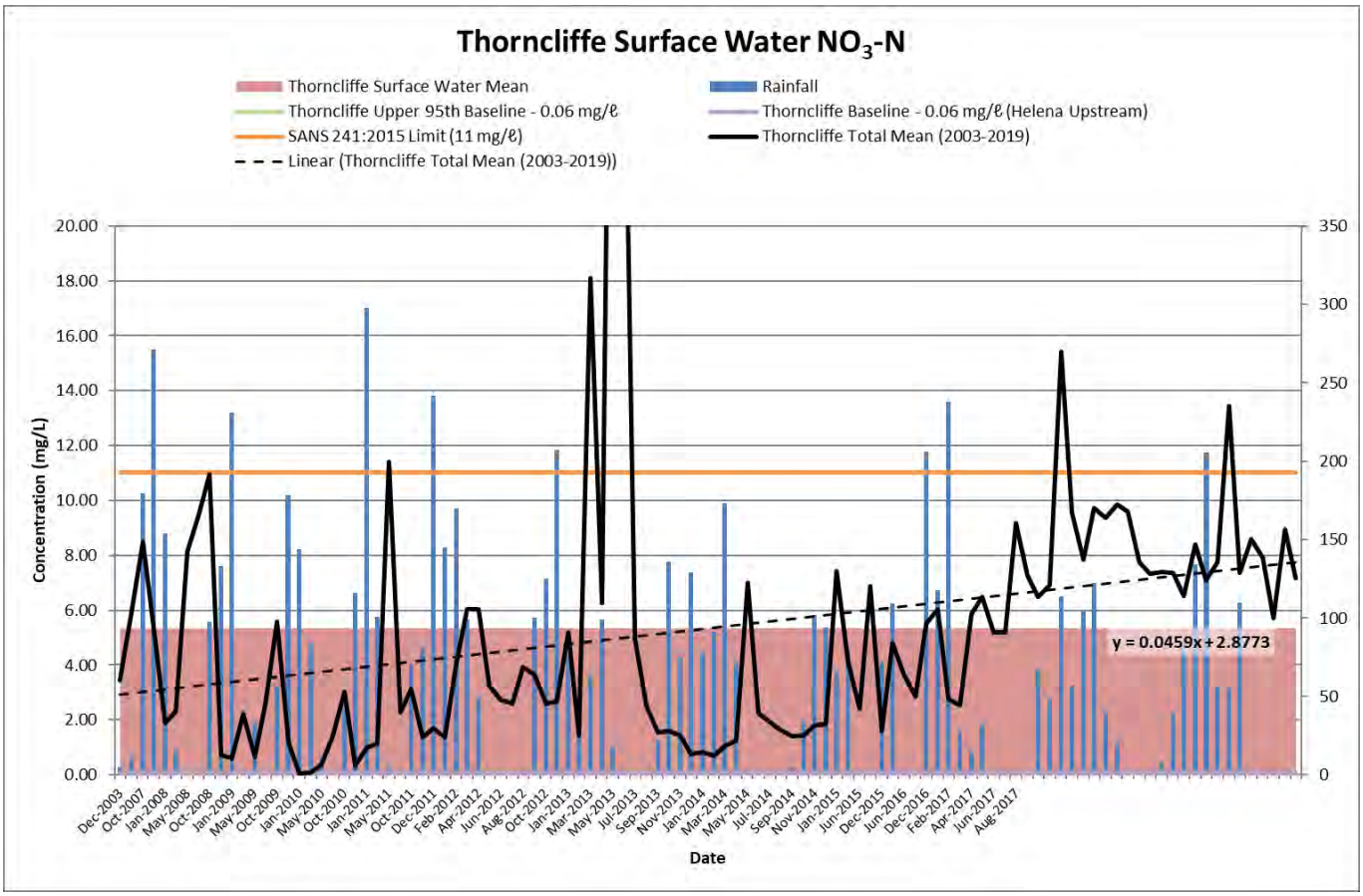


Figure 8-3 Nitrate impact on the Dwars River at Thorncliffe

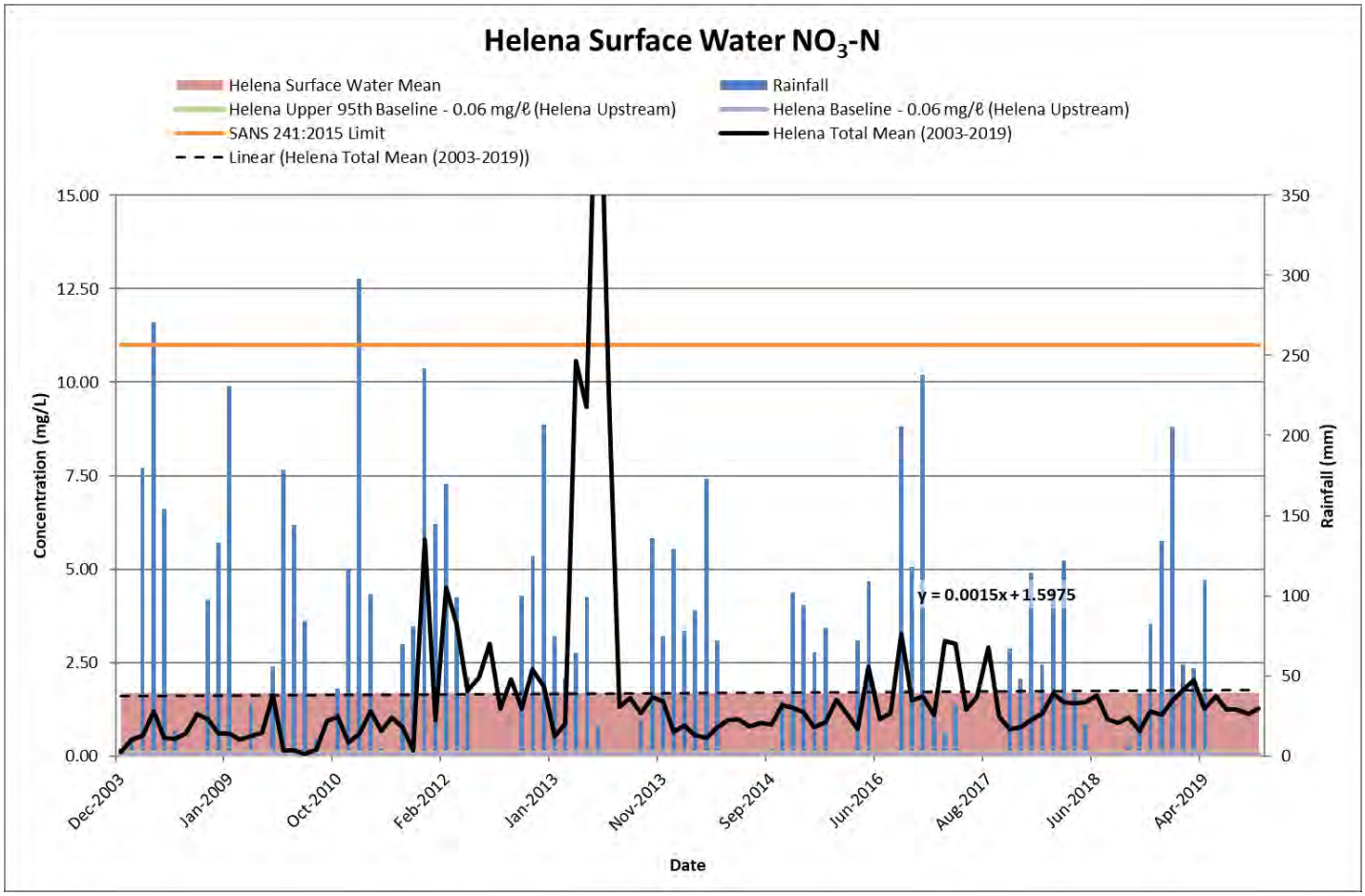


Figure 8-4 Nitrate impact on the Dwars River at Helena

9 MONITORING REQUIREMENTS

From the analysis and modelling conducted, the proposed additional boreholes required for seepage capture, monitoring, or a combination of the two (continual monitoring of the boreholes – inclusion in the monitoring network, to assess if seepage capture is required per borehole as time progresses) is presented in Table 9-1.

Table 9-1 Existing or Proposed additional monitoring and/or seepage capture boreholes

Mining Area	BH ID	X (TM 31)	Y (TM31)	Proposed/Actual Drilling Depth (m)	Borehole Diameter (mm)	Aquifer Monitored	Designation	Borehole Purpose
Thorncliffe	BHT12	-88632.3	-2762295.3	29	165	Shallow Aquifer	Drilled	Seepage Capture
	BHT13	-88557.5	-2762301.4	30	165	Shallow Aquifer	Drilled	Seepage Capture
	BHT14	-88449.2	-2762345.1	30	165	Shallow Aquifer	Drilled	Seepage Capture
	BHT15	-88315.4	-2763103.3	40	165	Shallow Aquifer	Drilled	Monitoring
	SCT01	-88478.3	-2762315	40-50	165	Shallow Aquifer	Proposed	Seepage Capture
	SCT02	-88462.3	-2762418.6	40-50	165	Shallow Aquifer	Proposed	Monitoring pending Seepage Capture
	SCT03	-88184.5	-2762377.1	40-50	165	Shallow Aquifer	Proposed	Monitoring pending Seepage Capture
	SCT04	-88566.4	-2762410.5	40-50	165	Shallow Aquifer	Proposed	Monitoring pending Seepage Capture
	MBT01	-88528.8	-2763086.5	40-50	165	Shallow Aquifer	Proposed	Monitoring
	MBT02	-88153.7	-2761507.6	40-50	165	Shallow Aquifer	Proposed	Monitoring
	THC03	-88463.4	-2762820.2	Unknown	165	Shallow Aquifer	Unknown	Monitoring
	THC04	-88542.9	-2762487.6	Unknown	165	Shallow Aquifer	Unknown	Monitoring

Mining Area	BH ID	X (TM 31)	Y (TM31)	Proposed/Actual Drilling Depth (m)	Borehole Diameter (mm)	Aquifer Monitored	Designation	Purpose
Helena	BHH7	-88707	-2766431	TBC	165	Shallow Aquifer	Drilled	Monitoring pending Seepage Capture
	BHH8	-88463.3	-2766100.8	TBC	165	Shallow Aquifer	Drilled	Monitoring
	BHH11	-88415.7	-2766433.9	TBC	165	Shallow Aquifer	Drilled	Monitoring
	SCH01	-88802.5	-2766609.4	40-50	165	Shallow Aquifer	Proposed	Monitoring pending Seepage Capture
	SCH02	-88553.1	-2766576.9	40-50	165	Shallow Aquifer	Proposed	Monitoring pending Seepage Capture
	SCH03	-88521.8	-2766291.6	40-50	165	Shallow Aquifer	Proposed	Monitoring pending Seepage Capture
	MBH01	-88714.1	-2766693.3	40-50	165	Shallow Aquifer	Proposed	Monitoring
	MBH02	-88446.2	-2766694.6	40-50	165	Shallow Aquifer	Proposed	Monitoring

An additional 6 boreholes are proposed to be drilled at the Thorncliffe operations, with an additional 5 locations proposed at the Helena mining operations to delineate and monitor the mass plumes more accurately. Some of the boreholes listed have already been drilled and tested and should be included as seepage capture boreholes pending continual monitoring as the infrastructure grows and leakages increase. Borehole coordinates are conceptual and may be

shifted by ±50 m pending geophysical results or site location constraints. The existing and proposed monitoring and/or seepage capture boreholes are presented in Figure 9-1.

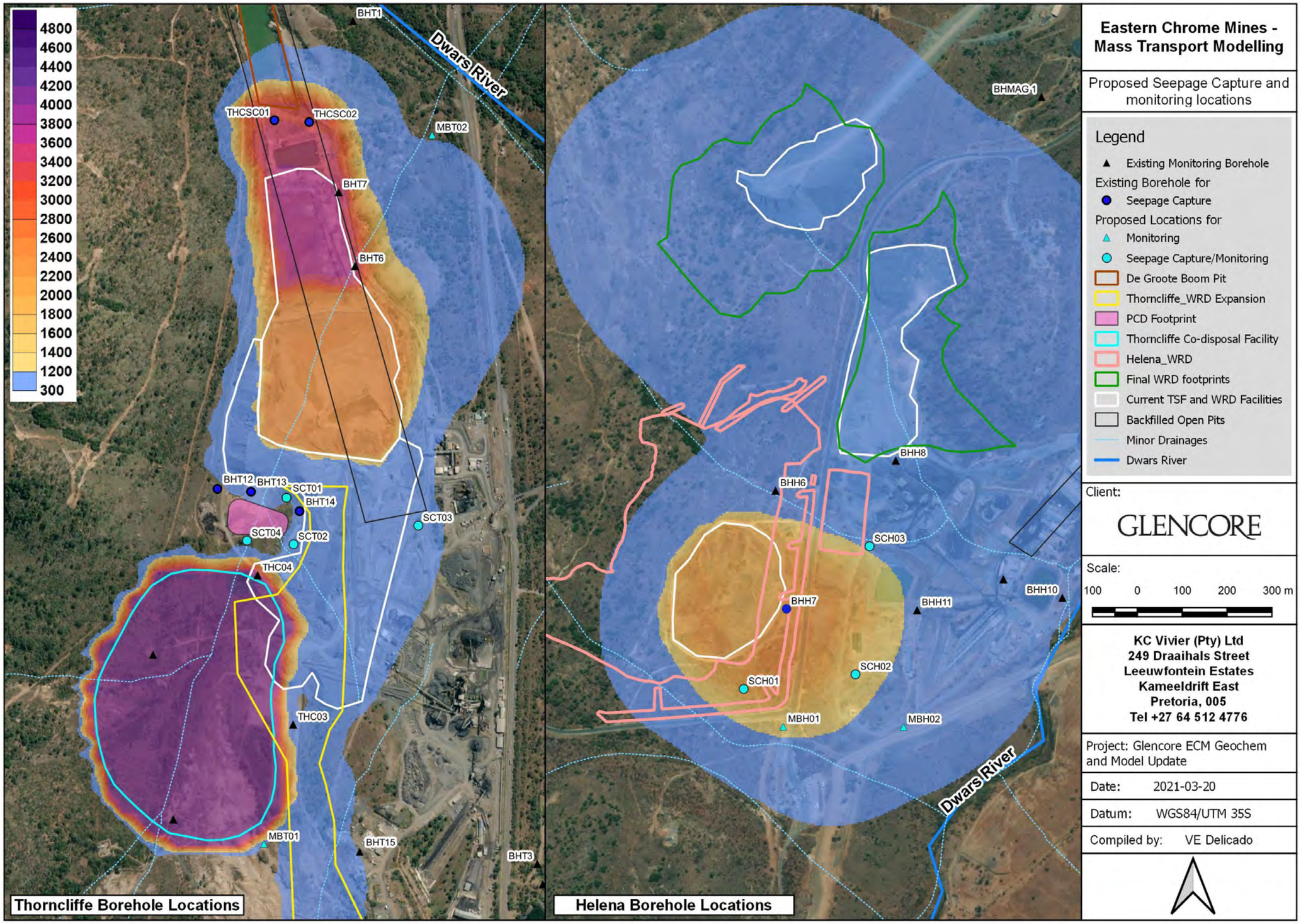


Figure 9-1 Existing and proposed monitoring and/or seepage capture borehole locations

10 IMPACT ASSESSMENT

The hydrochemical assessment and trend analysis would indicate that the Dwars River can be considered as the receptor of possible impacts from the new mining developments. TDS and Nitrate (and to a lesser extent sulphate, to be monitored and reviewed as indicated in Section 3) mass migration might have an impact on the aquifer system locally and the impacts are limited to the immediate mining area.

The groundwater levels from monitoring data indicate limited impacts from mine dewatering and groundwater use for mining purposes.

The detailed Impact Assessment methodology is presented in Appendix I: Impact Assessment and Matrix. The following important impacts and controls were included:

10.1 Construction phase

10.1.1 Possible impacts

- Contamination to surface- and groundwater systems from oil, grease, and diesel spillages from construction vehicles.
- Flooding of underground mine workings and infrastructure due to increased groundwater inflow at Thorncliffe, Helena and Magareng Mines.

10.1.2 Mitigation measures

- Road compaction and service facilities for mine vehicles with spillage sumps.
- Abstraction volume monitoring and observations if geological fractures are intersected at depth during construction.

10.2 Operational phase

10.2.1 Possible impacts

- Increased surface water flow from new waste facilities at Thorncliffe (Co-disposal) and Helena (WRDs) Mines along channels and drainages.
- TDS and nitrate seepage from waste facilities at Thorncliffe (existing TSFs and new Co-disposal) and Helena (WRDs) Mines to the groundwater system.
- Possible Nitrate seepage from waste facilities at Thorncliffe (existing TSFs and co-disposal) and Helena (WRD) Mines to the groundwater system.
- Increased mine dewatering volumes from underground workings and extensions at Thorncliffe, Magareng and Helena Mines.
- Increased seepage from new and existing waste facilities (TSFs, WRDs and co-disposal) towards the Dwars River during flooding events due to increased runoff at Thorncliffe and Helena Mines.

10.2.2 Mitigation measures

- Management and containment of surface water from the waste facilities (TSFs, WRDs and co-disposal) and construction of additional storage and settling facilities.
- The Thorncliffe Multiple hydraulic barrier management and mitigation system that must be implemented includes:
    - The CDSF has a multiple barrier approach to mitigate potential migration to the Dwars River via the groundwater pathway. Four barriers planned as follows:
        - PCD Bottom Drain: The modelled PCD drains abstract at an average of 10 m^3/d starting initially at 40 m^3/d. The drains are important to prevent pressure build up below the PCD to protect the liner and to capture seepage. A more detailed analysis of the PCD bottom drain is required.
        - Seepage capturing holes near: The additional seepage capture boreholes (x4) abstract at an additional ±20 m^3/d. Three additional seepage capturing holes should be provided for and only drilled pending reactions at the planned 4 holes monitoring in water levels and chemistry.
        - Seepage capturing holes distant: The seepage capture boreholes immediately upstream of the De Grootteboom Pit are effective, as some of the holes are drilled within the higher permeable backfilled open pit section, and abstract at an average of ±175 m^3/d per borehole.
        - The De Grootteboom pit captures and abstracts an average of 300 m^3/d for the operational phase.
- Six additional monitoring and/or seepage capturing boreholes (as indicated in the report) should be drilled and/or included in the current Water Monitoring Protocol up and down gradient of the new CDSF and WRD. Constant groundwater quality monitoring is required.
- The Helena Mine multiple hydraulic barrier management and mitigation system to include the following:
    - Stormwater and on-site seepage capturing measures to include:
        - Toe paddocks on the eastern toe of the new WRD to capture any possible seepage, capture sediment and attenuate storm water runoff;
        - Lined storm water channel from the northern valley (WRD 3) next to the main road to ensure long term stability and reduce sediment generation, as well as protect the road shoulder;
        - Sediment trap to maintain the capacity of the PCD;
        - Seepage capturing boreholes to capture and contain any fugitive seepage that may arise (if necessary, as per monitoring results).
        - For nitrate, the third barrier would be time, as nitrates naturally decay due to denitrification (calculated half-life of 300 days).

- Five additional seepage capture and/or monitoring boreholes should be drilled and included in the current Water Monitoring Protocol down gradient of WRD. The boreholes should be utilised as seepage capturing boreholes should the need arise (as specified above).

10.3 Post operational phase

10.3.1 Possible impacts

- TDS, Nitrate and possible Sulphate leaching from existing and new waste facilities at Thorncliffe and Helena Mines.
- Seepage towards the Dwars River during flooding events from the existing and new waste facilities at Thorncliffe (TS, WRD and co-disposal) and Helena (WRDs) Mines.

10.3.2 Mitigation measures

- Sealing-off of mine voids connecting the underground with the surface, medium term monitoring at void positions and employing seepage capturing (via PCD, pit and boreholes).
- Rehabilitation and vegetation of mine residue facilities.
- Phytoremediation downstream from mine waste facilities.

11 CONCLUSIONS

1. The current deep mine dewatering has an insignificant impact on the surface aquifer systems as is evident from the long-term monitoring data and water levels (2003-2021).
2. The geochemical tests and source term analysis indicated that TDS, nitrate and chrome are potential sources from the mine residue.
3. Based on the analysis of 12 years' monitoring data:
    - High TDS and nitrate concentrations are associated with the process water and onsite monitoring holes immediately downstream from mine residue facilities. No chromium is detected in the groundwater.
    - The water quality impacts on the Dwars River from TDS and nitrate is insignificant with mean TDS values of <250 mg/ℓ and nitrate values of <10 mg/ℓ.
    - Biomonitoring shows that the downstream (from Thorncliffe) monitoring river health is equal or better than the upstream (from Helena) monitoring.
4. The composite tailings from Helena, Thorncliffe and Magareng mines were classified as Type 4 waste. In terms of the leachate assessment, i.e., the liquid phase, the results show that TDS and NO3-N exceeds the leachable concentration threshold (LCT0). The TDS-concentration can be attributed to the NO_3-N concentration and the Ca and Mg that accumulates during the processing treatments. Ca and Mg do not have SANS 241-2015 limits and can thus be considered insignificant to the surrounding groundwater environment for drinking purposes. The principle of decay applies to the nitrate which

will thus not affect surrounding receptors.

5. The modelling results indicated limited to no impact due to dewatering on the aquifer systems with the underground mining extension.

6. Water supply to the current mining operations will not be affected significantly by mine dewatering as there is a maximum simulated increase dewatering from the underground extension of 600 m^3/d to a cumulative total of 1600 m^3/d for all 3 mine extension areas. Modelling of the potential mass transport impacts from the development of the Co-Disposal Facility at Thorncliffe and the Helena WRD, showed that the impact on the Dwars River TDS concentrations is insignificant. The increase in TDS (<2%) for both life of mine and post operational periods, and therefore no barrier for mining infrastructure (Thorncliffe co-disposal and Helena updated WRD) is required. The groundwater management and mitigation measures accounts for a multi-barrier mitigation approach to ensure mass plumes are mitigated before the receptor is reached. Nitrate degrades with time in the groundwater (half-life of 500-600 days) before it reaches the Dwars River receptor. The risks to the receptors from groundwater is low.

7. The CDSF vs TSF leakage decreased by 20-fold from 510 m^3/d to 70 m^3/d due to the technology design, which is much better in comparison to the original designs for mass plume migration and mitigation.

