GROUNDWATER ASSESSMENT
ST HELENA 10 SHAFT
July 2018

REVIEW RECORD

Version	Reviewers	Organisation	Date reviewed	Reviewer's signature
PMM18-301-D4 (ver 1)				

CONSULTANT'S EXPERTISE

Solution[H+] is the trading name of Terry Harck. Terry has extensive experience in hydrogeology and environmental geochemistry. He has contributed to many specialist groundwater and geochemistry assessments; waste assessments; contaminated land assessments; environmental impact assessments; mine feasibility studies; environmental management plans; environmental audits; environmental monitoring reports; closure and rehabilitation costs and plans; and development of environmental action plans.

Terry Harck is a registered professional natural scientist in the field of Earth Science with the South African Council for Natural Scientific Professions (Pr Sci Nat 400088/95). He has over 25 years' experience in environmental consulting. He has successfully completed dozens of environmental projects for mining and mining related activities. Terry's CV is included at the back of this document.

DECLARATION OF INDEPENDENCE

The undersigned herewith declares that this report represents an independent, objective assessment of groundwater conditions at St Helena 10 Shaft, Welkom.

Terry Harck (Pr.Sci.Nat 400088/95)

Hydrogeochemist

EXECUTIVE SUMMARY

This report describes groundwater conditions at St Helena 10 Shaft, Welkom. Harmony is applying for a closure certificate for St Helena 10 Shaft. As part of the closure application, a Basic Assessment Report (BAR) would be required for the decommissioning activities. Objectives are:

- To establish baseline groundwater conditions at the site
- To identify potential groundwater impacts due to decommissioning activities
- To recommend actions to mitigate significant groundwater impacts

Backfilling of 10 Shaft has been addressed directly between Harmony and the Department of Water and Sanitation (DWS) (refer to Harmony 2016). Therefore, assessment of groundwater impact from shaft backfilling is briefly discussed in this assessment.

The approach to the groundwater assessment at St Helena 10 Shaft is in general accordance with the Best Practice Guidelines for Water Resource Management in the South African Mining Industry, developed by the South African Department of Water Affairs and Forestry (DWAF)[1] in 2008.

Regional geology and hydrogeology

The Karoo Supergroup rocks form the surface and near-surface geology of the assessment area. The top of the Ventersdorp Supergroup lies approximately 550 m below surface while the Witwatersrand Supergroup rocks, which host the Welkom gold deposits, lie more than 1 000 m below surface.

This assessment considers near-surface impacts on groundwater arising from the St Helena 10 shaft decommissioning operations. Therefore, this assessment considers only the Karoo aquifer.

According to the National Aquifer Classification System of Parsons (1995), the Karoo aquifer in the St Helena 10 Shaft assessment area is described as a *Minor* aquifer system: "These can be fractured or potentially fractured rocks that do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are both important for local supplies and in supplying base flow for rivers".

The groundwater quality is generally good due to the dynamic recharge from rainfall. However, the Karoo siltstones were deposited in a marine environment and salinity is known to leach from these rocks. Further, this aquifer is vulnerable to contamination from surface sources including seepage from mine infrastructure such as tailings dams, waste rock dumps, process water pans and evaporation dams.

Groundwater levels typically follow the topography in the region. The assessment area topography suggests two directions of groundwater flow:

- West-northwest at a gradient of 0.0035 towards a series of pans
- South-southwest at a gradient of 0.0047 towards a small tributary of the Sand River

[1] Now called Department of Water and Sanitation (DWS)

Groundwater usage in the area occurs on agricultural holdings and is predominantly for small-scale irrigation and livestock watering. A smaller amount is used for domestic purposes.

Hydrocensus

The hydrocensus was conducted on 15 and 16 May 2018. It consisted of measuring groundwater depth in four boreholes, collection of two groundwater samples, and collection of one waste rock sample.

Based on the hydrocensus results and available data, the dominant groundwater flow direction is approximately west-northwest with a possible minor flow component to the south. The directions are consistent with the topography, although the inferred hydraulic gradients are generally flatter than the topographic gradients.