12 RECOMMENDATIONS

The following recommendations were formulated from this study:

- The mine water balance needs to be updated with new mining developments in terms of water supply to the mine as well as dewatering volumes from updated mine dewatering operations.
- The management and mitigation measures recommended in this study should be part of the EMP and a standard operating procedure with automated monitoring and control and internal and external monitoring should be developed.
- The proposed seepage capturing from BHT12 and BHT13 at the CDSF and WRD facility at Thorncliffe could be applied if the first mitigation measure is insufficient. These boreholes including the BHT14, BHT15and BHT16 need to be included into the monitoring program to monitor the effectiveness of the trench and sub-surface concrete barrier.
- The existing monitoring boreholes at Helena could possibly be destroyed with the new WRD development as they are in close proximity or inside the proposed WRD footprint. These boreholes include BHH06, BHH07 and BHH12.
- Three new monitoring requirements should be implemented as part of the current

monitoring program.

- The water monitoring parameters and frequencies should be reviewed and optimised as it is overabundant, and the risks can be managed by monitoring of critical control parameters.

13 REFERENCES

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14 APPENDIX A: GEOPHYSICAL SURVEY RESULTS

14.1 Electrical resistivity and magnetic results

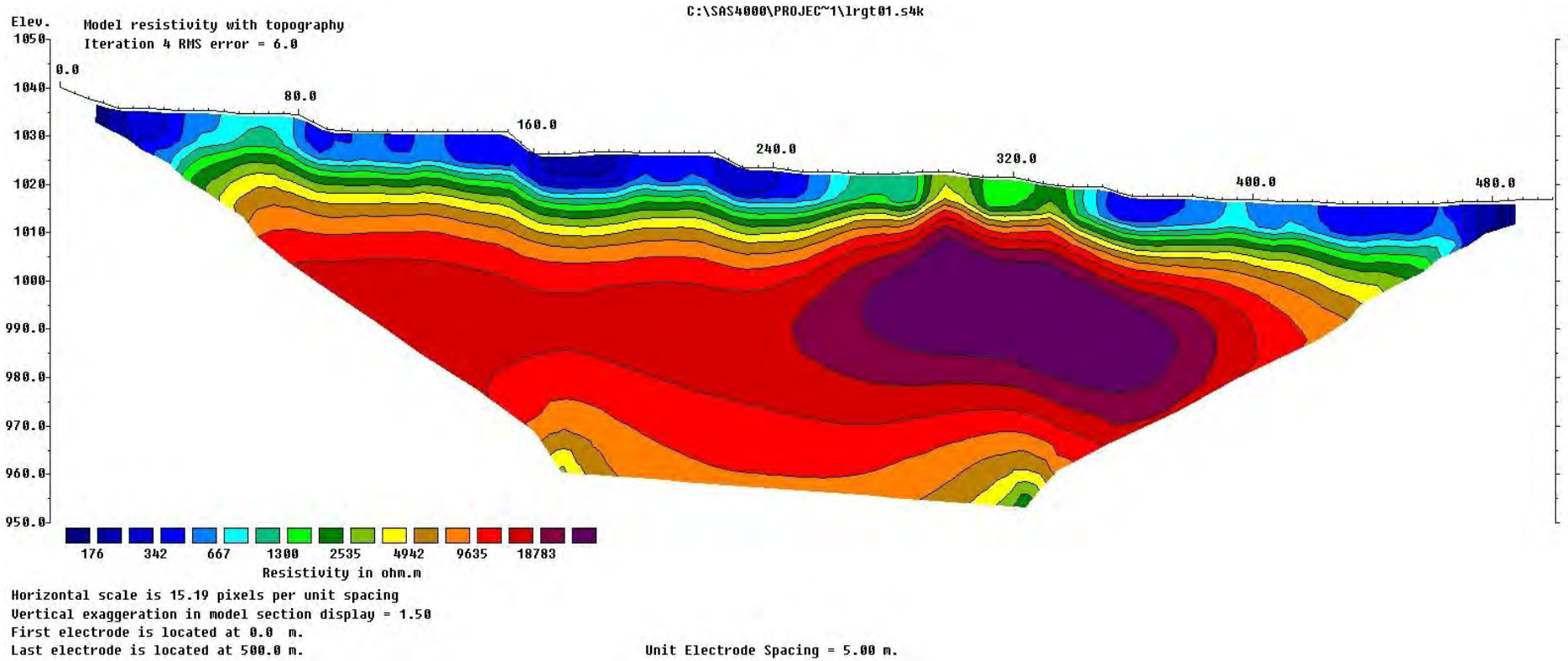
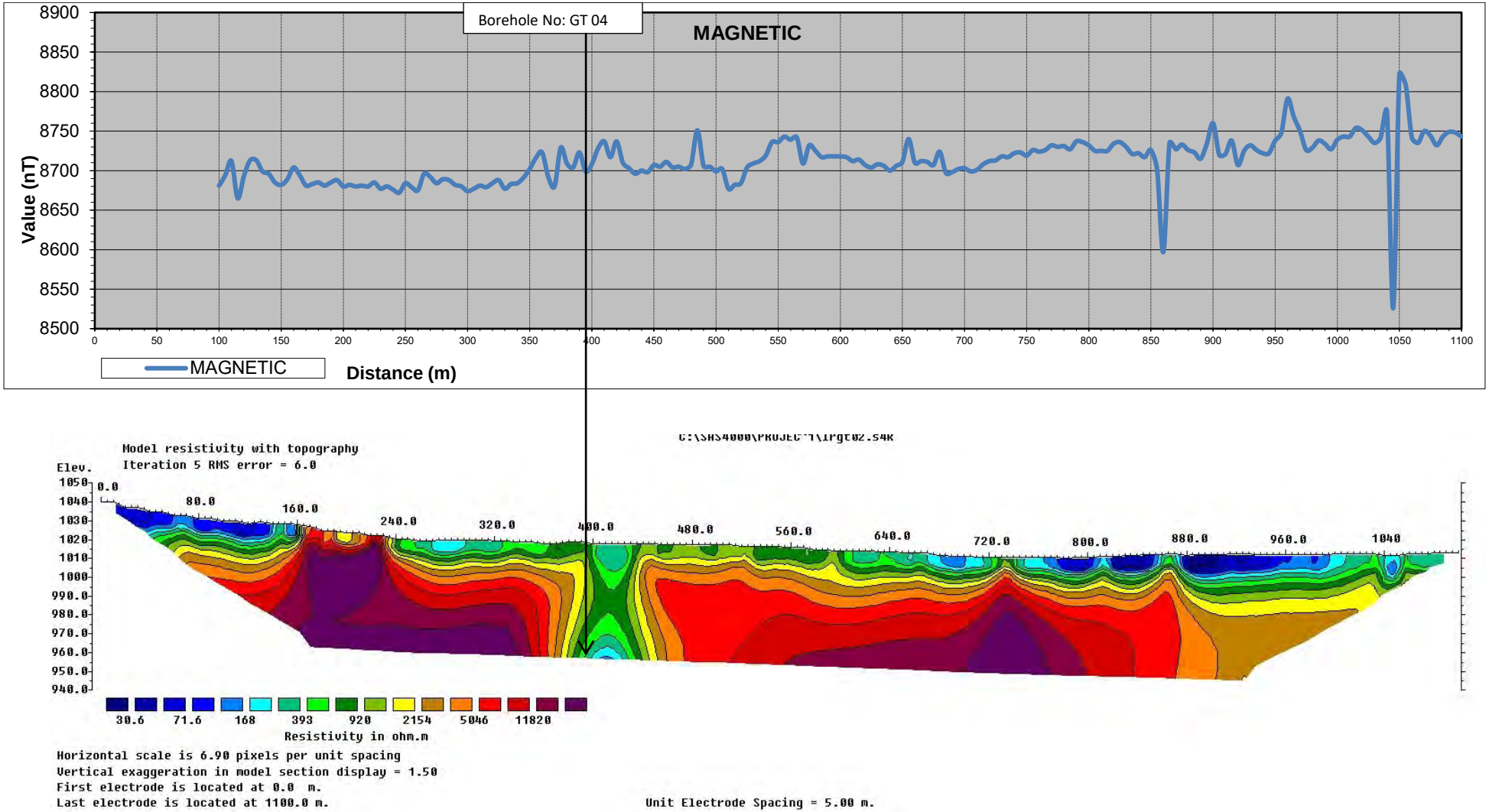


Figure 14-1 Traverse 1



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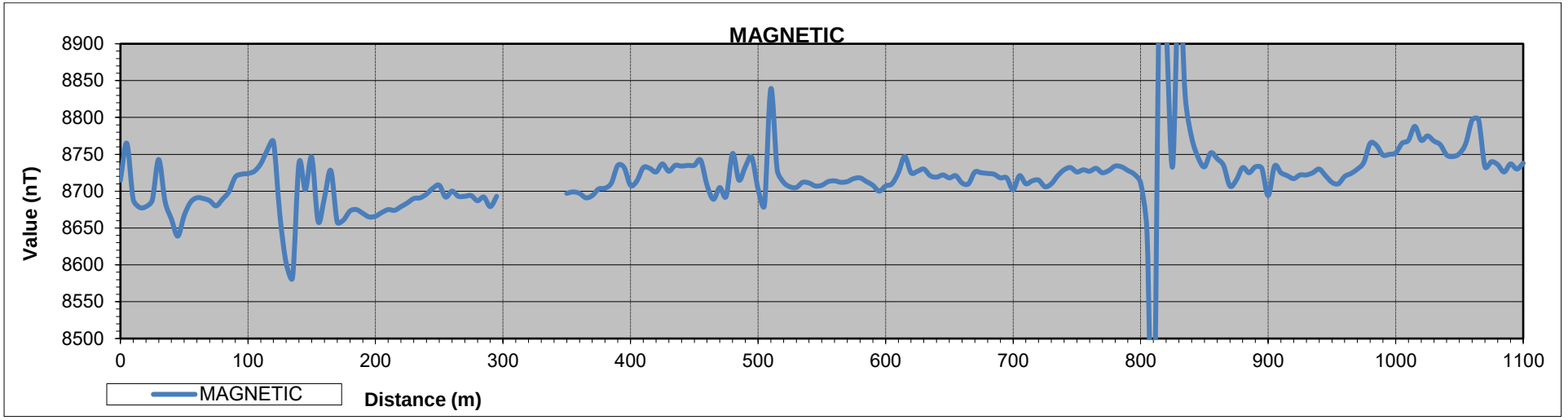


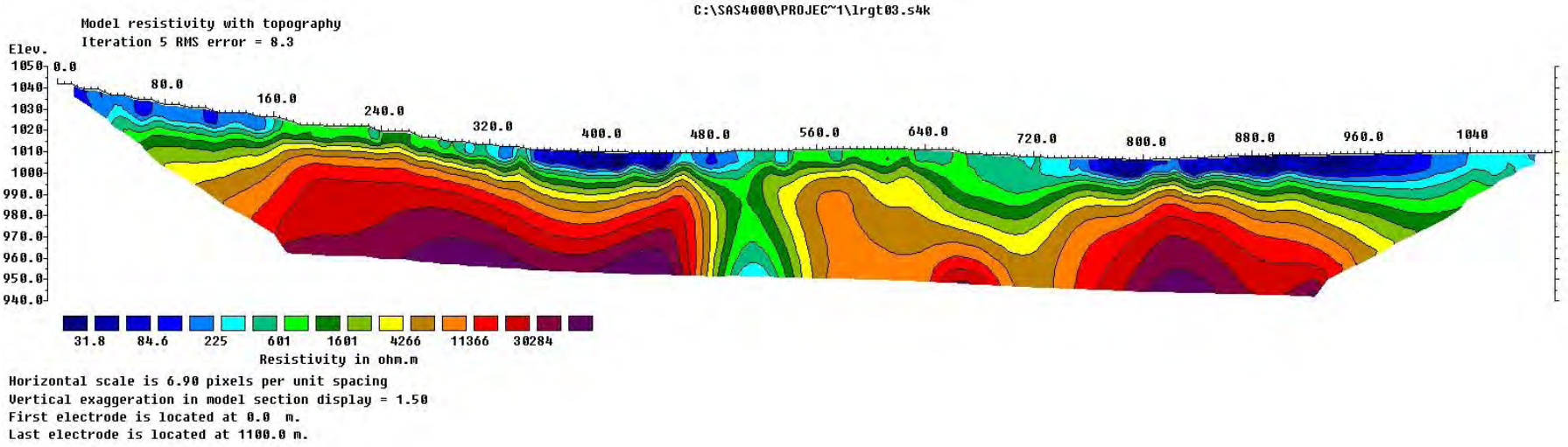
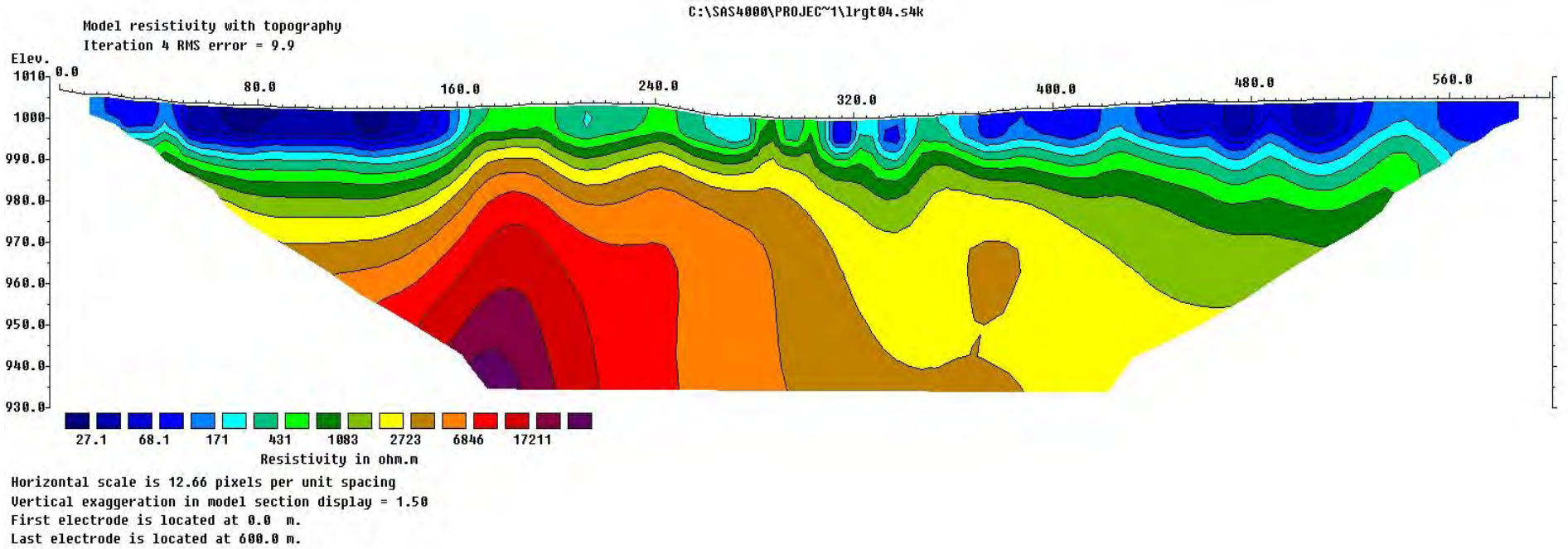


Figure 14-3 Traverse 3



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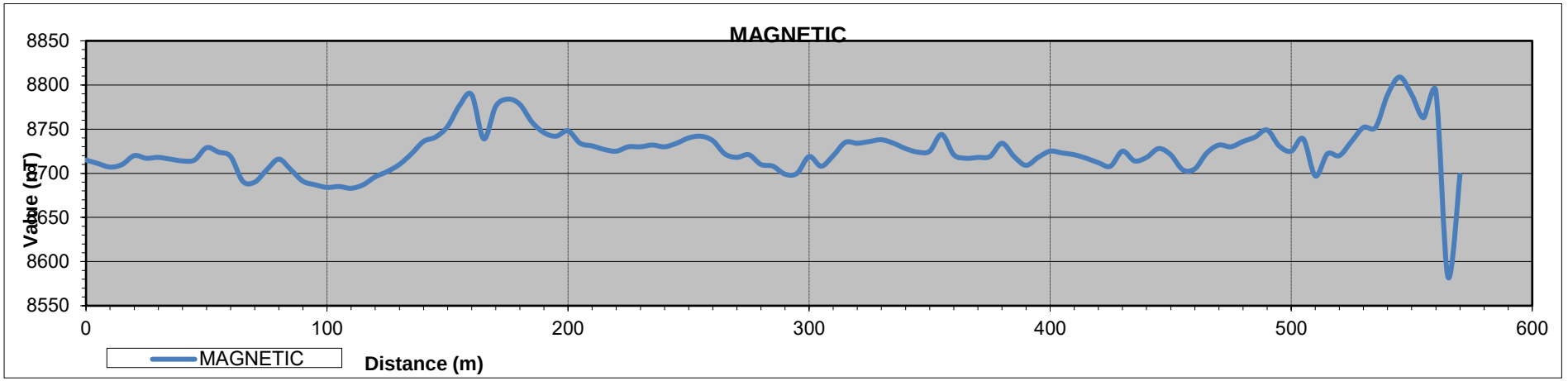


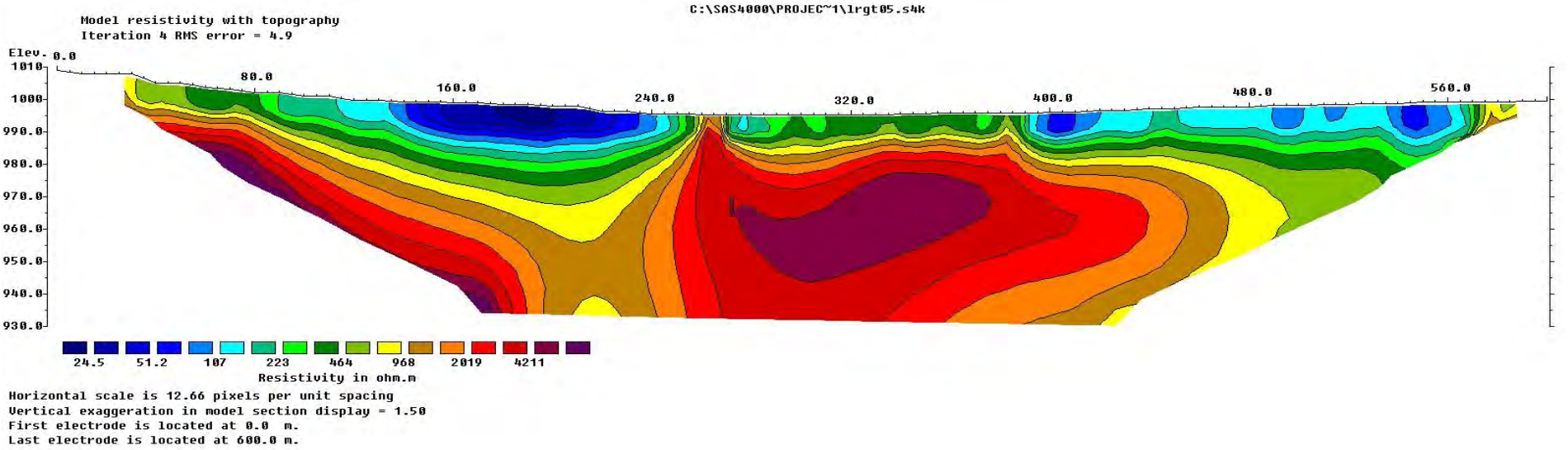
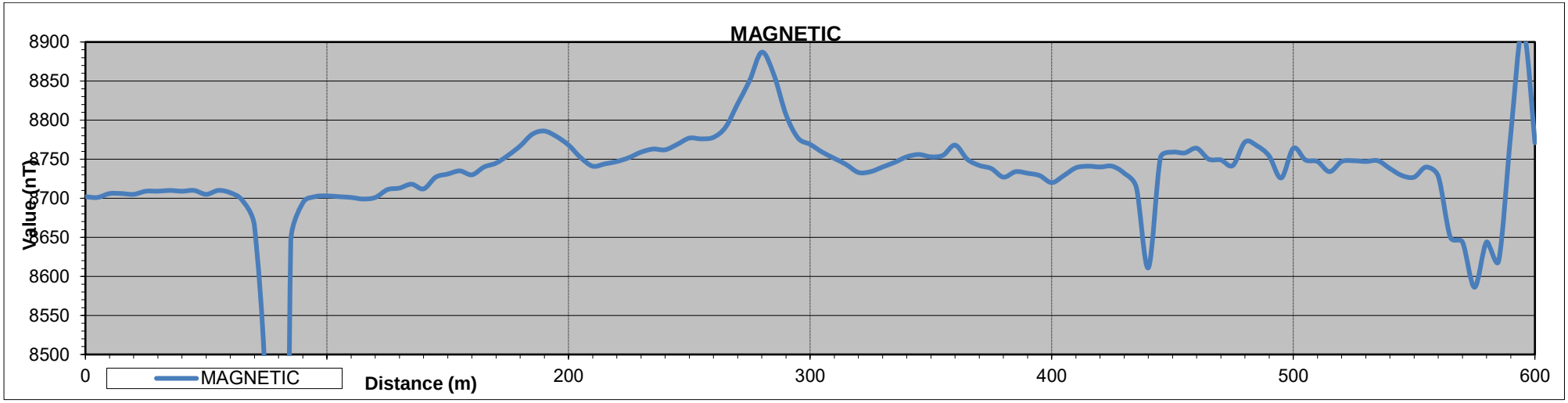


Figure 14-5 Traverse 5



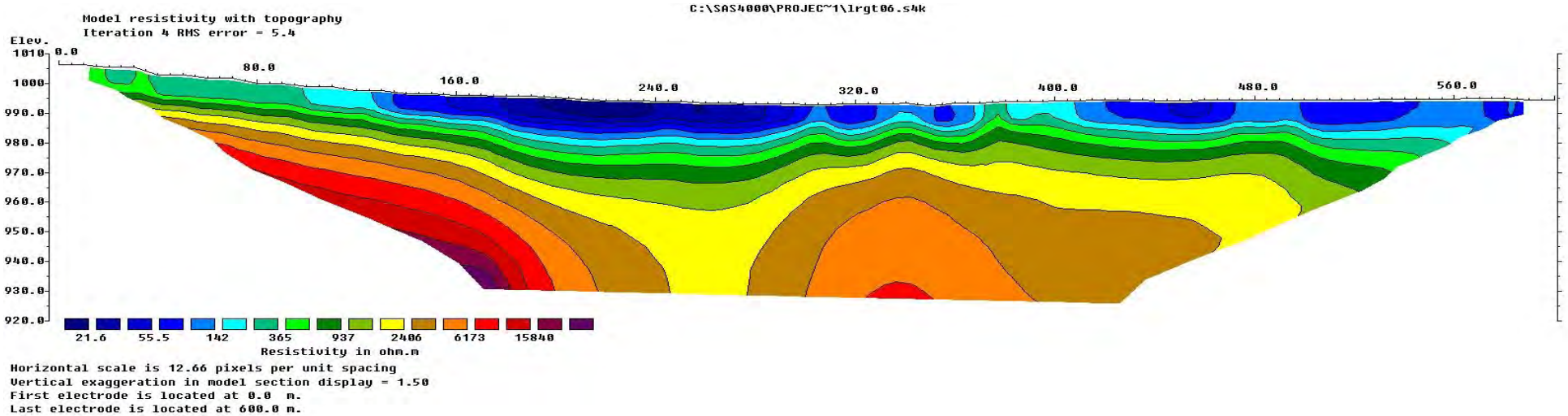
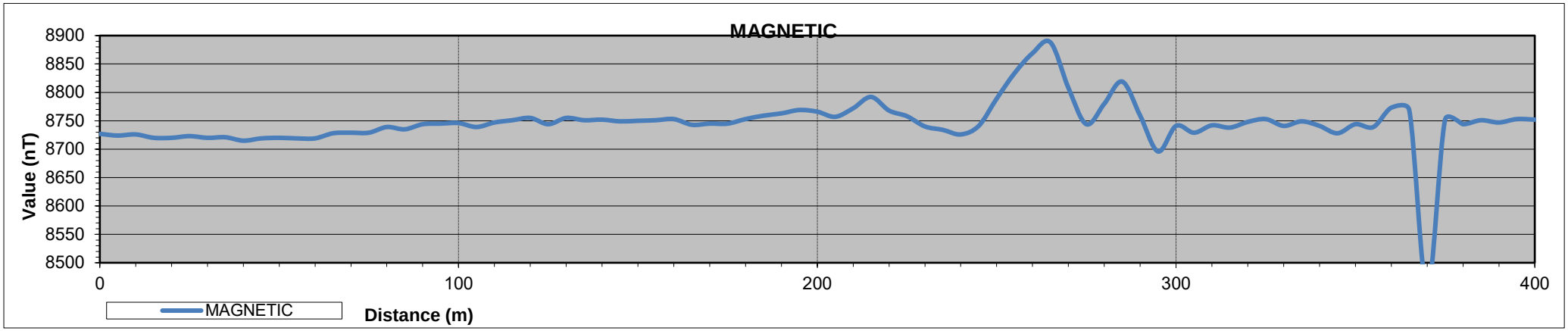


Figure 14-6 Traverse 6



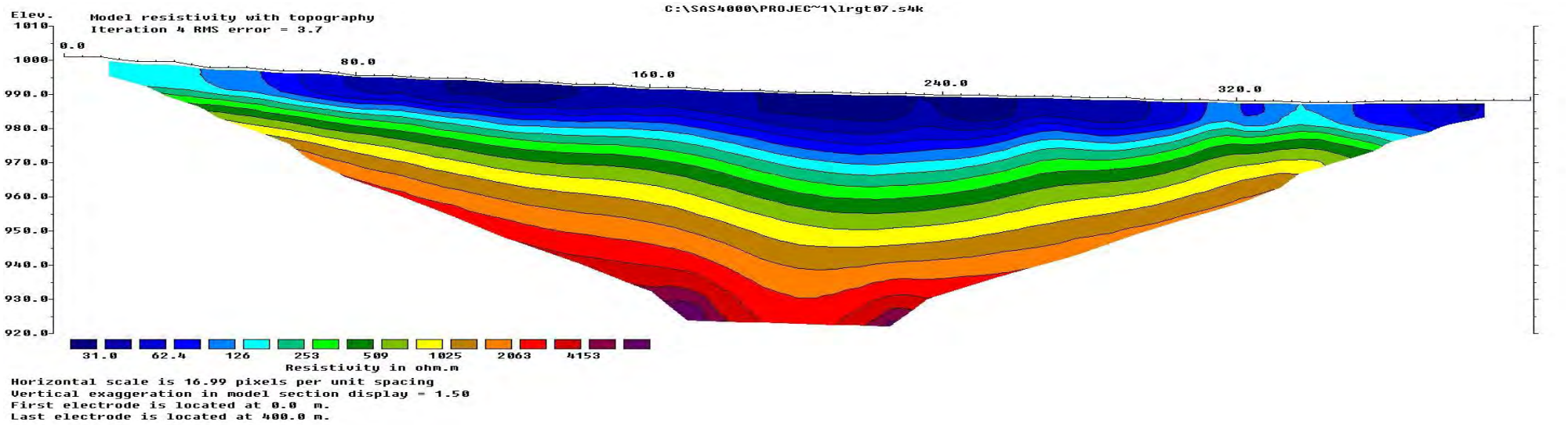
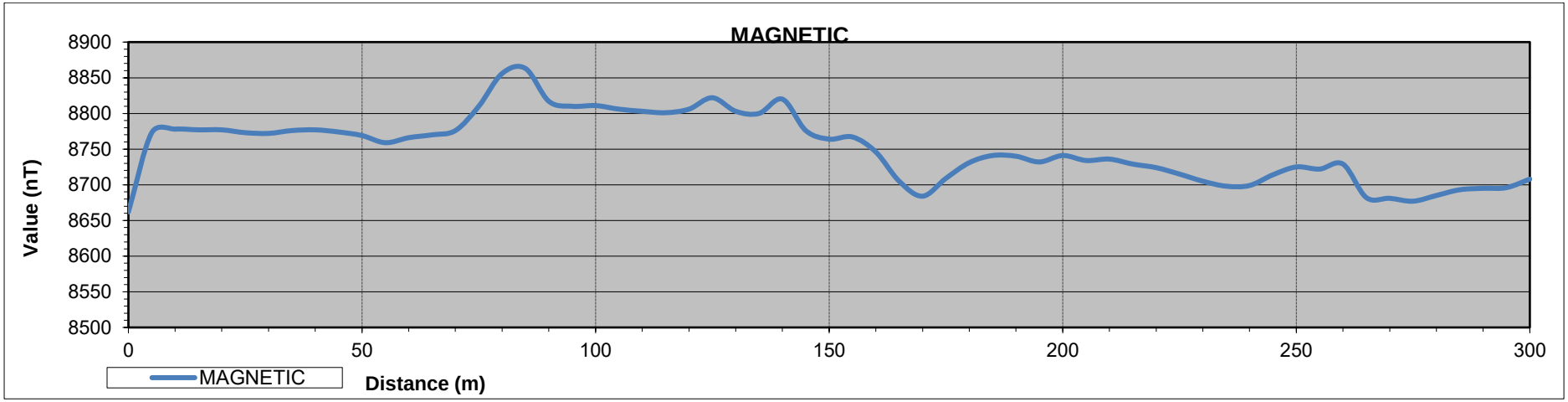
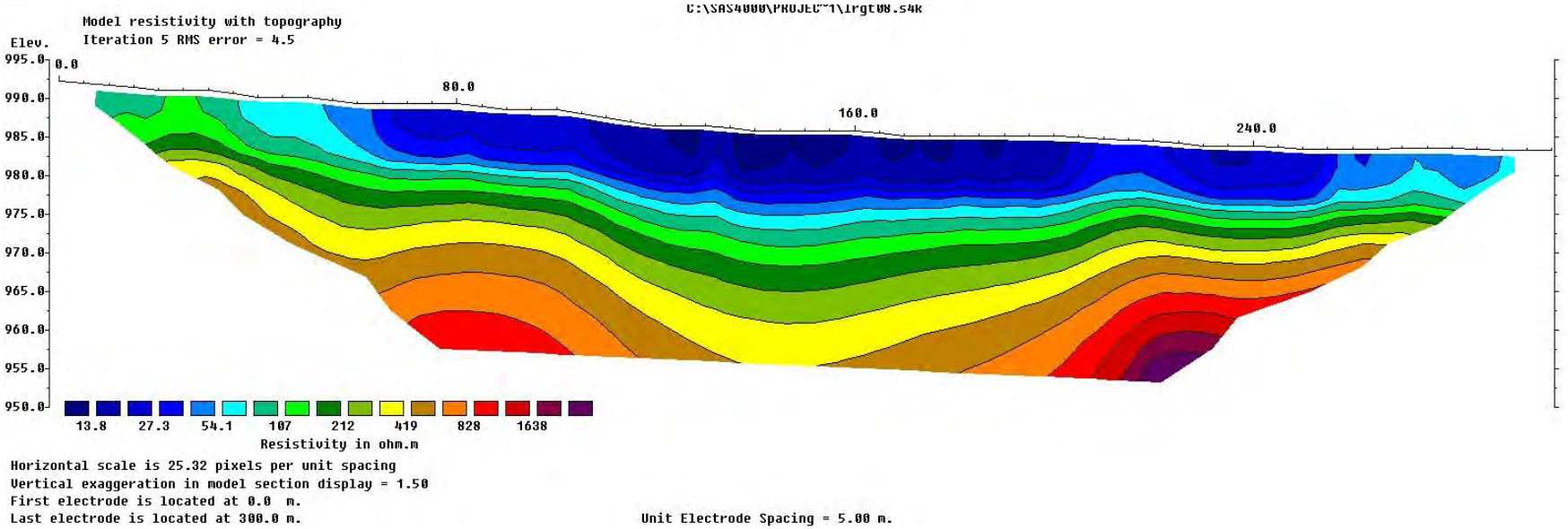


Figure 14-7 Traverse 7





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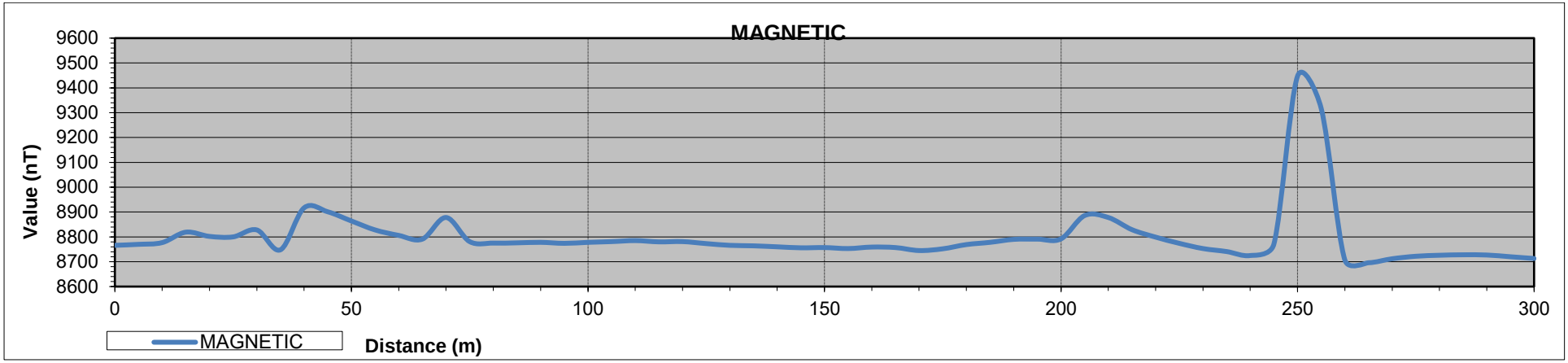


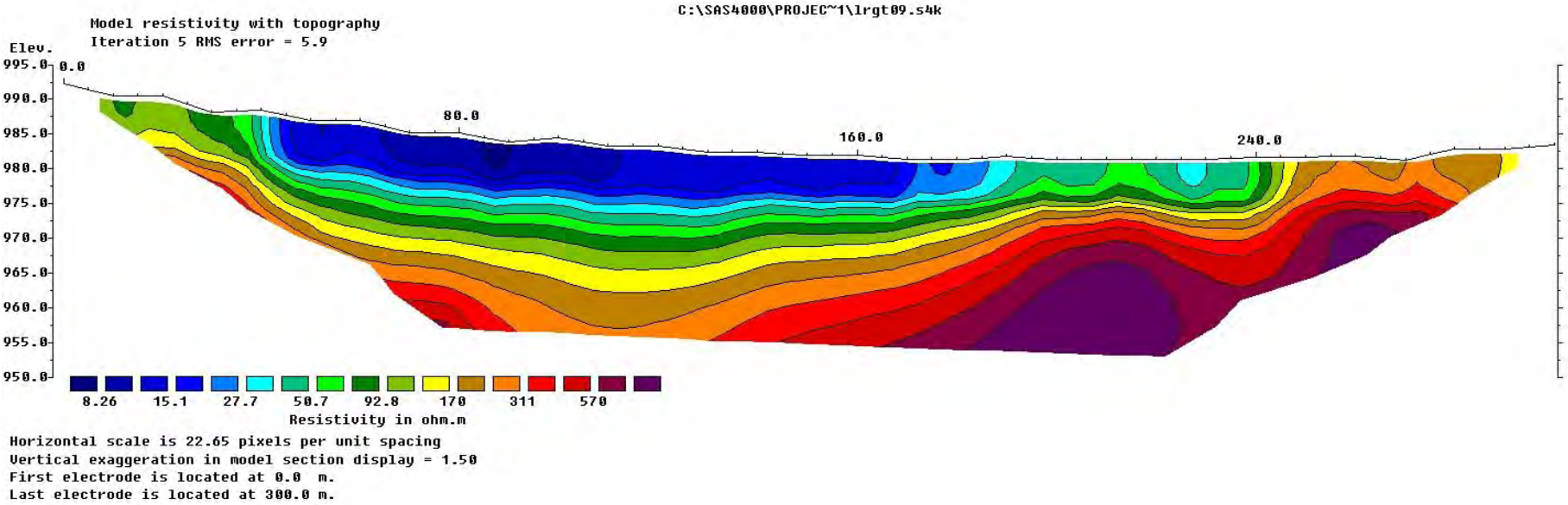
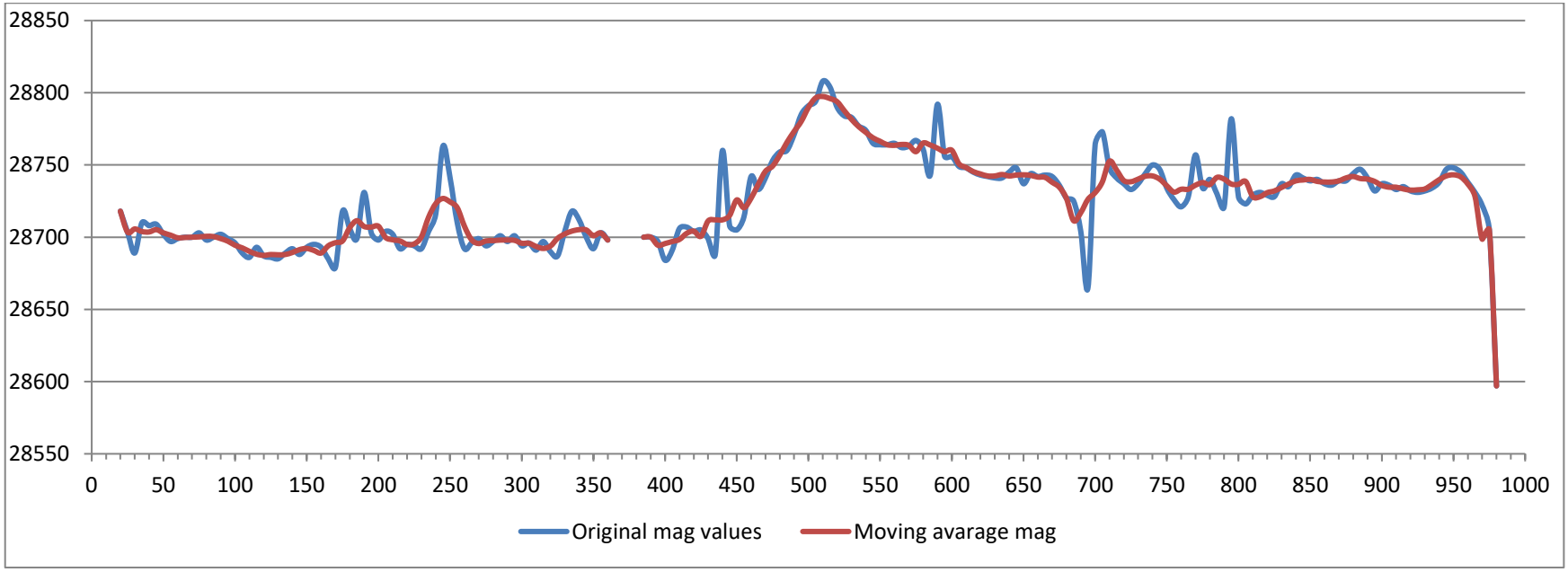


Figure 14-9 Traverse 9



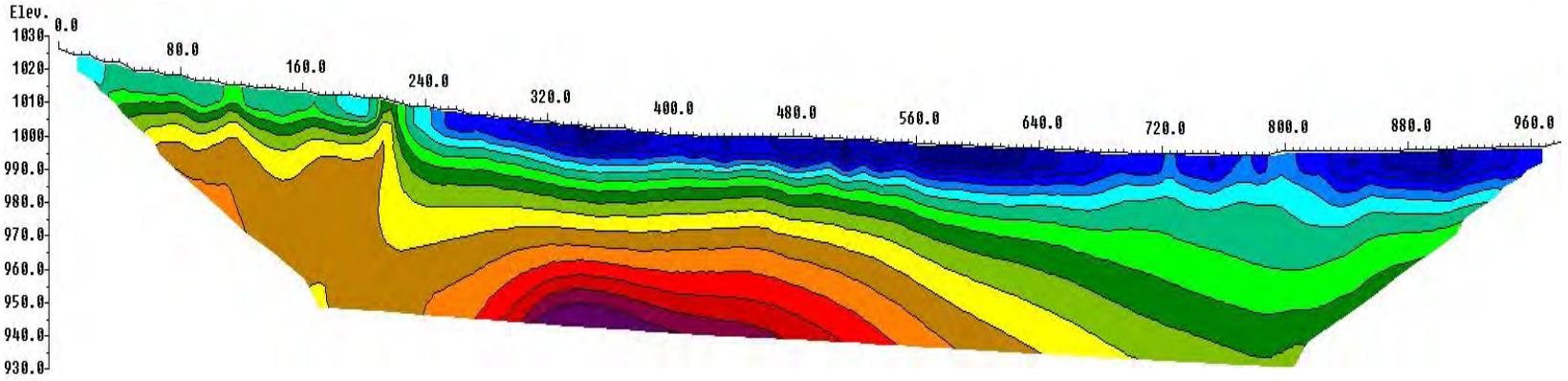
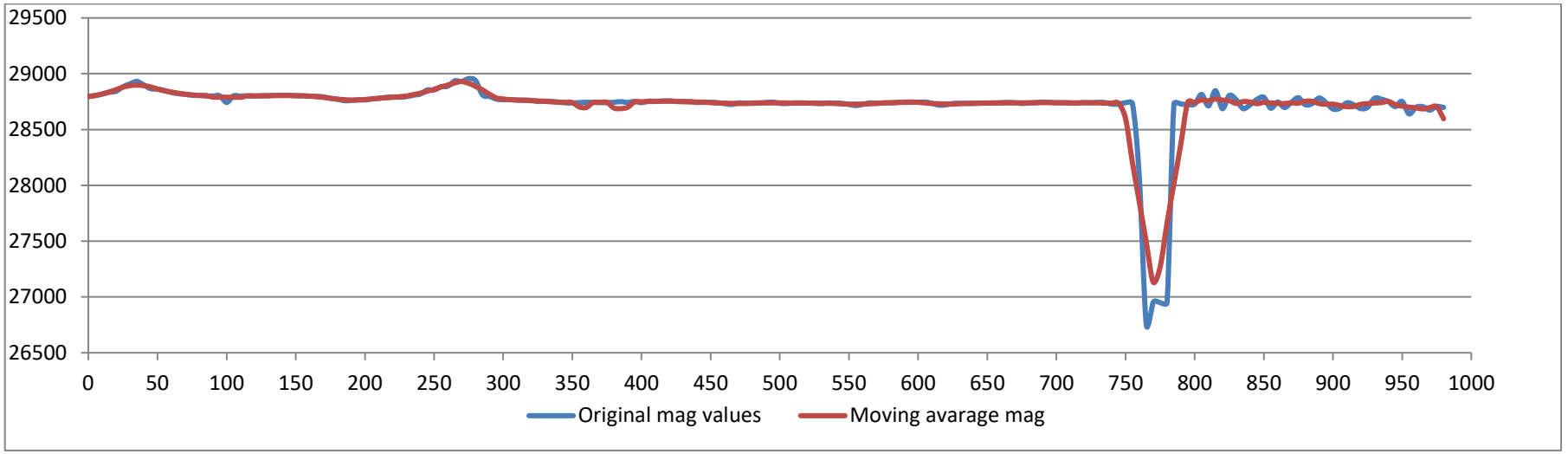