Based on the two samples analysed, groundwater in the St Helena 10 Shaft area is neutral and saline. Nitrate in STHH11 exceeds health-based drinking water guideline for nitrate, presumably contaminated by seepage from the adjacent cattle kraal. Both samples exceed health-based guidelines for selenium (Se). Selenium is associated with fine-grained sediments, such as the Ecca Group rocks which form the shallow Karoo aquifer. It is also associated with pyrite, a common mineral in gold tailings such as the St Helena tailings dam immediately upgradient of the 10 Shaft site.

The concentration of sulphate (SO_4) in the sample from borehole STHH 13 is higher than the background concentration of <200 mg/L. This may indicate background contamination of groundwater at St Helena 10 Shaft by mining activities to the east, particularly the St Helena tailings dam on the east boundary of the assessment area.

The Acid-base accounting (ABA) results indicate that the sample from the 10 Shaft waste rock dump is not acid generating.

Groundwater risks in the assessment area

Groundwater risk in the St Helena 10 Shaft assessment area is limited to the following potential impacts on groundwater quality:

- Hydrocarbon spillages from vehicles and earthmoving machinery during the demolition, shaft backfilling, topographic shaping, topsoil placement, and revegetation processes. Spillages may result in soil contamination and subsequent leaching of contaminants to groundwater.
- Groundwater contamination from the slimes used to backfill the shaft. As the shaft fills with groundwater, contaminants may leach from the backfill and move with the local groundwater flow and possibly migrate offsite.
- Seepage from the waste rock dump (WRD). As far as can be determined, the WRD is a legacy of original shaft development operations. Therefore, it has been present on the site for approximately 70 years. The WRD is likely to be removed as part of the site clearing and rehabilitation activities. However, the residual impact of 70 years of seepage on the underlying groundwater quality remains.

Numerical modelling of groundwater impacts

Based on numerical geochemical modelling using the PHREEQC software, sulphate concentration in WRD seepage is estimated to range from 50 mg/L to 150 mg/L.

The modelled WRD seepage concentration was applied in the CONSIM numerical model, which accounts for uncertainty in input parameters using Monte Carlo methods.

Based on general agreement with limited monitoring results, indicating current groundwater quality impacts (as sulphate concentrations), the CONSIM model is assumed to provide a credible indicator of future groundwater sulphate concentration downstream of the St Helena tailings dam and 10 Shaft WRD.

Model results indicate that the groundwater quality impact from the St Helena tailings dam obscures the relatively smaller impact from the 10 Shaft WRD. This suggests that the impact of the WRD alone on groundwater outside the 10 Shaft assessment area is likely to be indistinguishable from background groundwater sulphate concentration.

Impact assessment

No significant impacts on groundwater levels are expected from the decommissioning activities. Therefore, the assessed significance class of the impact is low, no mitigations are required, and the impact with mitigation remains low.

Regarding groundwater quality, the long-term impact of the 10 Shaft WRD has been modelled under the assumption that it is a conservative proxy for potentially groundwater contaminating activities associated with the 10 Shaft decommissioning, including hydrocarbon spillages and seepage from the WRD.

The model results have indicated that the current groundwater impact from the WRD is indistinguishable from background groundwater quality, which is extensively contaminated by the St Helena tailings dam. Further, removing the WRD source, one outcome of shaft decommissioning activities, results in a low level (as indicated from the modelled distribution of sulphate concentrations) of offsite groundwater impact. This is true for both the inferred groundwater flow directions: west and south.

Therefore, the impact on groundwater quality is low, and mitigation is not required.

Recommendations

Solution[H+] recommends the groundwater monitoring plan for the 10 Shaft site described in Section 7 of this report.

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1 INTRODUCTION

This report describes groundwater conditions at St Helena 10 Shaft, Welkom. Environmental Impact Management Services (IEMS) is conducting a Basic Assessment of the 10 Shaft closure for Harmony Gold Mining Company Ltd (Harmony). IEMS commissioned Solution[H+] to undertake the groundwater work described in this report.

1.1 Site location

St Helena 10 Shaft is located in the Free State approximately 8 km south of Welkom (Figure 1).

Figure 1: Location of St Helena 10 Shaft with Sand River to the south (assessment area outlined in white)

1.2 Terms of reference

IEMS provided Solution[H+] with the following terms of reference:

- Harmony is applying for a closure certificate for St Helena 10 Shaft. As part of the closure application, a Basic Assessment Report (BAR) would be required for the decommissioning activities.
- Based on the available information, the site consists of remnant shaft infrastructure, including a small waste rock dump, set in cultivated farmland. The assessment area is approximately 780 hectares, with the shaft at the centre.
- Work required would include:
    - Baseline groundwater conditions (quantity, quality and flow direction)
    - Conceptual model
    - Identification of impacts as a result of the decommissioning activities
    - Recommendations, mitigations relating to the decommissioning of the shaft
    - Drafting a monitoring programme
- The hydrogeology of the Welkom area, has been well-characterised as part of the permitting of mining activities in the area. Harmony maintains an extensive borehole monitoring network. Therefore, detailed field investigations, including borehole siting, drilling, and testing are not required for this assessment.

Backfilling of 10 Shaft has been addressed directly between Harmony and the Department of Water and Sanitation (DWS) (refer to Harmony 2016). Therefore, assessment of groundwater impact from shaft backfilling is briefly discussed in this assessment.

1.3 Objectives

Proposal PMM18-301-D1 (dated 21 February 2018) from Solution[H+] to IEMS documents the objectives and scope of the study. The objectives of the assessment are to:

- Establish baseline groundwater conditions at the site
- Identify potential groundwater impacts due to decommissioning activities
- Recommend actions to mitigate significant groundwater impacts

2 APPROACH

2.1 Groundwater assessment

The approach to the groundwater assessment at St Helena 10 Shaft is in general accordance with the Best Practice Guidelines for Water Resource Management in the South African Mining Industry, developed by the South African Department of Water Affairs and Forestry (DWAF)[2] in 2008. Best Practice Guideline G4: *Impact Prediction* is of particular relevance. Table 1 presents key tasks associated with this approach and application to this groundwater assessment.

Table 1: BPG G4 Impact assessment approach as applied to this groundwater assessment for St Helena 10 Shaft

Task	Application to this assessment
Site visit	Section 3 of this report Conducted hydrocensus and sampling of groundwater and waste rock on 15-16 May 2018
Information review	The following sources were reviewed: Groundwater Resources of the Republic of South Africa (map series, Vegter 1995) Harmony Rehabilitation Action Plan (2016)
Sampling and analytical programme	Section 3 of this report Conducted hydrocensus and sampling of groundwater and waste rock on 15-16 May 2018 Water samples: EC, TDS, pH, major cations and anions, and an ICP scan for trace elements Waste rock sample: acid-base accounting and contact water extractions
Make impact predictions	Section 3 of this report Developed site conceptual model Developed numerical groundwater assessment model Developed preliminary contaminant source term Predicted potential groundwater quality impact using numerical model
Identify appropriate management options	Section 4 and Section 5 of this report
Develop monitoring and validation programmes	Section 6 of this report

2.2 Guidelines/standards

For the purposes of this study, the following guidelines/standards have been applied:

- AMD potential is evaluated from the criteria of Mine Environment Neutral Drainage (MEND) report 1.50.1 (2009).
- With respect to mine drainage quality, the South African National Standards (SANS) 241 (2015) *Drinking Water* was considered as a risk indicator. Applying drinking water guidelines does not suggest that leachates and drainage from mine activities will be used for drinking purposes. These guidelines have been used as an indicator of general environmental risk.

[2] Now called Department of Water and Sanitation (DWS)

3 INFORMATION REVIEW

The information review is summarised under the following headings:

- Geological setting
- Hydrogeological setting

3.1 Geological setting

Three main geological units are of relevance in the assessment area (Table 2).

Table 2: Stratigraphy of the St Helena area (from Bailey 1991)

Supergroup	Group	Formation	Description	Thickness (m)	Age (Ma)
Karoo	Beaufort		Sandstone and siltstone	50	150 - 300
	Ecca		Sandstone and thin coal seams	450	
		Dwyka	Tillite (a glacially derived conglomerate set in a fine-grained matrix)	50	
Ventersdorp			Basic and acid volcanics with subordinate siliciclastic sediments (breccias, conglomerates, sandstones, mudrocks), with minor limestones and cherts in upper part of succession	500	2 500 – 2 700
Witwatersrand			Siliceous quartzites with grit and conglomerate bands	>6 500	2 700 – 3 060

Table 2 indicates that the Karoo Supergroup rocks form the surface and near-surface geology of the assessment area. The top of the Ventersdorp Supergroup lies approximately 550 m below surface while the Witwatersrand Supergroup rocks, which host the Welkom gold deposits, lie more than 1 000 m below surface.