Figure 14-10 Traverse 10



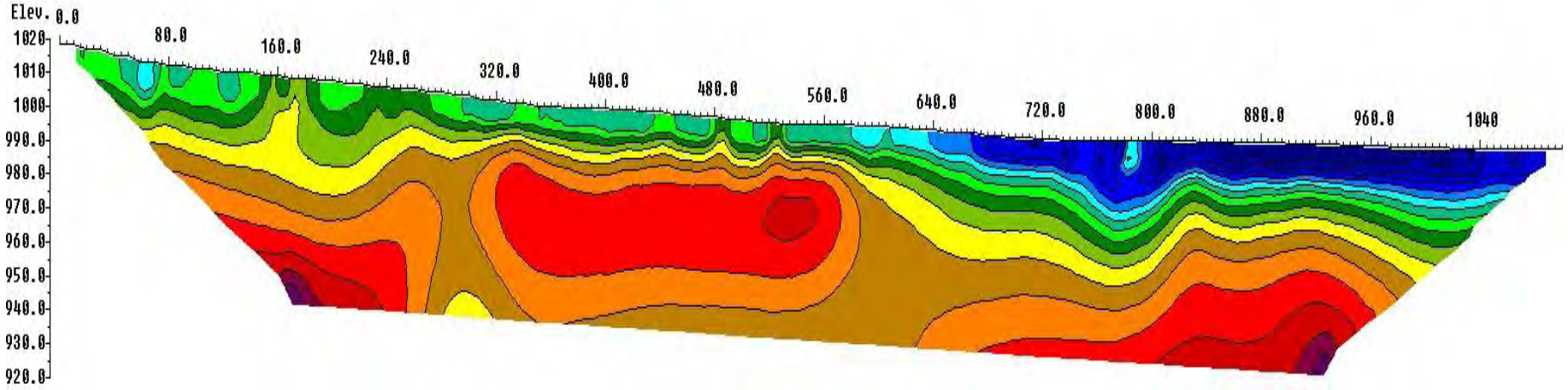
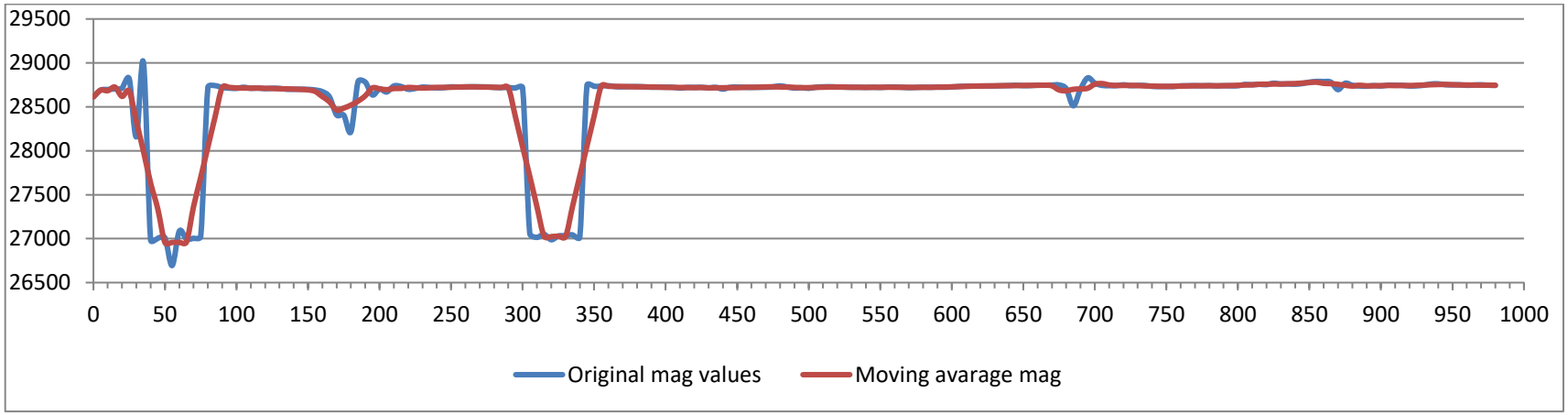


Figure 14-11 Traverse 11



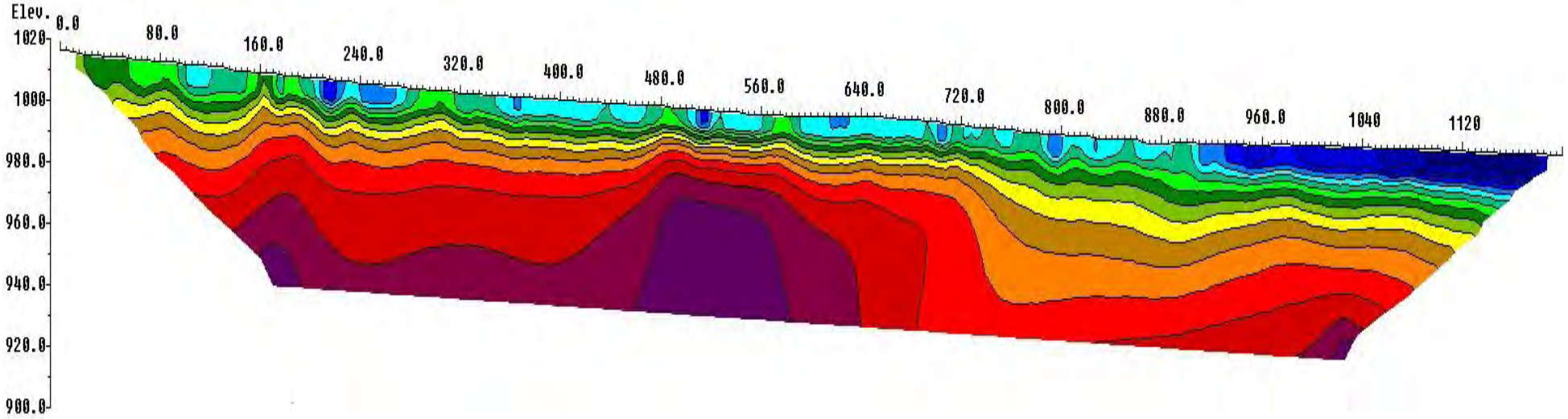


Figure 14-12 Traverse 12

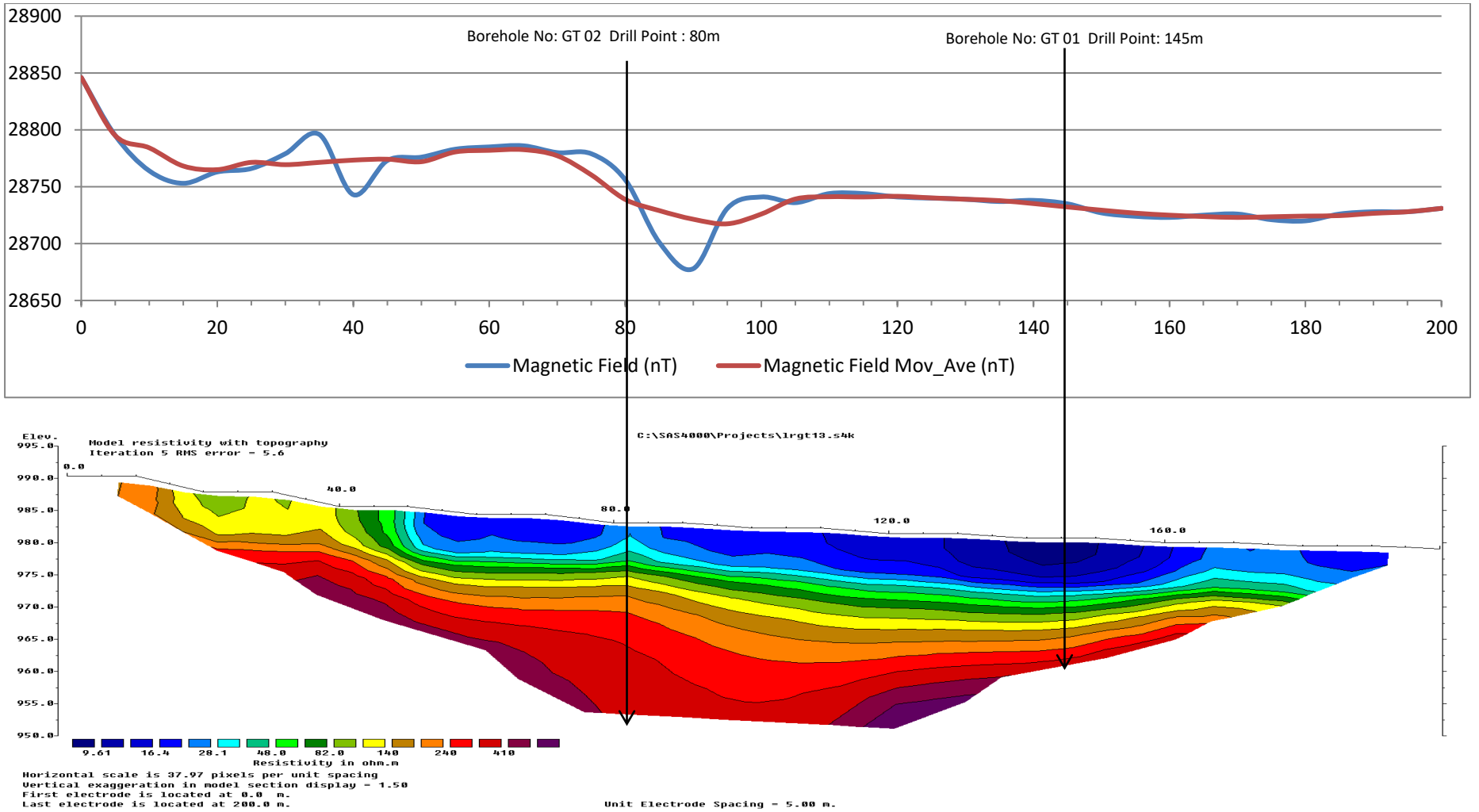


Figure 14-13 Traverse 13

14.2 3D Interpretation: electrical resistivity results

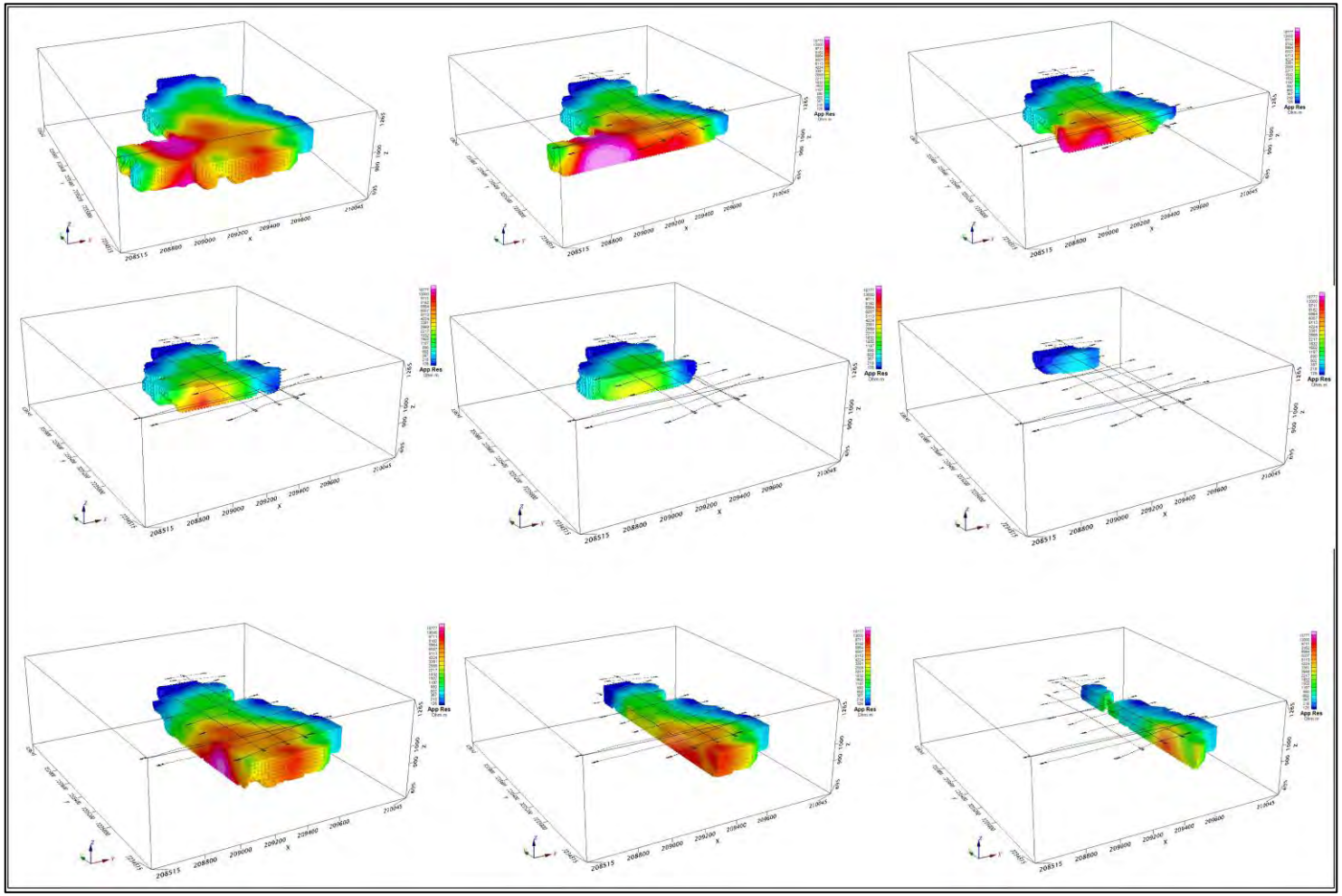
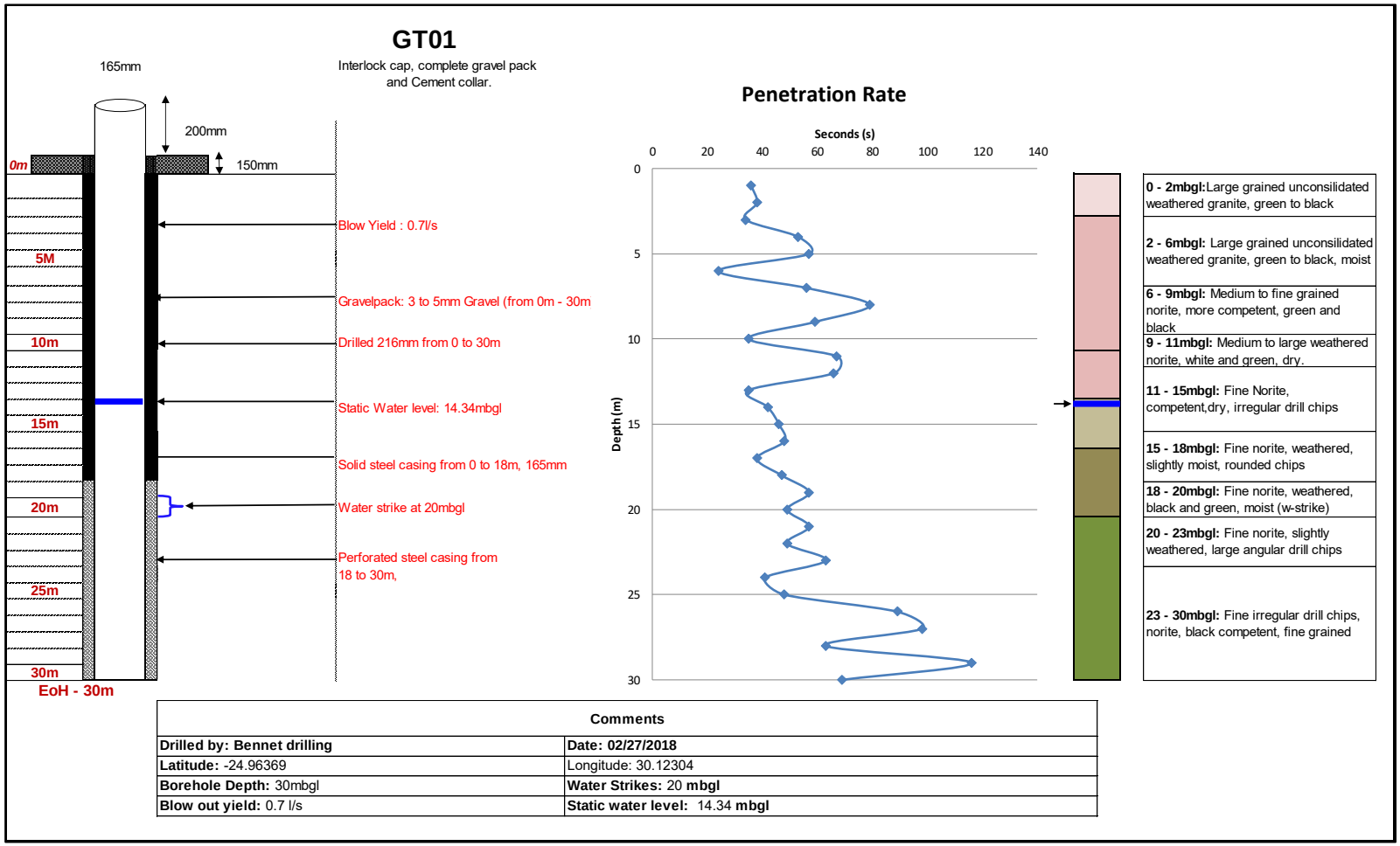


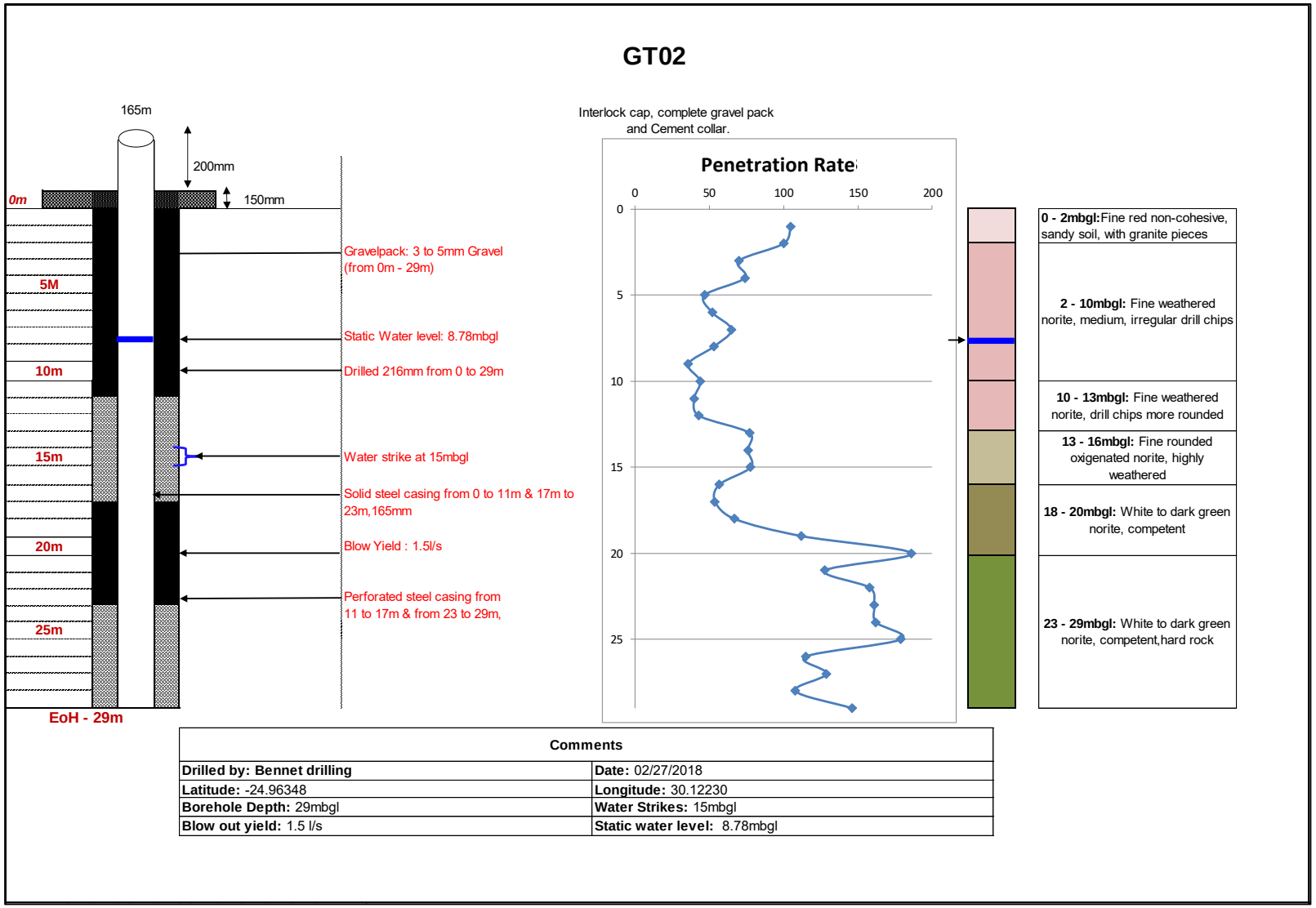
Figure 14-14 3D Interpretation (Electrical Resistivity)

15 APPENDIX B: NEW MONITORING BOREHOLE PROFILES



Comments	
Drilled by: Bennet drilling	**Date: 02/27/2018**
Latitude: -24.96369	Longitude: 30.12304
Borehole Depth: 30mbgl	**Water Strikes:** 20 **mbgl**
Blow out yield: 0.7 l/s	**Static water level:** 14.34 **mbgl**

Figure 15-1 Monitoring borehole GT01



Comments	
Drilled by: Bennet drilling	**Date:** 02/27/2018
Latitude: -24.96348	**Longitude:** 30.12230
Borehole Depth: 29mbgl	**Water Strikes:** 15mbgl
Blow out yield: 1.5 l/s	**Static water level:** 8.78mbgl