3.2 Hydrogeological setting

Two main aquifers exist in the area:

- Karoo aquifer, near surface and associated within the weathered and fractured Karoo Supergroup
- Deeper aquifer developed in the fractured and faulted Ventersdorp and Witwatersrand rocks

The deeper aquifer has been dewatered since the 1950s to keep the deep gold mining operations dry. Groundwater levels in the deeper aquifer have declined by hundreds of meters since dewatering was initiated. However, no corresponding drop in water levels in the Karoo aquifer has been reported (Harmony Saaiplaas EMPR, 2002). Therefore, it appears that no hydraulic connection exists between the Karoo aquifer and the deeper aquifer of the Ventersdorp and Witwatersrand Supergroups.

This assessment considers near-surface impacts on groundwater arising from the St Helena 10 shaft decommissioning operations. Therefore, this assessment considers only the Karoo aquifer.

The primary porosity of the Karoo rocks does not allow significant groundwater flow, except where the porosity has been increased by weathering and/or secondary geological structures (faulting and fracturing).Therefore, the Karoo aquifer comprises the near-surface weathered and fractured Beaufort and

Ecca Group rocks. The aquifer is confined to semi-confined. The impermeable shale horizons in the Beaufort and Ecca Groups often restrict the downward infiltration of rainwater into the aquifer. This gives rise to the numerous pans and vleis in the area west of Welkom, including the St Helena 10 Shaft assessment area.

The groundwater quality is generally good due to the dynamic recharge from rainfall. However, the Karoo siltstones were deposited in a marine environment and salinity is known to leach from these rocks. Further, this aquifer is vulnerable to contamination from surface sources including seepage from mine infrastructure such as tailings dams, waste rock dumps, process water pans and evaporation dams.

There may be a change in porosity and permeability where the weathered bedrock gives way to less weathered and fractured bedrock. There is often an accumulation of water just above this contact, which gives rise to useable groundwater yields. Borehole yields in this aquifer are generally low due to the low permeability of the soil zone and weathered Karoo rocks.

Other accumulations of groundwater occur in the fractured rocks associated with dolerite dykes and sills. The intrusion of dykes and sills caused the surrounding rock to fracture producing additional storage and conduits for groundwater flow, although not all these fractures are necessarily water bearing. These fracture systems may occasional result in high yielding boreholes, although they are generally not able to sustain excessive pumping and irrigation.

Table 3: Summary of aquifer parameters of the Karoo aquifer

Parameter	Unit	Value	Comment
Recharge	mm/yr	<12	1 – 3% of annual precipitation
Depth to water table	m	<10	
Hydraulic conductivity	m/d	10^{-6}	
Porosity	%	1 – 3	
Aquifer thickness	m	10 – 80	

Groundwater levels typically follow the topography in the region. This implies that flow takes place towards low points in the topography, which are occupied by pans and watercourses. The assessment area topography suggests two directions of groundwater flow (Figure 2):

- West-northwest at a gradient of 0.0035 towards a series of pans
- South-southwest at a gradient of 0.0047 towards a small tributary of the Sand River

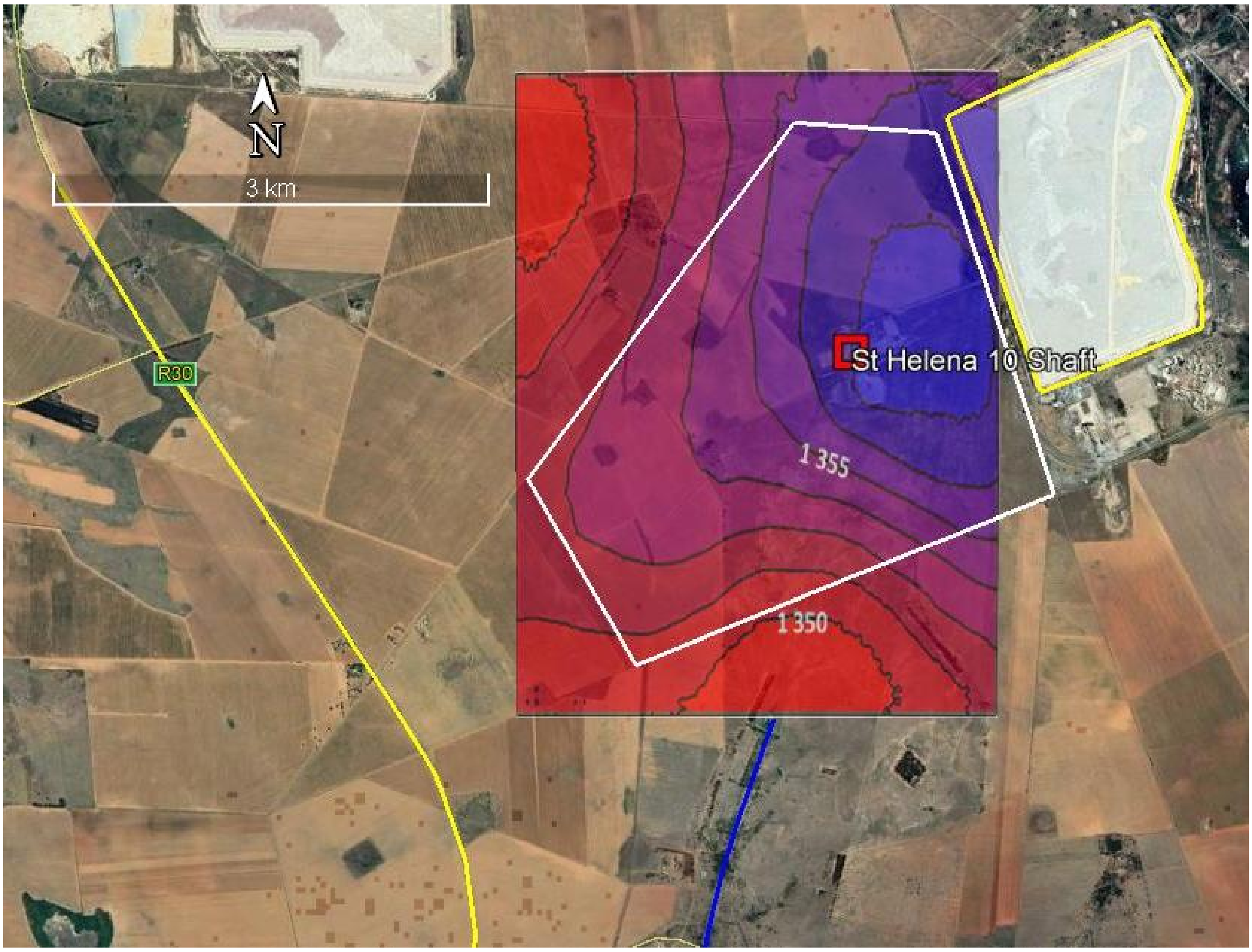

Figure 2: Topographic elevations (in mamsl) in the 10 Shaft assessment area

Groundwater usage in the area occurs on agricultural holdings and is predominantly for small-scale irrigation and livestock watering. A smaller amount is used for domestic purposes.

3.2.1 Groundwater quality

Information on background water quality is limited. The hydrogeological map of South Africa indicates groundwater in the Welkom area being dominated by the cations Ca, Mg, Na, and K; with HCO_3 as the dominant anion. This is common in Karoo aquifers where groundwater is recharged by rainfall (Ca-Mg-HCO_3). With time ion exchange processes substitute cations and the groundwater develops a Na-K-HCO3 signature. Salinity is variable (300 – 500 mg/L).

Harmony has run a groundwater quality monitoring programme in the Welkom area for many years. Limited water quality data (pH, Cl, and SO_4) is available for five boreholes to the north of the 10 Shaft assessment area and six borehole to the west of the assessment area (Figure 3).

Figure 3: Location of Harmony boreholes for which water quality data was available for this assessment.