Figure 15-2 Monitoring borehole GT02

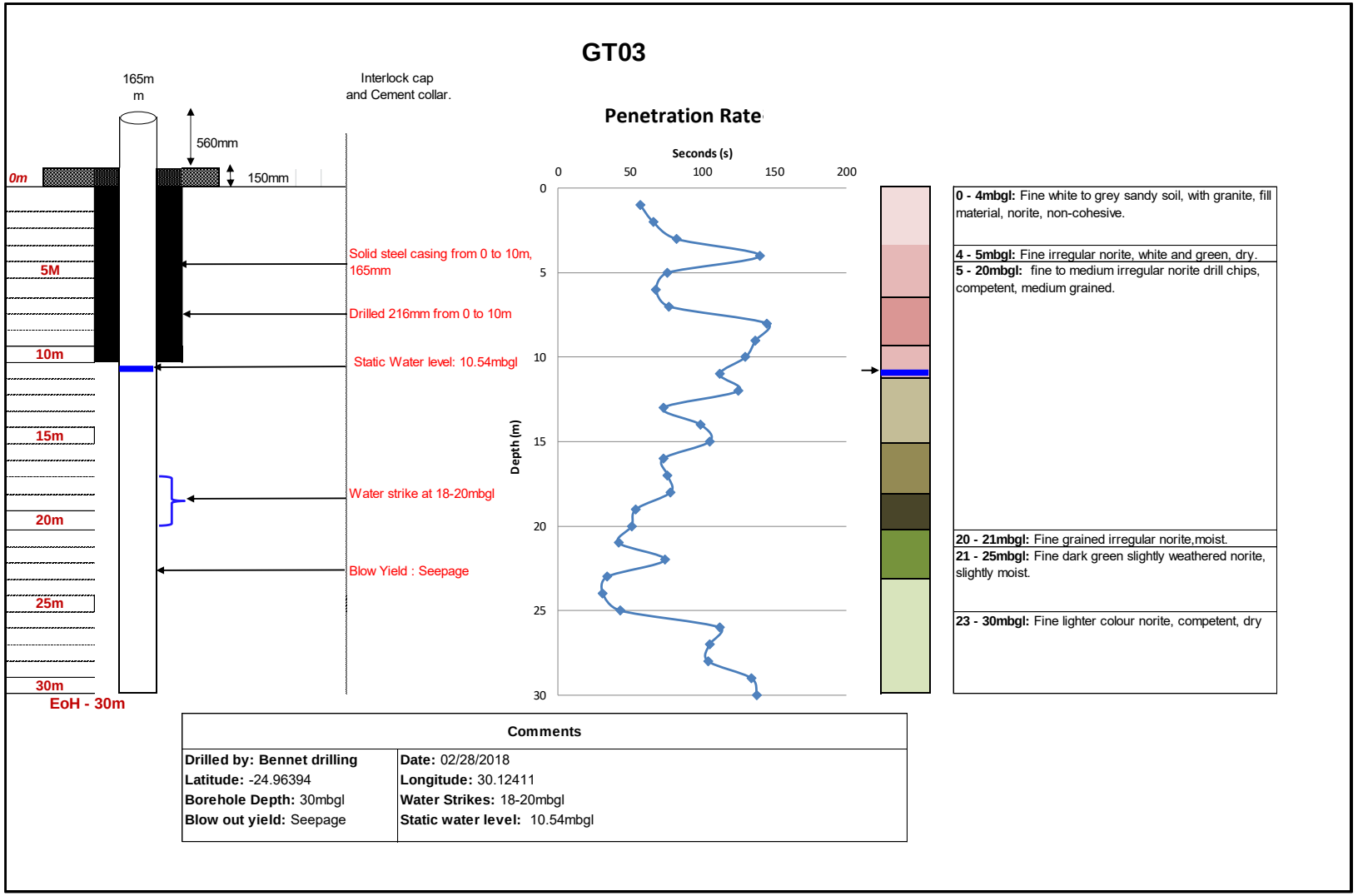


Figure 15-3 **Monitoring borehole GT03**

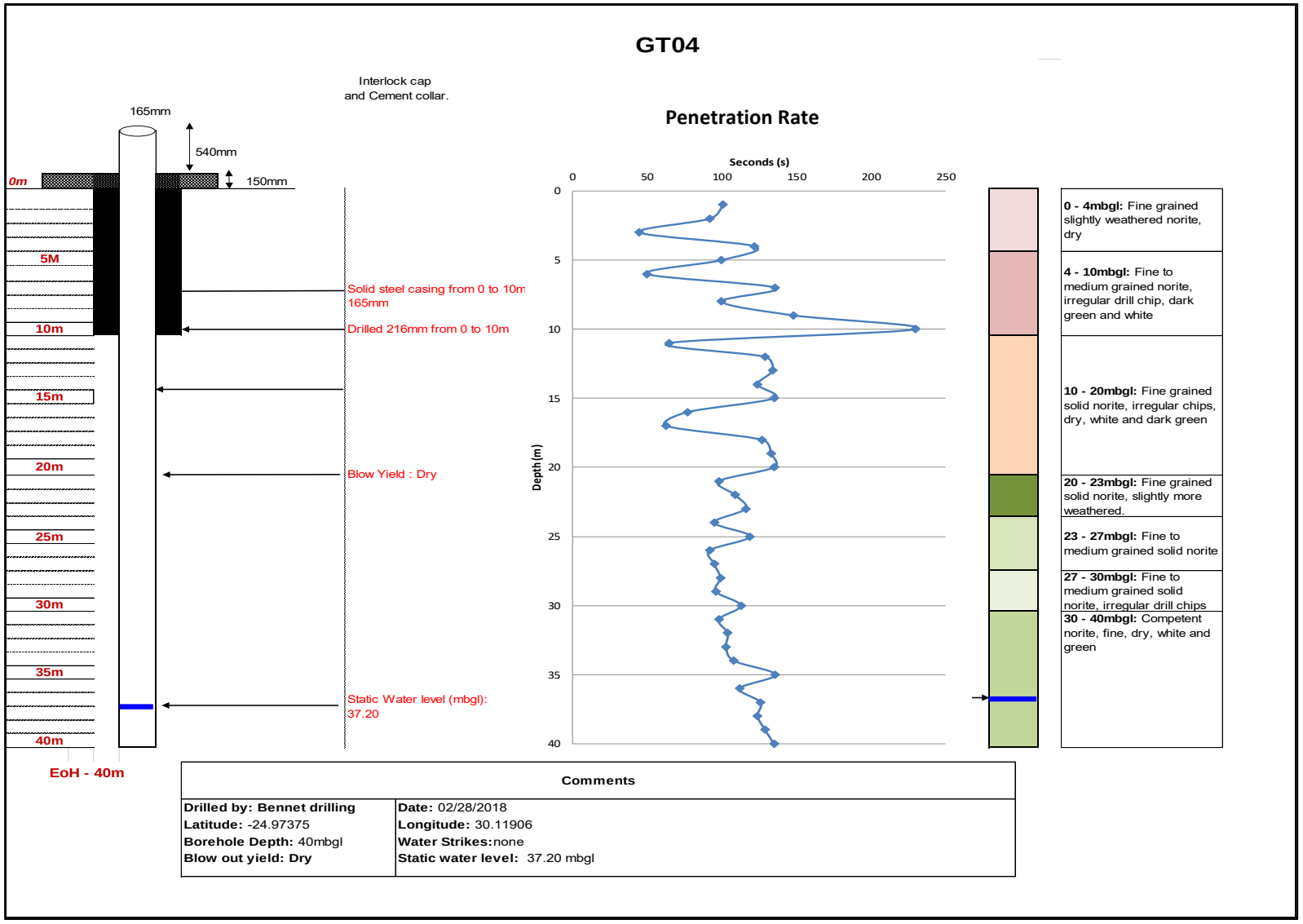


Figure 15-4 Monitoring borehole GT04

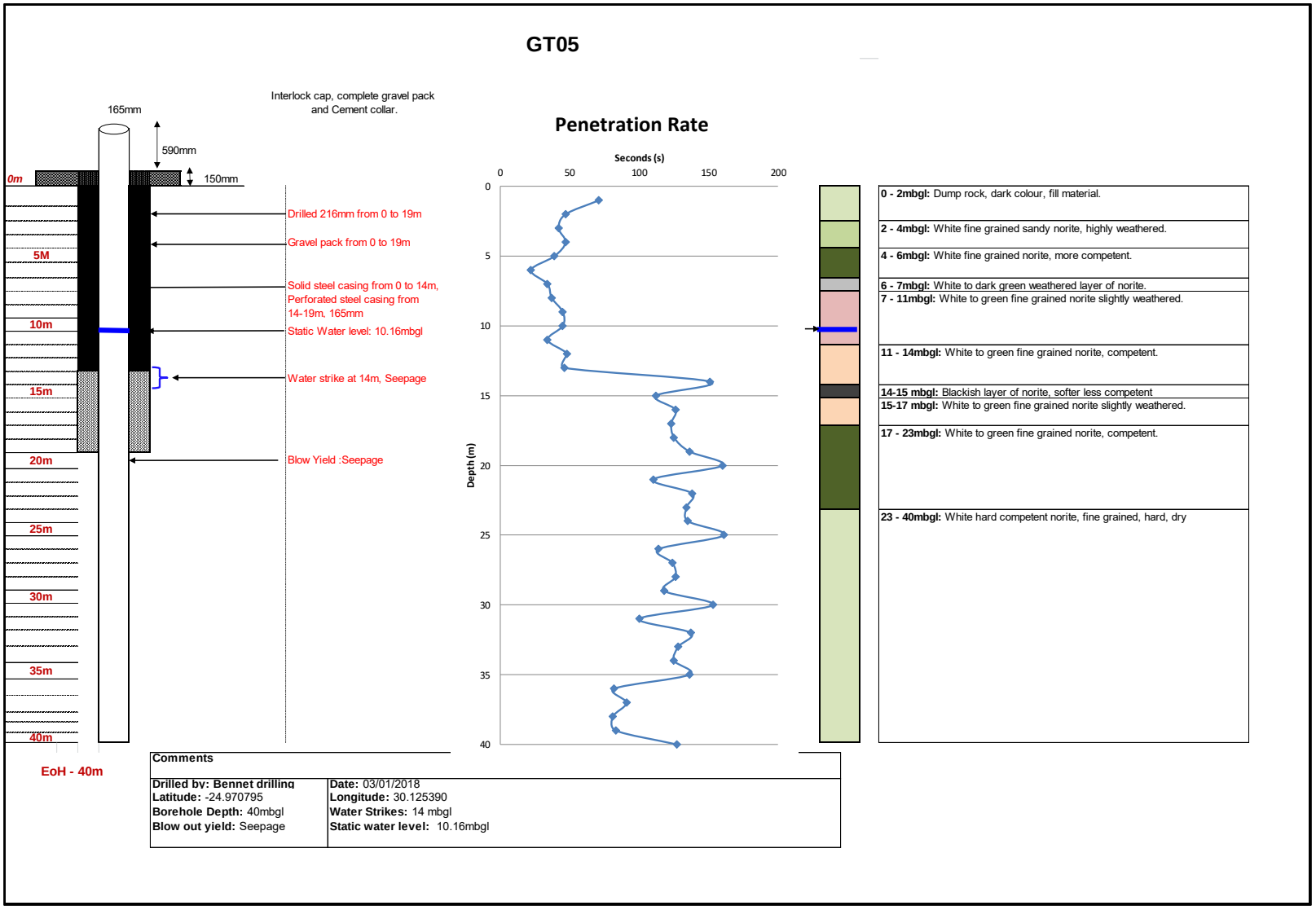


Figure 15-5 Monitoring borehole GT05

16 APPENDIX C: WATER QUALITY OF THE NEWLY DRILLED MONITORING BOREHOLES

Table 16-1 Water quality classification: New monitoring boreholes

SANS 241: 2011 Edition 1				BHT13	BHT12	BHT14	BHT16	BHT15
				GT01	GT02	GT03	GT04	GT05
Chemical requirements micro-determinants								
Aluminium as Al (health)	ug/L	Operational	<300	3	5	6	442	3
Antimony as Sb (health)	ug/L	Chronic health	<20					
Arsenic as As (health)	ug/L	Chronic health	< 10	-0.006	-0.006	-0.006	-0.006	-0.006
Cadmium as Cd (health)	ug/L	Chronic health	< 3	-0.002	-0.002	-0.002	-0.002	-0.002
Total Chromium as Cr (health)	ug/L	Chronic health	<50	-0.003	-0.003	-0.003	-0.003	-0.003
Cobalt as Co (health)	ug/L	Chronic health	< 500	-0.003	-0.003	-0.003	-0.003	-0.003
Copper as Cu (health)	ug/L	Chronic health	<2000	-0.002	-0.002	-0.002	-0.002	-0.002
Cyanide (recoverable) as CN (health)	ug/L	Acute health	< 50					
Iron as Fe (aesthetic / operations	ug/L	Chronic health	< 2000	-0.004	-0.004	-0.004	-0.004	-0.004
Lead as Pb (health)	ug/L	Chronic health	< 10	-0.004	-0.004	-0.004	-0.004	-0.004
Manganese as Mn (aesthetic)	ug/L	Chronic health	<500	126	420	144	-0.001	139
Mercury as Hg (health)	ug/L	Chronic health	<6					
Nickel as Ni (health)	ug/L	Chronic health	<70	-0.002	-0.002	-0.002	-0.002	-0.002
Selenium as Se (health)	ug/L	Chronic health	<10					
Vanadium as V (health)	ug/L	Chronic health	< 200					
Chemical requirements macro-determinants								
Ammonia as N (operational)	mg/L	Aesthetic	<1.5	2.64	0.708	0.355	0.032	4.12
Chloride as Cl (aesthetic)	mg/L	Aesthetic	<300	11.6	11.8	25.2	31.3	20.1
Fluoride as F (health)	mg/L	Chronic Health	<1.5	-0.263	-0.263	-0.263	0.497	-0.263
Nitrite (NO2) mg/l as N (health)	mg/L	Acute health	<0.9	0.631	0.117	0.198	0.04	0.124
Nitrate (NO3) mg/L N (health)	mg/L	Acute health	<11	55.4	21.1	304	0.335	43.2
Sodium as Na (aesthetic / health)	mg/L	Aesthetic	< 200	19.3	21.6	32.6	37.3	19.2
Sulphate as SO4 (health)	mg/L	Acute health	<500	47.2	43	104	2.34	58.3
Zinc as Zn (aesthetic / health)	mg/L	Aesthetic	< 5.0	0.038	0.04	0.059	0.012	0.034
Magnesium as Mg (aesthetic / health)	mg/L	-		115	81.9	237	0.349	94.2
Calcium as Ca (aesthetic / operational)	mg/L	-		63.1	76.6	151	7.96	58.5
Potassium as K (operational / health)	mg/L	-		0.398	0.567	1.55	0.922	1.35
HCO3- (Bicarbonate Alkalinity)	mg/l	-		584.38	584.38	397.72	32.21	485.56
Physical and Aesthetic determinants								
pH value at 25 C (aesthetic / operational)	pH units	Operational	5.0 - 9.7	7.83	7.78	7.46	9.95	7.81
Total Dissolved solids (aesthetic)	mg/L	Aesthetic	< 1200	820	674	2034	138	724
Electric Conductivity at 25 C (aesthetic)	ms/m	Aesthetic	< 170	106	87.6	247	20.5	95.3
Colour (aesthetic)	mg/L Pt-Co	Aesthetic	<15					
Turbidity (aesthetic / operational / indirect health	NTU	Aesthetic	<5					
Taste or Odour	-	Aesthetic	Inoffensive					

17 APPENDIX D: PACKER TEST DATA SUMMARY AND CONDUCTIVITY PROFILES

Table 17-1 Packer test data summary

THC 1				
From (mbgl)	To (mbgl)	Lugeon Average K (m/d)	Aqualitos Average K (m/d)	Overall Average
3.0	8.0	0.09200	0.10110	0.09655
7.0	12.0	0.00016	0.00013	0.00014
12.0	17.0	0.00022	0.00002	0.00012
17.0	22.0	0.00002	0.00002	0.00002
22.0	27.0	0.00002	0.00005	0.00003
25.0	30.0	0.00002	0.00002	0.00002
THC 2				
From (mbgl)	To (mbgl)	Lugeon Average K (m/d)	Aqualitos Average K (m/d)	Overall Average
2.0	7.0	0.12000	0.09198	0.10599
5.0	10.0	0.02800	0.02994	0.02897
10.0	15.0	0.00006	0.00004	0.00005
15.0	20.0	0.00008	0.00005	0.00006
20.0	25.0	0.00004	0.00003	0.00004
25.0	30.0	0.00006	0.00004	0.00005
THC 3				
From (mbgl)	To (mbgl)	Lugeon Average K (m/d)	Aqualitos Average K (m/d)	Overall Average
2.0	7.0	0.0756	0.0419	0.0587
5.0	10.0	0.0200	0.0215	0.0207
10.0	15.0	0.0492	0.0523	0.0507
15.0	20.0	0.0134	0.0140	0.0137
20.0	25.0	0.0800	0.0822	0.0811
25.0	30.0	0.0001	0.0000	0.0001
THC 4				
From (mbgl)	To (mbgl)	Lugeon Average K (m/d)	Aqualitos Average K (m/d)	Overall Average
3.0	8.0	0.2272	0.1680	0.1976
7.0	12.0	0.2744	0.2559	0.2652
12.0	17.0	0.2118	0.2157	0.2138
17.0	22.0	0.0086	0.0007	0.0046
22.0	27.0	0.0002	0.0001	0.0002
25.0	30.0	0.0001	0.0001	0.0001
THC 5				
From (mbgl)	To (mbgl)	Lugeon Average K (m/d)	Aqualitos Average K (m/d)	Overall Average
3.0	8.0	0.3046	0.2907	0.2976
7.0	12.0	0.2214	0.1602	0.1908
12.0	17.0	0.1436	0.1506	0.1471
17.0	22.0	0.2504	0.2456	0.2480
22.0	27.0	0.2030	0.1881	0.1955
25.0	30.0	0.0974	0.0924	0.0949
THC 6				
From (mbgl)	To (mbgl)	Lugeon Average K (m/d)	Aqualitos Average K (m/d)	Overall Average
3.0	8.0	0.0258	0.0151	0.0205
7.0	12.0	0.0001	0.0001	0.0001
12.0	17.0	0.0480	0.0505	0.0492
17.0	22.0	0.0072	0.0074	0.0073
22.0	27.0	0.0003	0.0002	0.0002
25.0	30.0	0.0002	0.0001	0.0001