There is significant variance in the data. However, pH is generally between 7 and 8, while sulphate is generally less than 200 mg/L (Figure 4). There appear to be no trends in the Cl data.

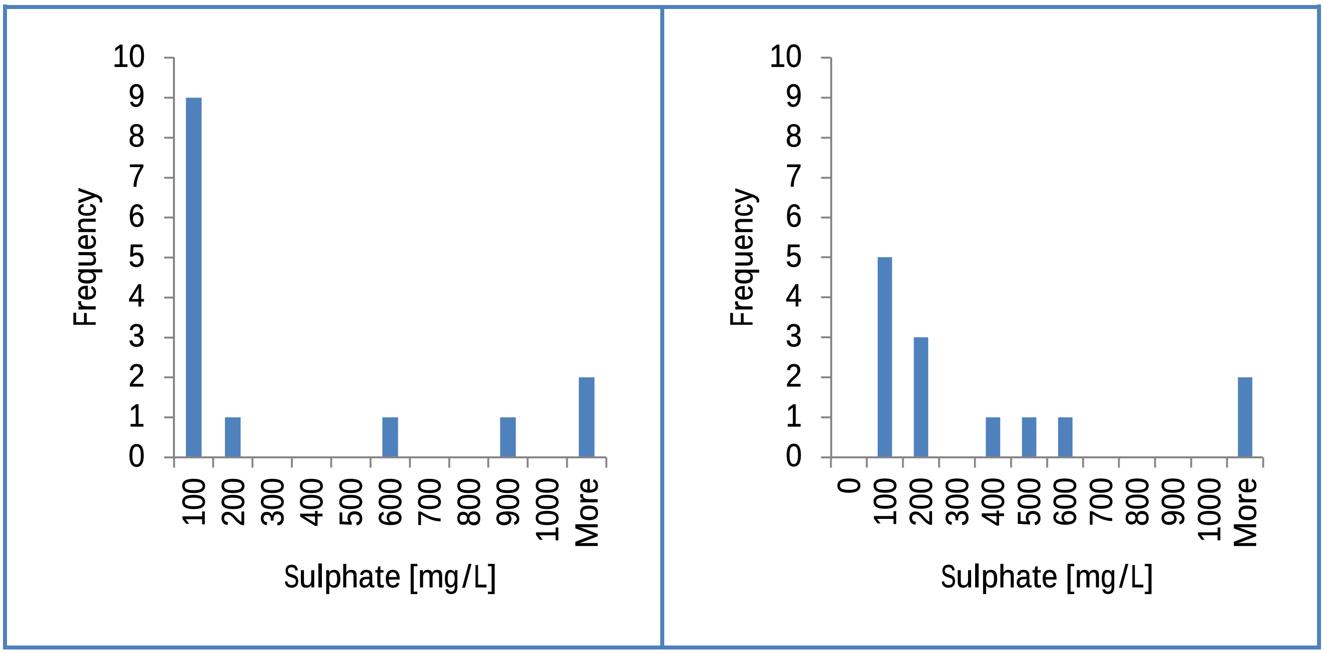

Figure 4: Histograms of SO_4 (sulphate) concentrations in Harmony monitoring boreholes west of (left) and north of (right) the 10 Shaft assessment area.

3.2.2 Aquifer classification

According to the National Aquifer Classification System of Parsons (1995), the Karoo aquifer in the St Helena 10 Shaft assessment area is described as a *Minor* aquifer system: “These can be fractured or potentially fractured rocks that do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are both important for local supplies and in supplying base flow for rivers”.

3.3 10 Shaft decommissioning

According to the Harmony Rehabilitation Action Plan (RAP) for the 10 Shaft decommissioning, the following actions will be conducted as part of the decommissioning process:

- Demolition of buildings and foundations using earthmoving equipment to break down infrastructure, brick, steel, and concrete structures up to but not exceeding 1m below ground level.
- Backfilling of 10 Shaft with inert waste material and slimes “suitable for rehabilitation” (the slimes will be neutralised through the addition of lime).
- Shaping of the surface topography to align with natural slopes and encourage free draining of surface water
- Placement of topsoil
- Revegetation of rehabilitated areas

4 RESULTS

This section presents the results of the groundwater assessment.