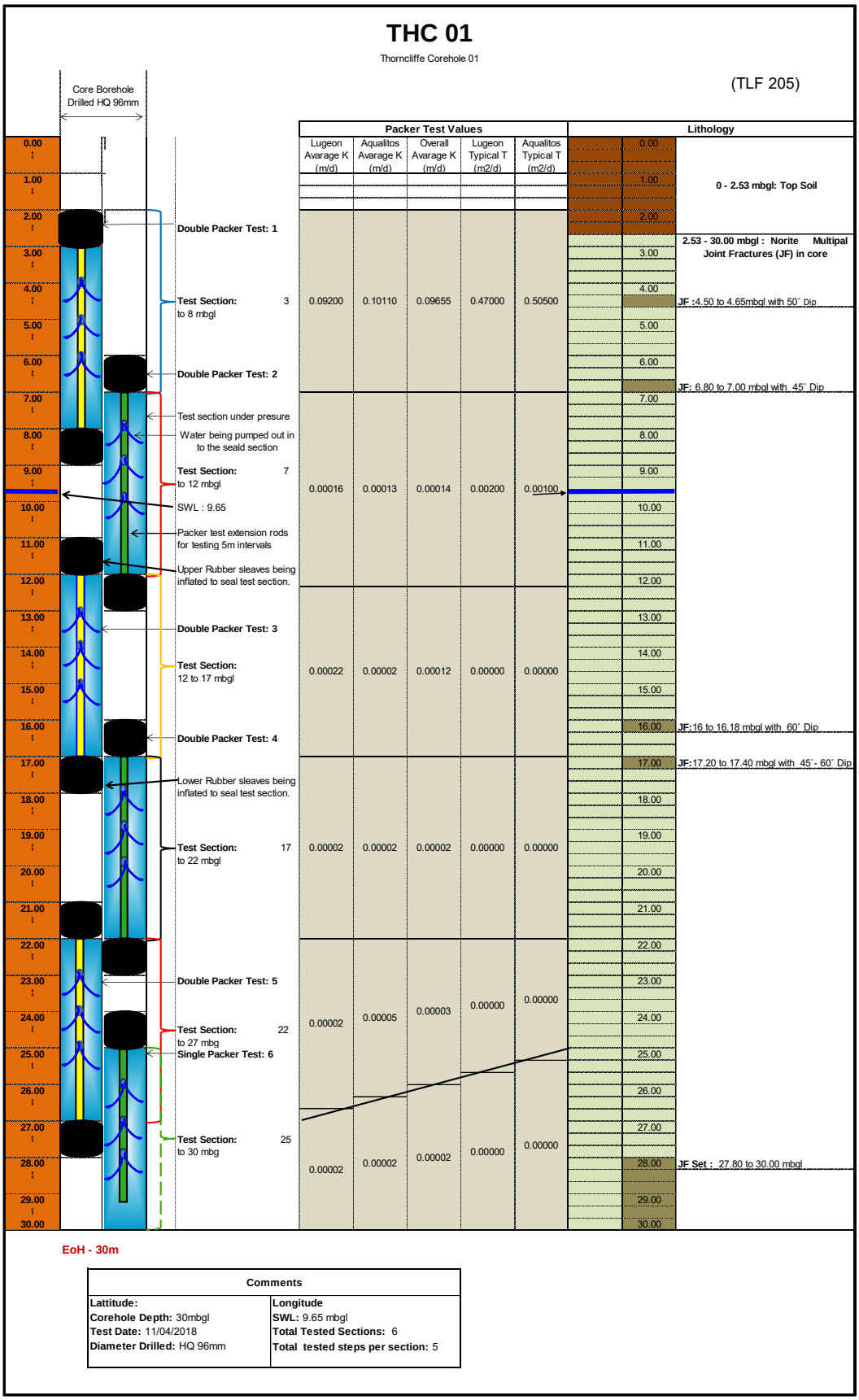


Figure 17-1 Packer test profile THC01

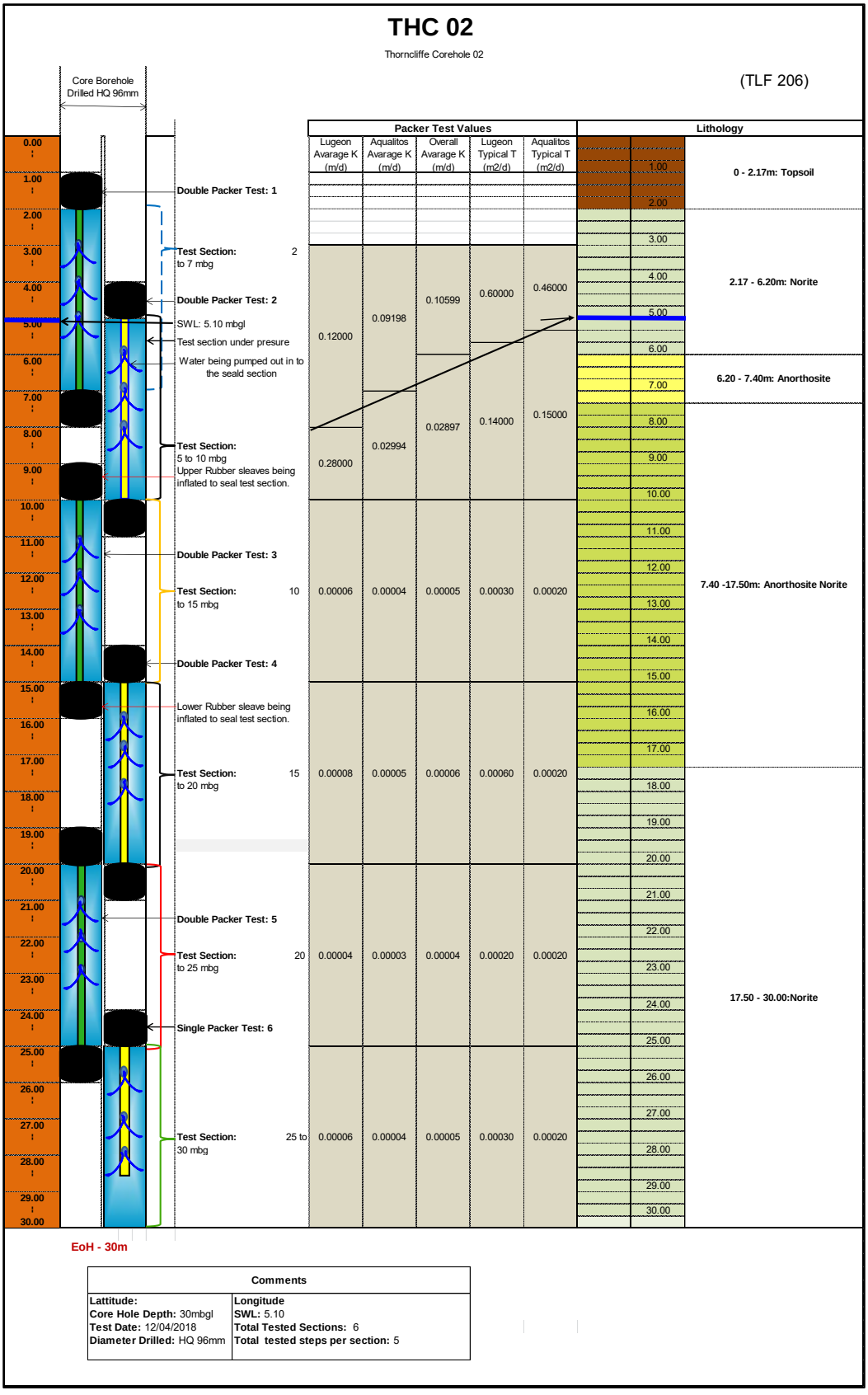


Figure 17-2 Packer test profile THC02

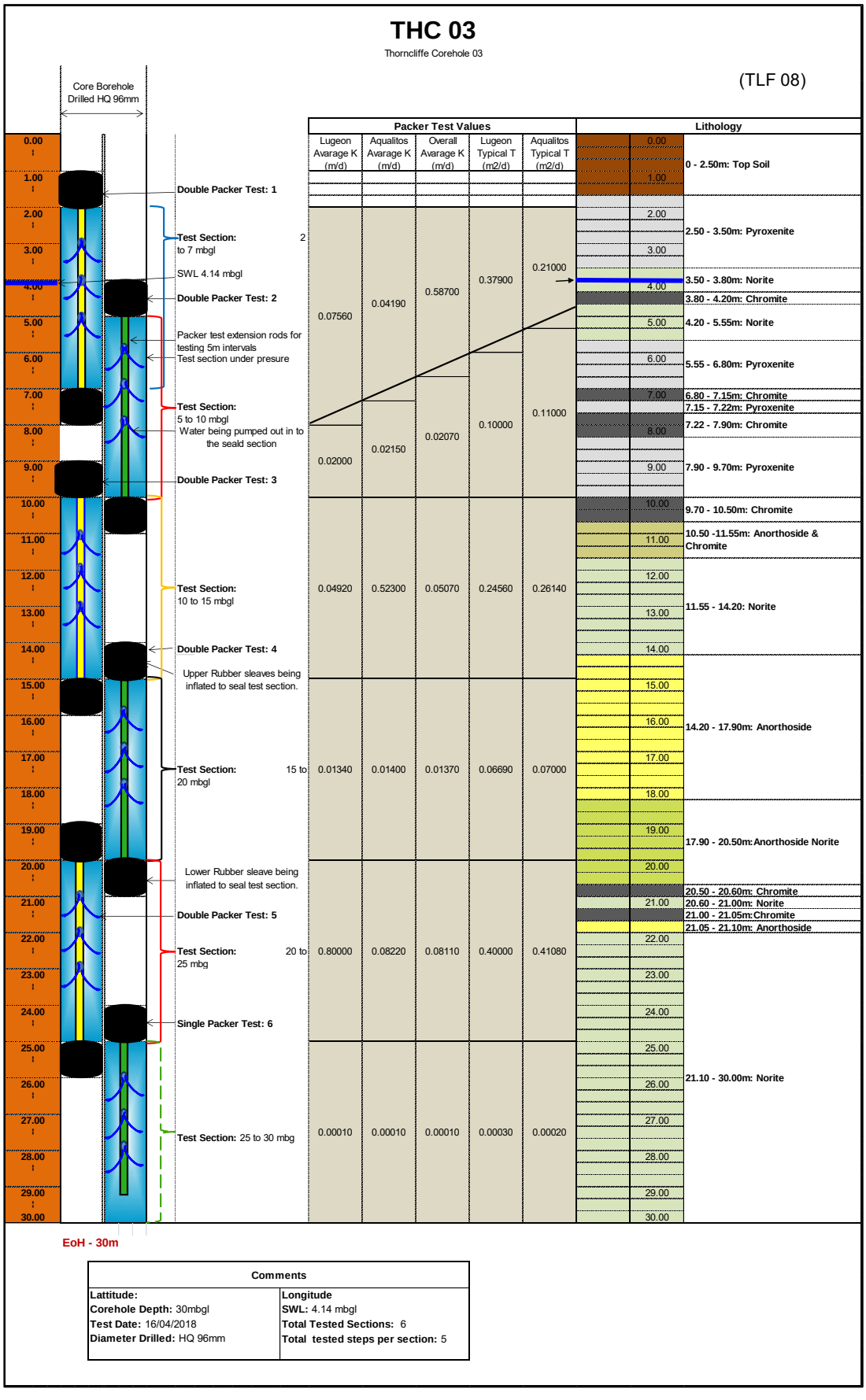


Figure 17-3 Packer test profile THC03

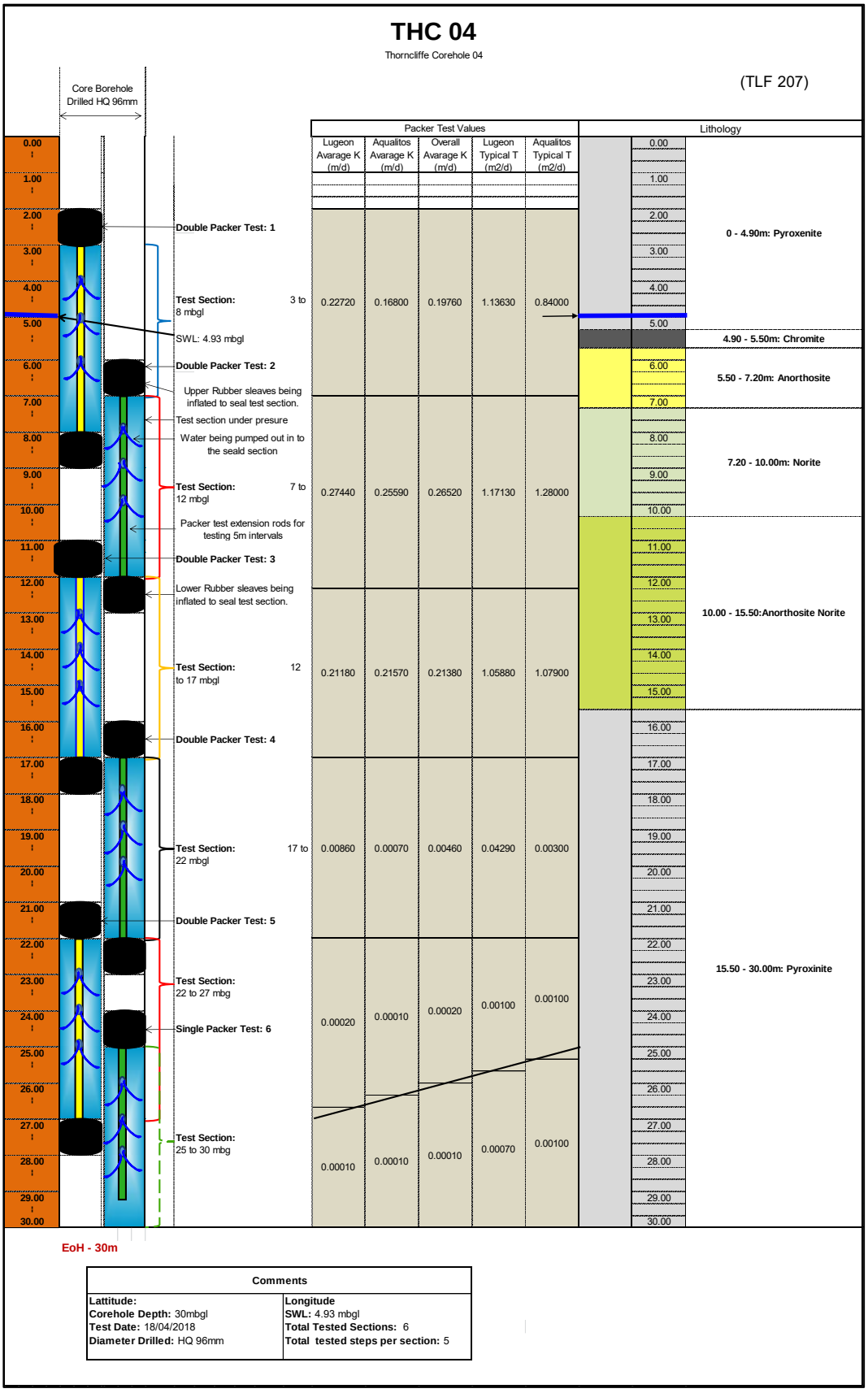


Figure 17-4 Packer test profile THC04

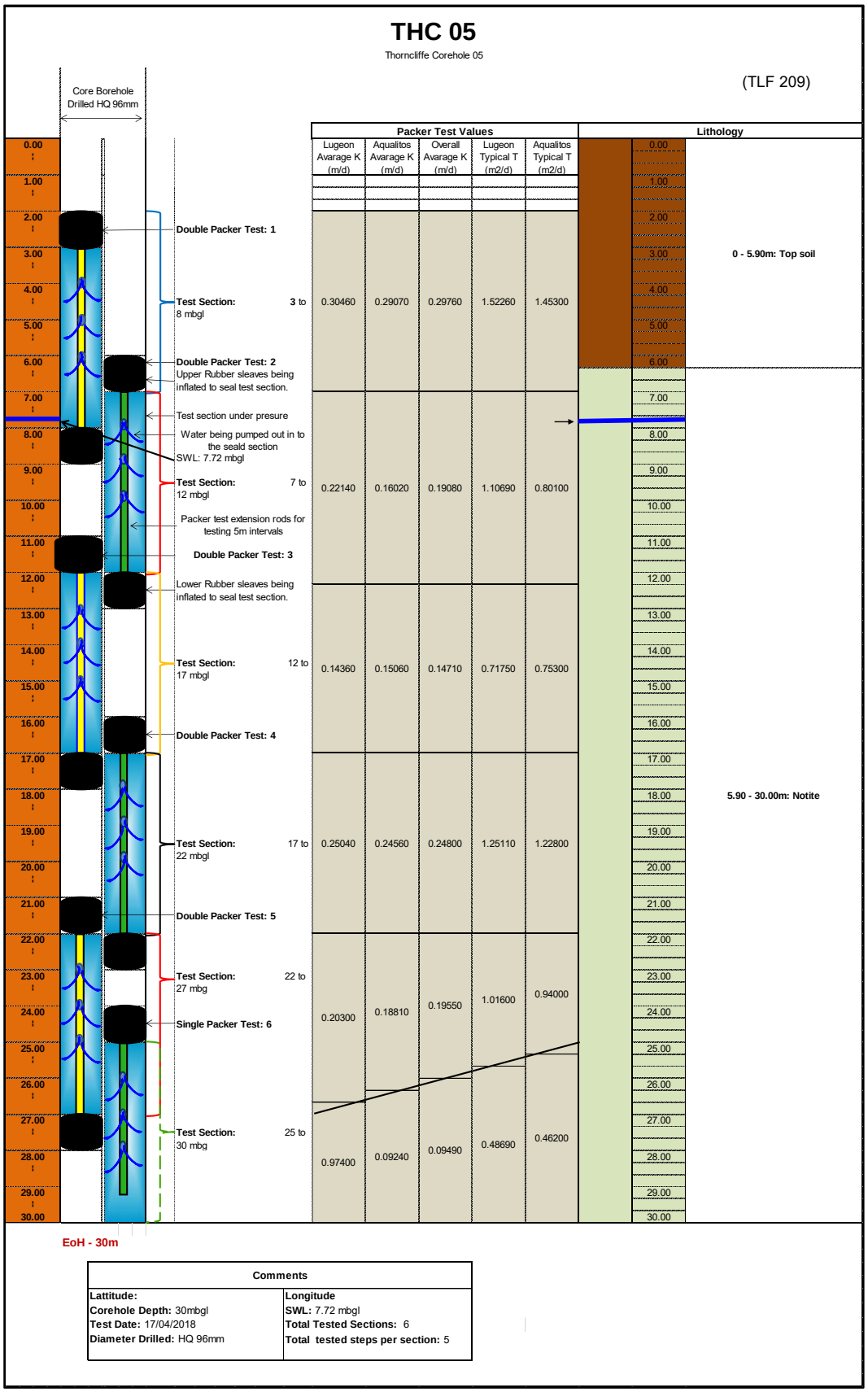


Figure 17-5 Packer test profile THC05

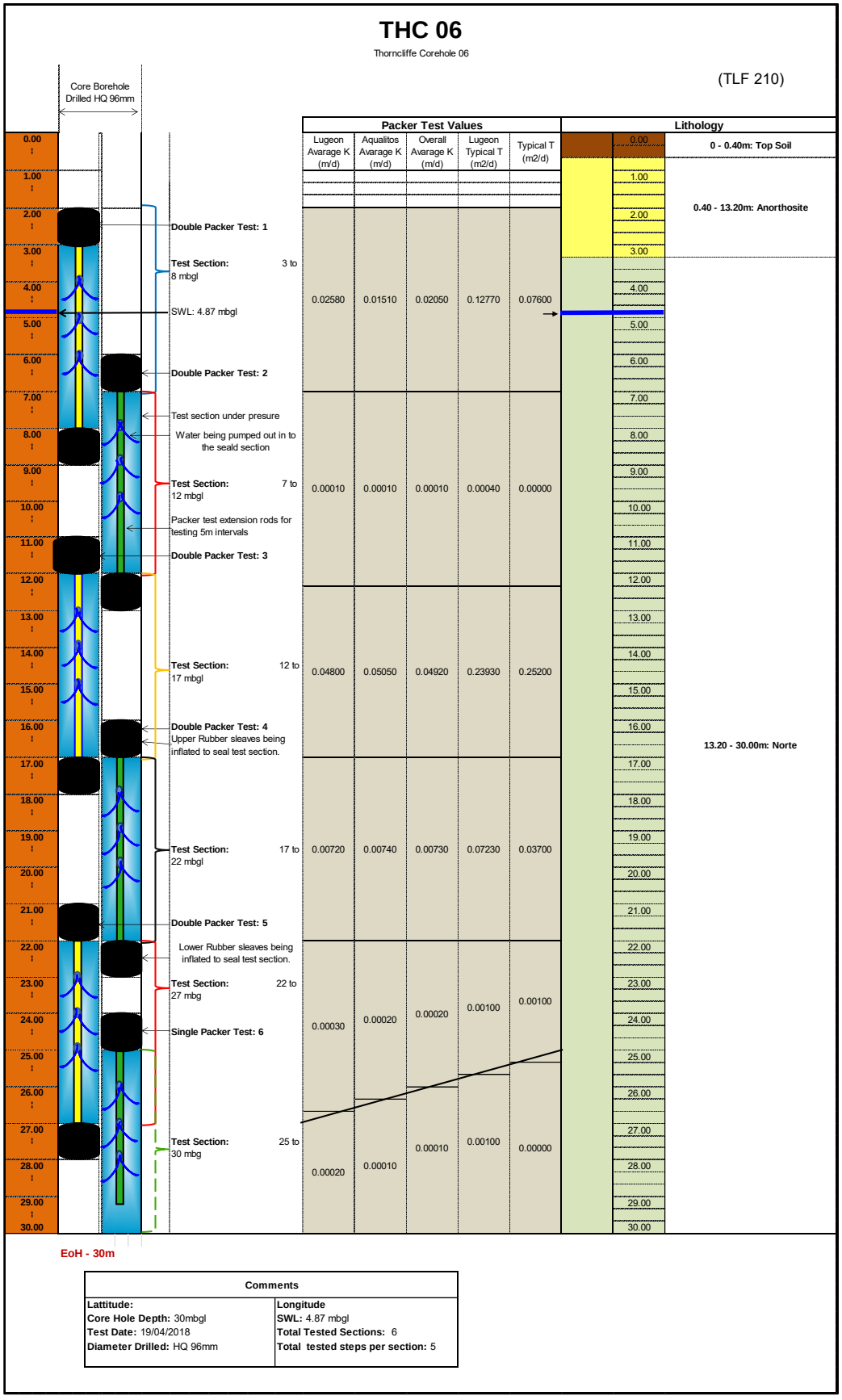


Figure 17-6 Packer test profile THC06

18 APPENDIX E: AQUIFER TEST PARAMETERS INCORPORATED INTO THE GROUNDWATER MODEL

Table 18-1 Historic aquifer parameters

General Information								Constant Discharge Test					Analysed Data				
Borehole Info								Draw Down			Recovery		Drawdown/ Displacement reached	Transmissivity			Hydraulic conductivity
Parameter method used	BH ID	Latitude	Longitude	Date Tested	BH Depth	SWL	Pump Depth	Time (min)	Drawdown (m)	Yield (l/s)	Time (min)	Recovery (m)	(m)	Early time (m^2/d)	Late time (m^2/d)	Recovery (m^2/d)	(m/d)
Aquifer Test	BHT06	-24.95902	30.12537	2008	30	7.17	29	500	8.51	1.1	200	0.6	8.5	3.9	18	51.3	0.8
Aquifer Test	BHT07	-24.95757	30.12504	2008	30	8.7	28	500	15.43	4.2	200	1.29	15.4	29.2	3.2	40.7	0.9
Aquifer Test	BH MN 01	-24.98434	30.11211	2016	60	4.18	55	1440	39.89	1.1	1440	1.16	39.9	1.5	5.3	1.9	0.1
Aquifer Test	BH MN 02	-24.98088	30.10947	2016	42	2.42	38	1440	30.91	2	1440	0.73	30.9	5.8	2.6	6.7	0.1
Aquifer Test	BH MN 05	-24.98522	30.10813	2016	25	6.42	23	720	10.29	0.5	90	0.17	10.3	2.3	5.7	5.8	0.2
Aquifer Test	BH MS 04	-24.99322	30.11197	2016	37	2.35	32	1440	1.98	3.1	1440	0.18	2	40.6	17.6	112	1.8
Falling Head Test	BH MN 06	-24.98403	30.10949	2016	25	7.2							5.3	0.3	0.1		0.008
Falling Head Test	BHMN 07	-24.98324	30.11018	2016	20	9.13							7.7	0.2	0.1		0.006
Falling Head Test	BHMS 05	-25.00233	30.11244	2016	35	16.87							7.4	0.2	0.1		0.003
Maximum					**60.3**	**16.9**		**1440**		**4.2**	**1440**	**1.3**		**40.6**	**18**	**112**	**1.8**
Minimum					**20**	**2.4**		**500**		**0.5**	**90**	**0.2**		**0.2**	**0.1**	**1.9**	**0**
Average					**33.8**	**7.2**		**1007**		**2**	**802**	**0.7**		**9.3**	**5.8**	**36.4**	**0.4**

Table 18-2 2018 Aquifer test parameters

Mine area	Name	Easting	Northing	Depth (mbgl)	Collar Height (m)	SWL (mbgl)	b - Aqr Thickness	Initial Displacement (m)	Logger Depth (mbgl)	Approx. time to recovery (min)	early K (m/d)	Late K (m/d)	Early T (m2/d)	Late T (m2/d)	Average T value (m2/d)
Thorncliffe	GT01	24.96354	30.12304	30	0.53	14.28	15	2.76	19.47	15	1.052	0.098	15.78	1.47	8.63
	GT02	-24.96348	30.1223	29	0.56	9.04	20	0.832	19.44	6.5	2.4	0.39	48	7.8	27.9
	GT03	-24.96394	30.12411	30	0.55	10.76	20	6.52	19.45	60	0.063	0.063	1.26	1.26	1.26
	GT04	-24.97375	30.11906	40	0.53	36.46	4	23.11	38.47	No recovery obs.	0.002	0.002	0.008	0.008	0.008
	GT05	-24.970795	30.12539	40	0.59	10.14	30	1.092	19.41	120	0.029	0.018	0.87	0.54	0.71
	BHT09	-24.95338	30.12399	5.2	0.1	2	3	2.061	5	3.5	7.75	0.25	23.25	0.75	12
	BHT08	-24.9638	30.12987	48.72	0.6	8.2	30	3.481	19.4	40	0.072	0.018	2.17	0.54	1.36
	BHT10	-24.95663	30.12852	35.78	0.21	7.68	30	5.281	19.79	12	0.273	0.088	8.18	2.63	5.41
Average				**32.3**		**12.3**	**19**	**5.6**	**20.1**	**36.7**	**1.5**	**0.1**	**12.4**	**1.9**	**7.2**
Maximum				**48.7**		**36.5**	**30**	**23.1**	**38.5**	**120**	**7.8**	**0.4**	**48**	**7.8**	**27.9**
Minimum				**5.2**		**2**	**3**	**0.8**	**5**	**3.5**	**0.002**	**0.002**	**0.008**	**0.008**	**0.008**
Helena	BHH04	-24.99735	30.12919	14.8	0.2	5.44	10	4.549	15	10	1.213	0.266	12.13	2.66	7.4
	BHH06	-24.99853	30.12109	36.08	0.23	11.31	25	4.547	20	83.33	0.023	0.02	0.59	0.49	0.54
	BHH07	-25.0008	30.12127	45.12	0.5	11.73	30	4.887	19.5	25	0.162	0.074	4.85	2.22	3.53
	BHH12	-25.0015	30.12084	43.71	0.53	11.41	30	2.828	19.47	16.66	0.381	0.096	11.44	2.88	7.16
Average				**34.9**		**10**	**23.8**	**4.2**	**18.5**	**33.7**	**0.4**	**0.1**	**7.2**	**2.1**	**4.7**
Maximum				**45.1**		**11.7**	**30**	**4.9**	**20**	**83.3**	**1.2**	**0.3**	**12.1**	**2.9**	**7.4**
Minimum				**14.8**		**5.4**	**10**	**2.8**	**15**	**10**	**0.02**	**0.02**	**0.59**	**0.49**	**0.54**
Magareng	BHMAG04	-24.9815	30.13278	70	0.45	12.76	30	2.803	24.55	10	0.537	0.133	16.1	4	10.05
	BHMAG07	-24.98143	30.13097	33.94	0.2	1.54	30	1.815	9.8	12	0.361	0.124	10.83	3.71	13
	BHMAG08	-24.97945	30.13251	46.99	0.33	4.97	30	0.908	19.67	10	0.571	0.134	17.14	4.02	10.58
	BHMAG10	-24.98553	30.13223	48.68	0.26	6.5	30	3.984	14.74	20	0.453	0.032	13.59	0.95	7.27
Average				**49.9**		**6.4**	**30**	**2.4**	**17.2**	**13**	**0.5**	**0.1**	**14.4**	**3.2**	**10.2**
Maximum				**70**		**12.8**	**30**	**4**	**24.6**	**20**	**0.6**	**0.1**	**17.1**	**4**	**13**
Minimum				**33.9**		**1.5**	**30**	**0.9**	**9.8**	**10**	**0.36**	**0.03**	**10.83**	**0.95**	**7.27**
Average all mines				**39.1**		**9.6**	**24.3**	**4.1**	**18.6**	**27.8**	**0.8**	**0.1**	**11.4**	**2.4**	**7.3**
Maximum all mine				**70**		**36.5**	**30**	**23.1**	**38.5**	**120**	**7.8**	**0.4**	**48**	**7.8**	**27.9**
Minimum all mines				**5.2**		**1.5**	**3**	**0.8**	**5**	**3.5**	**0**	**0**	**0**	**0**	**0**

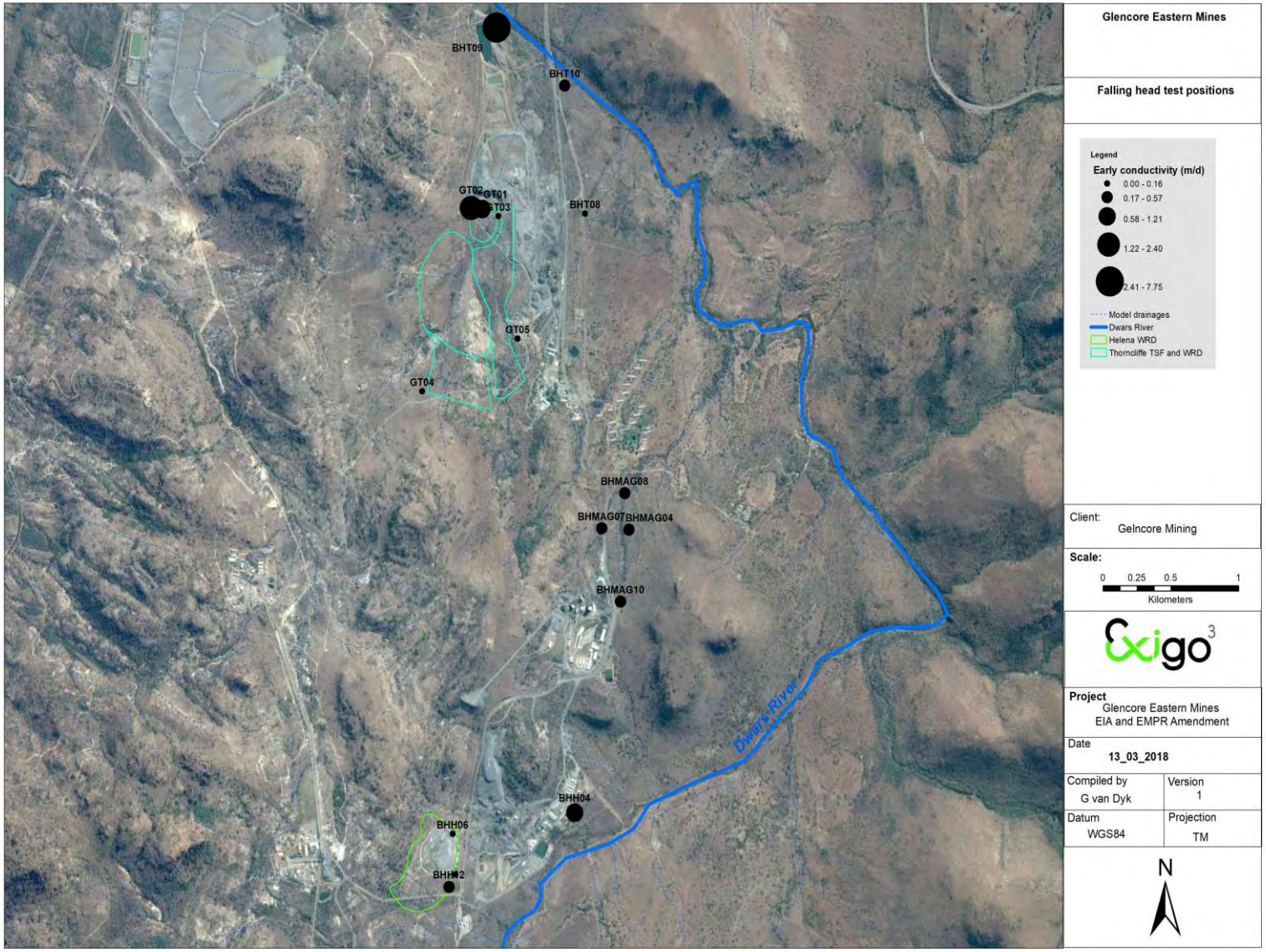


Figure 18-1 Falling head test positions and distribution

19 APPENDIX F: RAINFALL FIGURES FROM 2002 – 2020 FOR THE MINING AREA

Table 19-1 Rainfall figures for the Glencore mining area

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
2002	63	39	84	0	0	0	0	0	0	39	0	116	341
2003	62	0	23	0	0	0	0	0	0	0	211	5	301
2004	48	59	102	33	0	0	0	0	0	63	0	67	372
2005	35	40	10	0	0	0	0	0	0	4	86	94	269
2006	281	139	151	17	5	0	0	9	7	12	179	131	930
2007	47	75	30	76	0	10	10	0	0	180	271	39	737
2008	154	99	99	16	0	0	0	0	0	98	133	58	656
2009	231	91	127	0	33	16	0	22	20	56	179	76	850
2010	144	15	84	148	11	0	0	0	0	42	116	220	780
2011	298	80	90	101	5	13	2	0	0	70	81	242	982
2012	145	170	99	49	0	0	0	0	100	125	92	207	987
2013	75	48	64	99	18	0	0	0	22	136	75	129	666
2014	78	91	173	72	0	0	0	0	4	34	102	94	648
2015	65	55	80	30	0	0	0	0	0	25	50	72	377
2016	60	113	109	0	8	0	6	0	0	58	184	206	743
2017	118	238	28	15	32	0	0	0	1	67	48	114	661
2018	57	104	122	39	20	0	0	0	7	39	82	134	604
2019	205	57	55	110	0	0	0	0	8	47	102	45	629
2020	123	121	23	35	0	0	0	0	4	53	56	59	477
Minimum	**35**	**0**	**10**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**269**
Maximum	**298**	**238**	**173**	**148**	**33**	**16**	**10**	**22**	**100**	**180**	**271**	**242**	**987**
Average	**121**	**86**	**82**	**44**	**7**	**2**	**1**	**2**	**9**	**60**	**108**	**111**	**632**
Total	**2290**	**1633**	**1552**	**840**	**132**	**39**	**18**	**31**	**174**	**1146**	**2046**	**2107**	**12009**

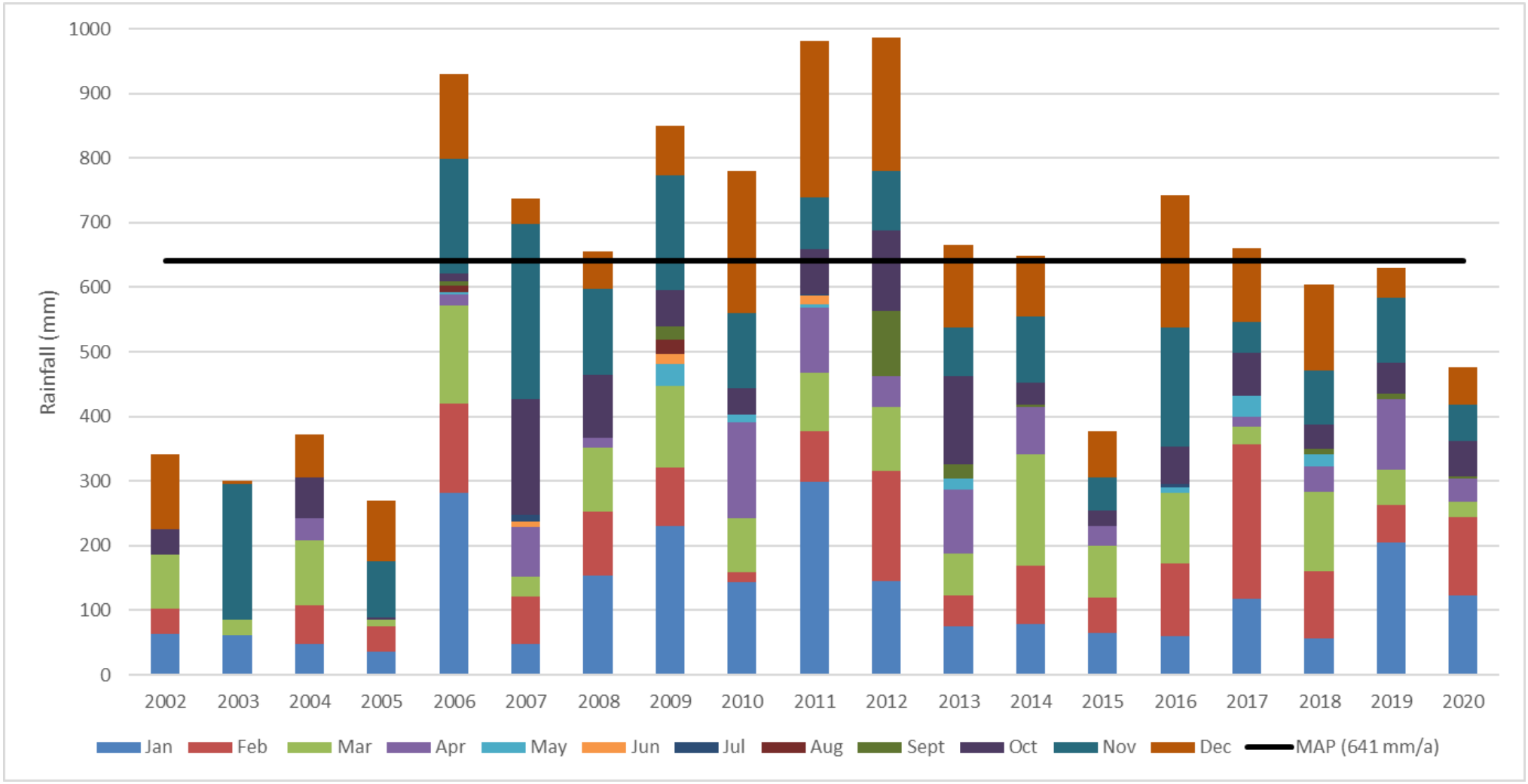


Figure 19-1 Graph showing the rainfall figures as acquired for the mining area

20 APPENDIX G: MODEL CALIBRATION STATISTICS AND INPUTS

Table 20-1 Detailed model inputs and sources

Input parameter	Scale	Source, parameter, or assumption description	Data uncertainty
Topography (DEM)		The topographic elevations were interpolated from the 1:50 000 scale 20 m contour intervals.	Low - Moderate
Rivers, streams, drainages	1:50 000	Digitised from topographical maps and aerial imagery.	Low
Lithology	1:250 000	Geological map 2430 PELGRIM'S RUST.	Moderate
Geological structures		High resolution aerial magnetic surveys. While the positions and extent are known the hydraulic characteristics are associated with uncertainty.	Moderate
Mine Layout		A mine layout was supplied by the client.	Low
Boreholes and pumping rates		2009, AGES, Xstrata Magareng: Model Update and Baseline Hydrological Assessment. 2016, Exigo Sustainability, Glencore Mototolo: Geophysical Surveys and Drilling of Monitoring Boreholes 2018, Exigo Sustainability, Aquifer tests.	Moderate
Rainfall		Supplied by the client and measured at the mine from 2002 to 2020.	Low - Moderate
Steady State Modelling Parameters – Flow Model			
Boundary conditions		Northern, Eastern and Western model boundary – Fixed hydraulic head boundary with a max flow constraint = 0 m^3/d. These boundaries represent the Klein (west) and Groot (east) Dwars Rivers (The two rivers converge in the north).	Low - Moderate
		Southern boundary - Use of no flow boundary correlating with surface water divides.	Low - Moderate
		Rivers and drainages within the model domain are described by fixed head boundary conditions and maximum flow constraints of 0 m^3/d.	Low - Moderate
Recharge		Use of the chloride method as an indication and previous groundwater studies conducted (calibration process)	Moderate
Hydraulic Conductivity		The hydraulic conductivity was estimated from pumping tests, falling head tests and literature.	Low
Aquifer thickness		The aquifer thickness is represented by a 30m weathered profile, 300 m sub-basement geological unit and 500 m basement hard rock.	Moderate
Transient State Modelling Parameters & Mass transport model			
Initial Hydraulic Heads		Simulated heads obtained from simulated steady state conditions as calibrated. Initial hydrauilic heads taken for 2003.	Moderate
Initial mass transport plumes		Historic and current hydrochemistry data from monitoring data were used to calibrate the initial mass plumes accordingly. A Kd of 0 was also used within the modelling. 2017 - 2018, Waste assessment reports and results to determine source terms.	Moderate
Specific Storage		The volume of water that a unit volume of aquifer releases from or takes into storage per unit change in head. $S = S_s \times D$. S_s, Storage was developed according to each layer thickness as indicated in Table 8-1	High
Effective Porosity		Porosity is the ratio of the volume of void space to the total volume of the rock of earth material. Assumed conservative porosity of 1-2% was used in the transient simulations for the rock matrix and 20% were applied to the backfilled open pits (Table 8-1).	High
Nitrate Decay Rate		There exists a decay component for Nitrates and this decay rate was applied during modelling (500–600-day de-nitrification process as indicated by measured concentrations at BHT8) - 0.003.	High
Longitudinal dispersion coefficient		No field work has been conducted to determine the dispersivity. An approximation of 5 m was used.	High
Transverse dispersion coefficient		Transverse dispersivity was assumed to be 10 x smaller than the longitudinal dispersivity (0.5 m)	High

Table 20-2 Model observation points and calibration statistics

Observation no	Site name	X	Y	Z (mamsl) RL	Water Level - Dec 16 (mbgl)	Measured Head (mamsl)	Simulated Head (mamsl)	Error - Above or below actual (m)	Mean Absolute Error (m) MAE	Mean Error (m) ME	Root Mean Square Error (m) RMS
1	001B	-89844.61	-2769220.00	1129.12	4.82	1124.30	1122.82	-1.48	1.48	1.48	2.19
2	HE GW 02 - 01	-89277.92	-2769081.90	1084.20	2.92	1081.28	1080.60	-0.68	0.68	0.68	0.47
3	HE GW 02 - 24	-89319.80	-2769082.95	1085.37	3.23	1082.14	1081.08	-1.07	1.07	1.07	1.14
4	HE GW 02 - 25	-89292.95	-2769051.53	1084.47	1.97	1082.50	1079.59	-2.91	2.91	2.91	8.49
5	HEGW90	-89323.96	-2769234.64	1088.17	9.38	1078.79	1085.28	6.50	6.50	-6.50	42.20
6	HEGW92	-89238.15	-2769205.61	1085.02	6.44	1078.58	1082.44	3.86	3.86	-3.86	14.94
7	HEGW94	-89234.93	-2769280.37	1085.71	4.93	1080.78	1082.48	1.69	1.69	-1.69	2.87
8	HEX100	-89287.43	-2769403.02	1090.08	9.88	1080.20	1084.92	4.71	4.71	-4.71	22.23
9	HE27	-89557.98	-2769660.04	1126.08	10.67	1115.41	1113.75	-1.66	1.66	1.66	2.77
10	HE GW 02 - 19	-89051.36	-2769956.63	1079.52	4.06	1075.46	1076.03	0.56	0.56	-0.56	0.32
11	HE GW 02 - 20	-89046.77	-2770118.13	1079.82	3.48	1076.34	1075.14	-1.20	1.20	1.20	1.44
12	HE GW 02 - 28	-89097.93	-2769965.47	1080.49	7.75	1072.74	1077.33	4.59	4.59	-4.59	21.11
13	HE5B	-89326.71	-2769956.99	1095.45	11.21	1084.24	1084.93	0.69	0.69	-0.69	0.48
14	HE7B	-89373.06	-2770046.03	1095.97	4.20	1091.77	1090.77	-1.00	1.00	1.00	1.00
15	HE GW 02 - 35	-88831.16	-2770834.18	1079.45	4.23	1075.22	1076.44	1.23	1.23	-1.23	1.50
16	HE6B (HE6)	-89145.96	-2770880.99	1103.96	15.61	1088.35	1088.19	-0.16	0.16	0.16	0.03
17	HE8B	-89151.95	-2770844.03	1101.61	14.63	1086.98	1087.96	0.99	0.99	-0.99	0.98
18	HEGW54	-88813.43	-2770829.86	1079.59	3.18	1076.41	1075.65	-0.77	0.77	0.77	0.59
19	HEGW55	-88810.84	-2770839.26	1079.59	3.93	1075.66	1075.48	-0.19	0.19	0.19	0.03
20	HE GW 02 - 21	-88840.02	-2770915.33	1079.60	5.13	1074.47	1076.87	2.40	2.40	-2.40	5.78
21	HE GW 02 - 30	-88877.84	-2770904.50	1079.86	6.35	1073.51	1078.96	5.45	5.45	-5.45	29.72
22	HE GW 02 - 31	-88819.81	-2770935.37	1079.81	4.28	1075.53	1075.44	-0.08	0.08	0.08	0.01
23	MBH7	-89796.30	-2767752.42	1119.58	5.60	1113.98	1110.50	-3.48	3.48	3.48	12.10
24	DB-BH05	-89532.04	-2769259.60	1093.14	12.57	1080.57	1083.83	3.25	3.25	-3.25	10.59
25	DB-BH02	-89382.04	-2769505.67	1094.82	16.08	1078.74	1082.50	3.76	3.76	-3.76	14.12
26	DB-BH01	-89329.82	-2769774.55	1097.02	15.72	1081.30	1082.61	1.31	1.31	-1.31	1.71
27	DB-BH09	-89212.47	-2770588.06	1095.22	26.02	1069.20	1072.55	3.35	3.35	-3.35	11.20
28	MBH6	-89134.48	-2767378.07	1071.52	5.70	1065.82	1068.11	2.29	2.29	-2.29	5.24

Observation no	Site name	X	Y	Z (mamsl) RL	Water Level - Dec 16 (mbgl)	Measured Head (mamsl)	Simulated Head (mamsl)	Error - Above or below actual (m)	Mean Absolute Error (m) MAE	Mean Error (m) ME	Root Mean Square Error (m) RMS
29	MBH1	-89165.46	-2767582.12	1075.23	0.54	1074.70	1068.75	-5.95	5.95	5.95	35.41
30	MBH2	-89141.21	-2767585.28	1073.09	0.16	1072.93	1067.44	-5.49	5.49	5.49	30.16
31	MBH4	-88980.82	-2767565.40	1060.64	2.71	1057.93	1058.31	0.38	0.38	-0.38	0.15
32	MBH7R	-89769.92	-2767619.31	1111.29	10.13	1101.16	1105.49	4.32	4.32	-4.32	18.67
33	MBH8	-89285.96	-2767834.39	1091.13	2.36	1088.77	1082.24	-6.53	6.53	6.53	42.66
34	MBH9	-89159.51	-2768338.75	1099.69	15.99	1083.70	1083.69	0.00	0.00	0.00	0.00
35	MBH10	-88906.18	-2768487.77	1060.52	4.58	1055.94	1062.29	6.36	6.36	-6.36	40.41
36	MBH11	-89618.98	-2768561.88	1110.95	19.32	1091.63	1094.98	3.35	3.35	-3.35	11.25
37	MBH3	-89163.08	-2768719.88	1076.81	0.17	1076.64	1074.75	-1.89	1.89	1.89	3.57
38	MBH5	-89020.57	-2768747.75	1066.67	2.66	1064.01	1064.25	0.23	0.23	-0.23	0.05
39	BHT1	-88329.99	-2761253.05	946.38	3.55	942.83	940.42	-2.41	2.41	2.41	5.82
40	BHT9	-88461.75	-2761181.89	946.02	2.94	943.08	939.85	-3.23	3.23	3.23	10.41
41	BHT6	-88325.46	-2761799.20	960.32	7.12	953.20	960.75	7.55	7.55	-7.55	57.05
42	BHT7	-88361.88	-2761634.36	959.50	8.97	950.53	957.20	6.67	6.67	-6.67	44.44
43	BHT8	-87872.68	-2762322.52	975.71	7.43	968.28	964.40	-3.88	3.88	3.88	15.08
44	BHT2	-87906.60	-2763175.78	1000.08	15.42	984.66	991.07	6.40	6.40	-6.40	41.02
45	BHT3	-87919.00	-2763130.44	999.02	3.74	995.28	990.13	-5.15	5.15	5.15	26.50
46	BH3	-87409.24	-2763097.26	993.03	4.52	988.51	975.19	-13.32	13.32	13.32	177.55
47	TGF5	-87411.29	-2763092.85	993.03	3.65	989.38	975.05	-14.33	14.33	14.33	205.37
48	BH1	-87913.79	-2763470.51	1012.74	11.57	1001.17	1004.03	2.85	2.85	-2.85	8.14
49	BH2	-87732.37	-2763574.60	1011.35	3.12	1008.23	1005.03	-3.21	3.21	3.21	10.28
50	TGF1	-87580.60	-2763778.58	1018.95	6.03	1012.92	1013.00	0.08	0.08	-0.08	0.01
51	BH4	-87500.02	-2763747.04	1015.95	1.64	1014.31	1009.82	-4.50	4.50	4.50	20.21
52	TGF2	-87386.44	-2763664.34	1011.87	2.76	1009.11	1000.57	-8.54	8.54	8.54	72.97
53	TGF3	-87502.05	-2763744.84	1015.95	1.59	1014.36	1009.63	-4.73	4.73	4.73	22.40
54	TGF4	-87729.37	-2763570.15	1011.35	2.97	1008.38	1004.68	-3.70	3.70	3.70	13.72
55	BHT-GF1	-86674.76	-2764424.23	1037.42	11.10	1026.32	1027.49	1.17	1.17	-1.17	1.36
56	BHT-GF2	-86657.47	-2764442.96	1036.91	10.30	1026.61	1027.71	1.09	1.09	-1.09	1.19
57	BHMN2	-89915.34	-2764231.31	1012.61	2.60	1010.01	1007.40	-2.61	2.61	2.61	6.82