4.1 Hydrocensus

The hydrocensus was conducted on 15 and 16 May 2018. It consisted of measuring groundwater depth in four boreholes, collection of two groundwater samples, and collection of one waste rock sample.

4.1.1 Groundwater levels

Table 4 summarises the groundwater levels used in this assessment: a combination of levels measured in the hydrocensus and additional information provided from Harmony's groundwater monitoring programme. Borehole elevations were estimated from Google Earth for both hydrocensus and Harmony data to obtain a consistent datum to compare groundwater levels.

Table 4: Groundwater levels used in this study

Borehole ID	Measured GW level (mbgl)	Estimated GW elevation (mamsl)	Comment
STHH 11	no access	none	Hydrocensus data. Water sample collected
STHH 13	10.03	1 350	Hydrocensus data. Water sample collected
Target 2	8.10	1 338	Hydrocensus data.
STHH 9	3.32	1 348	Harmony data
BH 13	4.75	1 343	Hydrocensus data
BH 187	2.99	1 350	Hydrocensus data
STHH 10	3.09	1 348	Harmony data
STHH 12	4.04	1 340	Harmony data
STHH 17	4.26	1 337	Harmony data
STHH 21	7.23	1 350	Harmony data
STHH 23	1.93	1 348	Harmony data
STHH 6	10.15	1 316	Harmony data

The map in Figure 5 shows the distribution of measurements and inferred contours of groundwater elevations around the assessment area. No levels were obtained within the assessment area itself. The one operating borehole (STHH 11) could not be accessed for measurement due to the installed pump (although a groundwater sample was collected).

Figure 5 indicates the dominant groundwater flow direction is approximately west-northwest with a possible minor flow component to the south. The directions are consistent with the topography, although the inferred hydraulic gradients are generally flatter than the topographic gradients.