Observation no	Site name	X	Y	Z (mamsl) RL	Water Level - Dec 16 (mbgl)	Measured Head (mamsl)	Simulated Head (mamsl)	Error - Above or below actual (m)	Mean Absolute Error (m) MAE	Mean Error (m) ME	Root Mean Square Error (m) RMS
58	BHMN7	-89844.96	-2764492.30	1025.76	8.64	1017.12	1017.26	0.13	0.13	-0.13	0.02
59	BHMAG 3	-88678.23	-2764250.94	1114.98	11.09	1103.89	1067.42	-36.46	36.46	36.46	1329.67
60	BHMAG 4	-87562.21	-2764285.86	1052.42	13.56	1038.86	1041.11	2.25	2.25	-2.25	5.06
61	BH6	-86631.96	-2764326.47	1031.84	7.83	1024.01	1022.51	-1.51	1.51	1.51	2.27
62	BHMN1	-89646.26	-2764612.86	1024.57	7.39	1017.18	1021.20	4.01	4.01	-4.01	16.11
63	BHMN4	-89839.83	-2764658.45	1032.79	3.40	1029.39	1022.57	-6.81	6.81	6.81	46.42
64	BHMN5	-90049.48	-2764716.33	1053.15	6.39	1046.76	1039.81	-6.95	6.95	6.95	48.27
65	BHMN6	-89913.07	-2764575.84	1035.10	5.11	1029.99	1021.50	-8.49	8.49	8.49	72.13
66	BHMAG 6	-87685.33	-2764928.09	1098.59	18.09	1080.50	1071.50	-9.00	9.00	9.00	81.06
67	BHMAG 1	-88138.38	-2765291.06	1104.12	5.85	1098.27	1080.15	-18.12	18.12	18.12	328.38
68	BHMAG 5	-87643.56	-2765301.17	1083.62	11.85	1071.77	1072.95	1.18	1.18	-1.18	1.39
69	BHMS4	-89653.95	-2765596.70	1079.90	2.68	1077.22	1079.76	2.54	2.54	-2.54	6.48
70	BHH1	-87974.04	-2766038.91	1056.49	14.12	1042.37	1042.82	0.45	0.45	-0.45	0.21
71	BHH4	-87917.47	-2766042.98	1052.24	6.56	1045.68	1042.49	-3.19	3.19	3.19	10.17
72	BHH5	-87872.99	-2766052.66	1049.30	14.56	1034.74	1035.50	0.75	0.75	-0.75	0.57
73	BHH8	-88463.31	-2766100.78	1065.54	8.89	1056.65	1066.46	9.81	9.81	-9.81	96.14
74	BHMS3	-89608.32	-2766089.40	1101.92	19.43	1082.49	1085.41	2.93	2.93	-2.93	8.56
75	BHH2	-87966.91	-2766205.04	1050.10	12.20	1037.90	1038.44	0.54	0.54	-0.54	0.29
76	BHH3	-87930.95	-2766144.99	1048.87	12.03	1036.84	1039.57	2.73	2.73	-2.73	7.47
77	BHH6	-88731.44	-2766167.88	1076.22	11.06	1065.16	1070.91	5.76	5.76	-5.76	33.12
78	BHH9	-88223.34	-2766365.12	1045.43	5.33	1040.10	1042.86	2.76	2.76	-2.76	7.63
79	BHH10	-88091.82	-2766406.37	1040.07	4.51	1035.56	1034.58	-0.98	0.98	0.98	0.95
80	BHMS2	-89575.01	-2766397.16	1117.23	45.82	1071.41	1072.47	1.06	1.06	-1.06	1.12
81	BHH11	-88415.73	-2766433.94	1051.85	27.94	1023.91	1027.72	3.80	3.80	-3.80	14.46
82	BHH7	-88706.51	-2766431.39	1069.84	11.66	1058.18	1061.41	3.23	3.23	-3.23	10.41
83	BHMS5	-89601.90	-2766607.83	1107.21	18.12	1089.09	1089.90	0.81	0.81	-0.81	0.66
84	BHMS1	-89572.54	-2766773.82	1102.34	31.36	1070.98	1075.51	4.53	4.53	-4.53	20.52
85	BHMS6	-89653.32	-2766772.13	1100.72	17.19	1083.53	1085.80	2.27	2.27	-2.27	5.17
86	THC01	-88608.39	-2763401.76	1009.90	9.65	1000.25	1000.92	0.67	0.67	-0.67	0.45

Observation no	Site name	X	Y	Z (mamsl) RL	Water Level - Dec 16 (mbgl)	Measured Head (mamsl)	Simulated Head (mamsl)	Error - Above or below actual (m)	Mean Absolute Error (m) MAE	Mean Error (m) ME	Root Mean Square Error (m) RMS
87	THC02	-88730.76	-2763031.53	996.36	5.10	991.26	992.37	1.11	1.11	-1.11	1.23
88	THC03	-88463.60	-2762820.20	994.14	4.14	990.00	987.78	-2.22	2.22	2.22	4.94
89	THC04	-88542.60	-2762487.47	983.41	4.93	978.48	979.87	1.39	1.39	-1.39	1.92
90	THC05	-88776.06	-2762664.68	992.35	7.72	984.63	987.36	2.73	2.73	-2.73	7.45
91	THC06	-89108.65	-2763372.77	1015.03	4.87	1010.16	1010.21	0.05	0.05	-0.05	0.00
Average				**1057.05**	**8.71**	**1048.34**	**1047.76**	**-0.59**	**3.76**	**0.59**	**36.36**
Minimum				**946.02**	**0.16**	**942.83**	**939.85**	**-36.46**	**0.00**	**-9.81**	**0.00**
Maximum				**1129.12**	**45.82**	**1124.30**	**1122.82**	**9.81**	**36.46**	**36.46**	**1329.67**
Correlation (R)							**0.99**		Σ = 342.50	Σ = 53.31	Σ = 3308.56
									1/n = 3.76	1/n = 0.59	1/n =36.36
											SQRT = 6.03
											RMS% of water level range = 3.32%

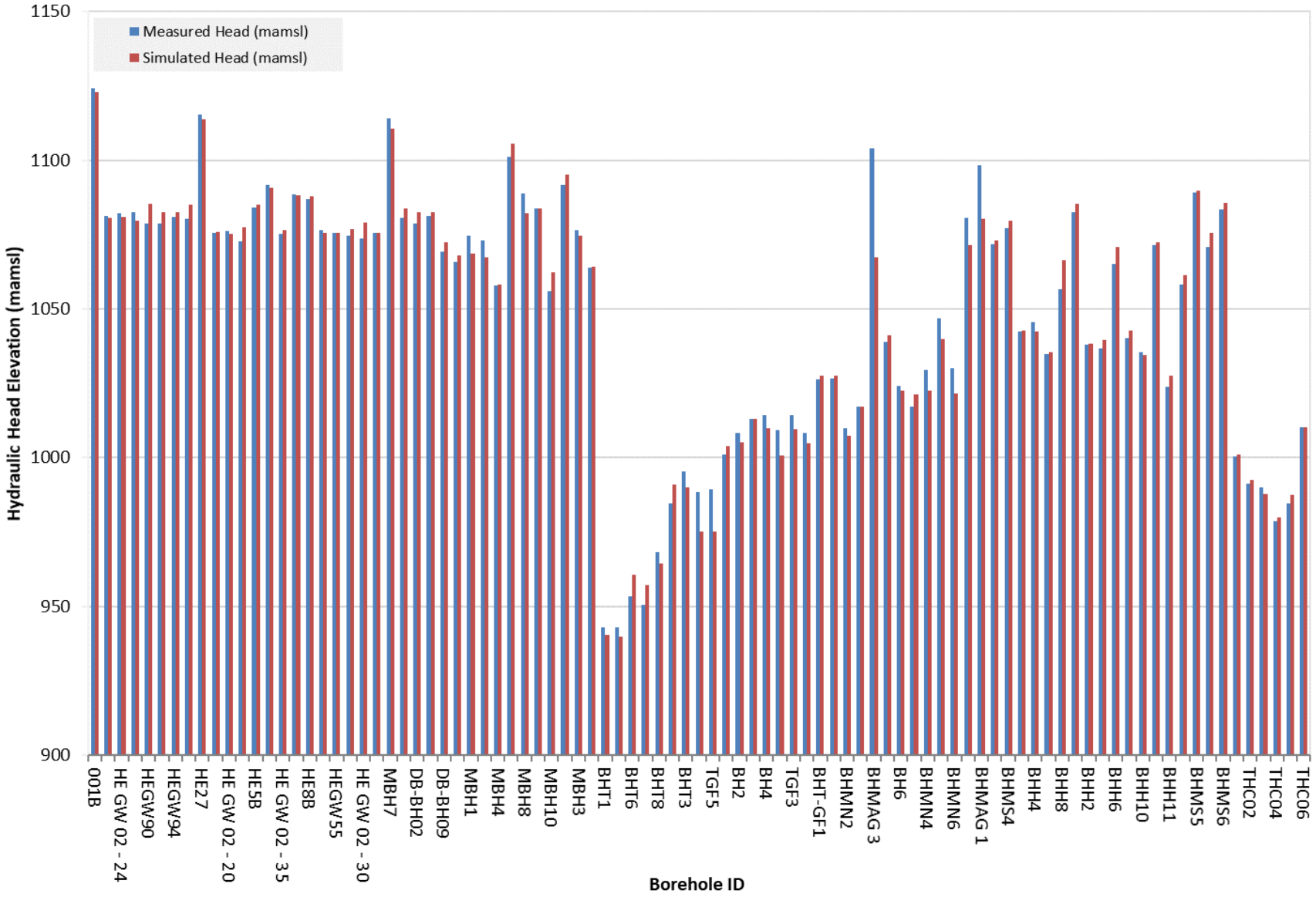


Figure 20-1 Graph indicating measured hydraulic head against simulated hydraulic head.

21 APPENDIX H: DEVELOPMENT OF THE UNDERGROUND ZONE OF INFLUENCE WITH NO SHALLOW AQUIFER IMPACTS

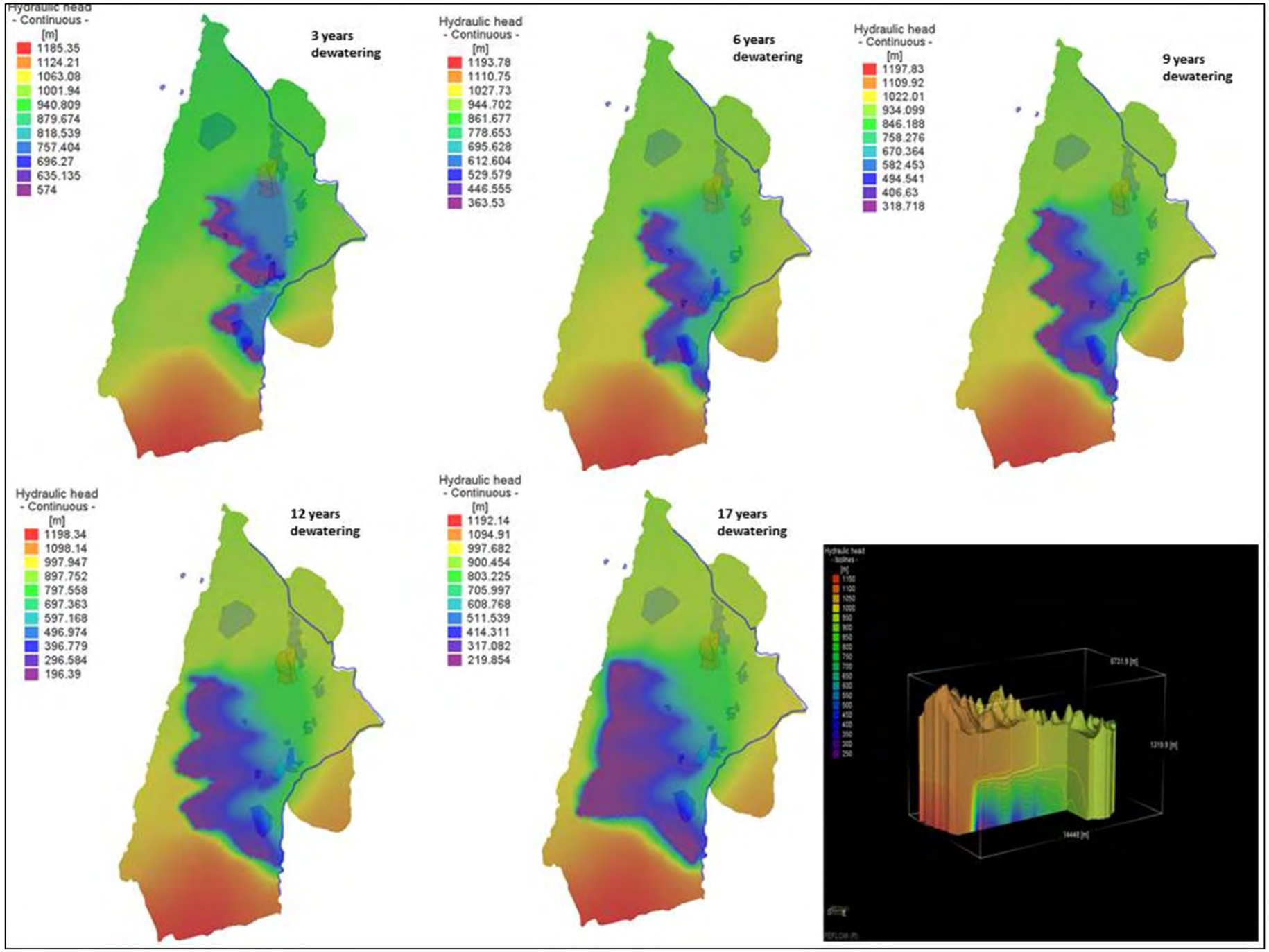


Figure 21-1 Development stages of the underground extension

22 APPENDIX I: IMPACT ASSESSMENT AND MATRIX

Table 22-1 Impact assessment matrix

Nr	Activity	Impact	Without or With Mitigation	Probability	Duration	Scale	Magnitude/ Severity	Significance	Mitigation Measures	Mitigation Effect
				Magnitude	Magnitude	Magnitude	Magnitude	Magnitude		
Construction Phase										
1	Contamination to ground- and surface water systems from oil, grease and diesel spillages from construction vehicles.	Contamination to groundwater systems	**WOM**	Probable	Medium term	Site	Medium	Low	Road compaction and service facilities for mine vehicles with spillage sumps	Can be avoided, managed or mitigated
			WM	Improbable	Short term	Site	Medium	Negligible		Can be avoided, managed or mitigated
2	On-site sanitation.	Contamination to groundwater systems	**WOM**	Probable	Medium term	Local	Medium	Negligible	Monitoring systems to detect leaking and as well as visual observations of facilities conditions	Can be avoided, managed or mitigated
			WM	Improbable	Short term	Local	Medium	Negligible		Can be avoided, managed or mitigated
3	Storage of chemicals and building materials during construction of waste facilities.	Contamination to groundwater systems	**WOM**	Probable	Medium term	Site	Medium	Low	Monitoring systems to detect leaking and as well as visual observations of facilities conditions	Can be avoided, managed or mitigated
			WM	Improbable	Medium term	Site	Medium	Negligible		Can be avoided, managed or mitigated
Operational Phase										
3	Mine dewatering	Reduction in groundwater resource availability	**WOM**	Probable	Long term	Site	Low	Negligible	Water volumes abstracted are low. Update mine water balance. Monitor abstraction rates. Grout (seal) water intersections	Can be avoided, managed or mitigated
			WM	Probable	Medium term	Site	Low	Negligible		Can be avoided, managed or mitigated
5	Abstraction from Dwars River for mine water supply	Reduction in surface water resource availability	**WOM**	Definite	Medium term	Site	Low	Low	Water volumes abstracted are low. Update mine water balance. CDPF conserves water. Monitor abstraction rates	Can be avoided, managed or mitigated
			WM	Definite	Long term	Site	Low	Low		Can be avoided, managed or mitigated
6	Abstraction from aquifer for mine water supply	Reduction in groundwater resource availability	**WOM**	Definite	Medium term	Site	Medium	Moderate	Groundwater management plan. Mine water use minimisation. Mine water balance management and monitoring	Can be avoided, managed or mitigated
			WM	Definite	Long term	Site	Low	Low		Can be avoided, managed or mitigated
7	Nitrate seepage from new waste facilities at Thorncliffe and Helena mines to the groundwater system.	Contamination to groundwater systems	**WOM**	Definite	Medium term	Site	Medium	Moderate	Multiple barrier design and operation. Continuous groundwater quality monitoring.	Can be avoided, managed or mitigated
			WM	Probable	Medium term	Site	High	Low		Can be avoided, managed or mitigated
8	Sulphate seepage from new waste facilities at Thorncliffe and Helena mines to the groundwater system.	Contamination to groundwater systems	**WOM**	Definite	Long term	Site	Low	Low	Seepage capturing trench or seepage capturing boreholes. Continuous groundwater quality monitoring.	May cause irreplaceable loss of resources
			WM	Highly Probable	Long term	Site	Low	Low		Can be avoided, managed or mitigated
9	TDS Mass seepage towards Dwars River from new waste facilities at Thorncliffe and Helena mines along surface drainages and groundwater pathways.	Contamination to surface- and groundwater systems	**WOM**	Highly Probable	Long term	Site	Low	Low	Multiple barrier design and operation. Continuous groundwater quality monitoring.	Can be avoided, managed or mitigated
			WM	Highly Probable	Long term	Site	Low	Low		Can be avoided, managed or mitigated

Nr	Activity	Impact	Without or With Mitigation	Probability	Duration	Scale	Magnitude/ Severity	Significance	Mitigation Measures	Mitigation Effect
				Magnitude	Magnitude	Magnitude	Magnitude	Magnitude		
10	Increased seepage from new and existing waste facilities towards the Dwars River during flooding events due to increased runoff at Thorncliffe and Helena mines.	Contamination to surface- and groundwater systems	WOM	Definite	Long term	Site	Low	Low	Water quality monitoring from the Dwars River and seepage capturing from non-perennial drainages. Diversion channels and re-enforcement of storage facilities. Continuous maintenance and monitoring.	Can be avoided, managed or mitigated
			WM	Probable	Long term	Site	Medium	Low		Can be avoided, managed or mitigated
Post Operational Phase										
11	TDS & Nitrate leaching from new waste facilities at Thorncliffe and Helena mines.	Contamination to surface- and groundwater systems	WOM	Highly Probable	Long term	Site	Low	Low	Rehab mine resdiue facilities Source term and pathways is not significant. Nitrate decays with time	Can be avoided, managed or mitigated
			WM	Probable	Long term	Site	Medium	Low		Can be avoided, managed or mitigated
12	Mine re-watering and decanting	Contamination to groundwater and surface water systems	WOM	Probable	Long term	Site	Low	Negligible	Mine water quality not deleterious. Seal shafts	Can be avoided, managed or mitigated
			WM	Probable	Long term	Site	Low	Negligible		Can be avoided, managed or mitigated

Table 22-2 Impact assessment criteria

Probability: This describes the likelihood of the impact actually occurring.	
Improbable:	The possibility of the impact occurring is very low, due to the circumstances, design or experience.
Probable:	There is a probability that the impact will occur to the extent that provision must be made therefore.
Highly Probable	It is most likely that the impact will occur at some stage of the development.
Definite:	The impact will take place regardless of any prevention plans, and there can only be relied on mitigatory actions or contingency plans to contain the effect.
Duration: The lifetime of the impact	
Short term:	The impact will either disappear with mitigation or will be mitigated through natural processes in a time span shorter than any of the phases.
Medium term:	The impact will last up to the end of the phases, where after it will be negated.
Long term:	The impact will last for the entire operational phase of the project but will be mitigated by direct human action or by natural processes thereafter.
Permanent:	Impact that will be non-transitory. Mitigation either by man or natural processes will not occur in such a way or in such a time span that the impact can be considered transient.
Scale: The physical and spatial size of the impact	
Local:	The impacted area extends only as far as the activity, e.g., footprint
Site:	The impact could affect the whole, or a measurable portion of the above-mentioned properties.
Regional:	The impact could affect the area including the neighbouring residential areas.
Magnitude/ Severity: Does the impact destroy the environment or alter its function.	
Low:	The impact alters the affected environment in such a way that natural processes are not affected.
Medium:	The affected environment is altered, but functions and processes continue in a modified way.
High:	Function or process of the affected environment is disturbed to the extent where it temporarily or permanently ceases.
Significance: This is an indication of the importance of the impact in terms of both physical extent and time scale, and therefore indicates the level of mitigation required.	
Negligible:	The impact is non-existent or unsubstantial and is of no or little importance to any stakeholder and can be ignored.
Low:	The impact is limited in extent, has low to medium intensity; whatever its probability of occurrence is, the impact will not have a material effect on the decision and is likely to require management intervention with increased costs.
Moderate:	The impact is of importance to one or more stakeholders, and its intensity will be medium or high; therefore, the impact may materially affect the decision, and management intervention will be required.
High:	The impact could render development options controversial or the project unacceptable if it cannot be reduced to acceptable levels; and/or the cost of management intervention will be a significant factor in mitigation.

Table 22-3 Impact assessment scoring criteria

Aspect	Description	Weight
Probability	Improbable	1
	Probable	2
	Highly Probable	4
	Definite	5
Duration	Short term	1
	Medium term	3
	Long term	4
	Permanent	5
Scale	Local	1
	Site	2
	Regional	3
Magnitude	Low	2
	Medium	6
	High	8
Significance		
	Negligible	<20
	Low	<40
	Moderate	<60
	High	>60