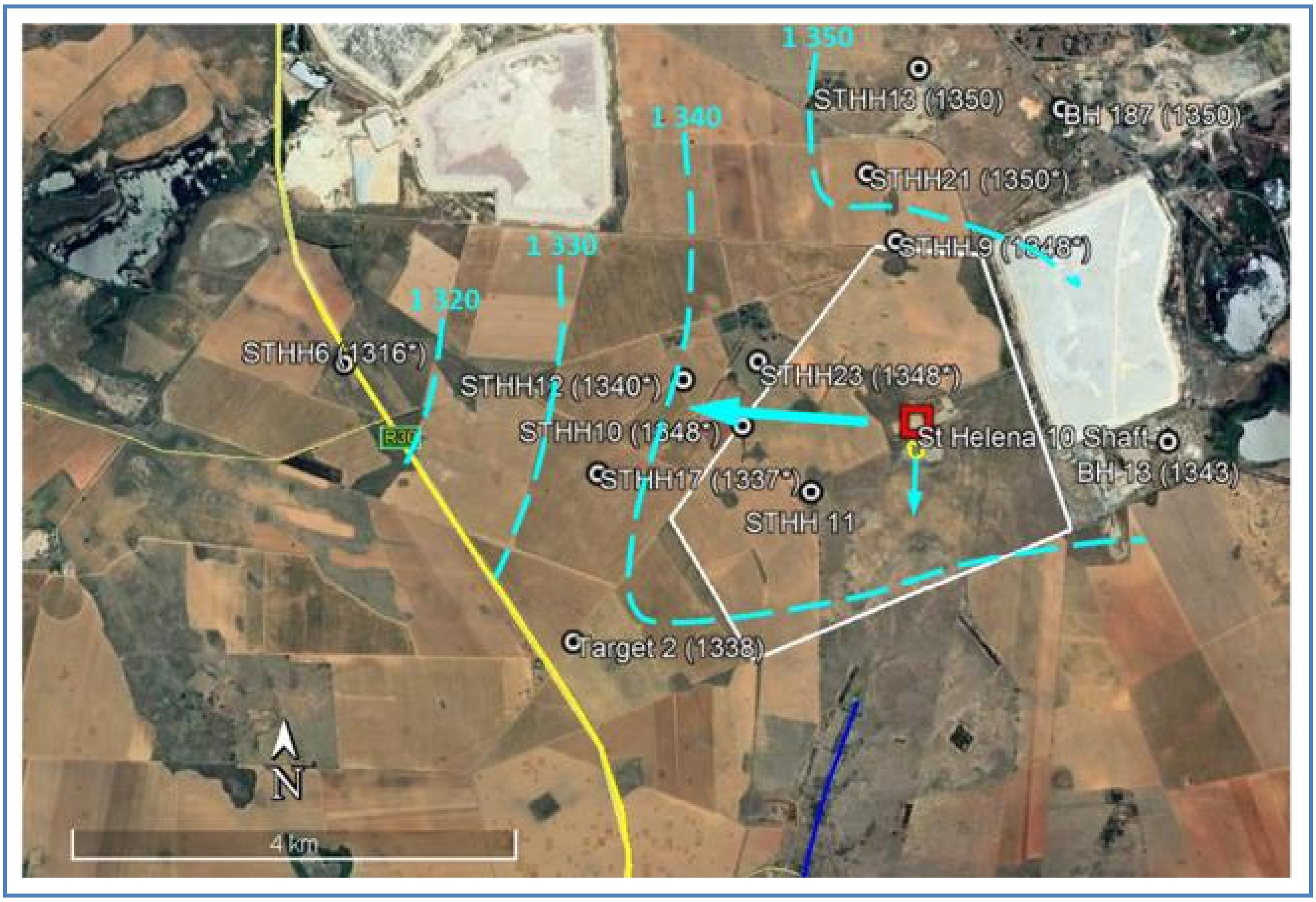

Figure 5: Inferred groundwater elevations at the St Helena 10 Shaft assessment area (turquoise arrows show inferred groundwater flow direction)

4.1.2 Groundwater quality

Based on the two samples analysed, groundwater in the St Helena 10 Shaft area is neutral and saline (Table 5). Nitrate in STHH11 exceeds health-based drinking water guideline for nitrate, presumably contaminated by seepage from the adjacent cattle kraal. Both samples exceed health-based guidelines for selenium (Se). Selenium is associated with fine-grained sediments, such as the Ecca Group rocks which form the shallow Karoo aquifer. It is also associated with pyrite, a common mineral in gold tailings such as the St Helena tailings dam immediately upgradient of the 10 Shaft site.

Table 5: Groundwater analysis results (copies of the laboratory reports are presented in Appendix A)

Aqueous component/ parameter	Units	STHH13	STHH11	SANS 241[A]
pH	pH units	7.9	7.5	
Total Dissolved Solids	mg/L	1 322	914	1 200
Total Alkalinity as $CaCO_3$	mg/L as $CaCO_3$	220	252	
Chloride (Cl)	mg/L	326	248	300
Sulphate (SO_4)	mg/L	358	61	500*
Fluoride (F)	mg/L	<0.2	0.4	1.5*
Nitrate (NO_3)	mg/L as N	0.2	15	11*
Ortho Phosphate (PO_4)	mg/L as P	<0.1	<0.1	
Free & Saline Ammonia (NH_3)	mg/L as N	1.1	0.7	1.5
Al	mg/L	<0.100	<0.100	0.3

Aqueous component/ parameter	Units	STHH13	STHH11	SANS 241[A]
As	mg/L	<0.010	<0.010	0.01*
B	mg/L	0.167	0.086	2.4*
Ba	mg/L	0.061	0.114	0.7*
Ca	mg/L	60	120	
Cd	mg/L	<0.010	<0.010	0.003*
Cr	mg/L	<0.010	<0.010	0.05*
Cu	mg/L	<0.010	<0.010	2*
Fe	mg/L	0.430	<0.025	2*
Hg	mg/L	<0.010	<0.010	0.006*
K	mg/L	32	10.5	
Mg	mg/L	87	49	
Mn	mg/L	0.193	<0.025	0.4*
Na	mg/L	194	70	200
Ni	mg/L	<0.010	0.035	0.07
Sb	mg/L	<0.010	<0.010	0.02*
Se	mg/L	0.076	0.059	0.04*
U	mg/L	<0.010	<0.010	0.03*
Zn	mg/L	0.258	1.30	5

Notes:
[A] South African National Standard 241 *Drinking water* (* signifies health-based guideline value)

The concentration of sulphate (SO_4) in the sample from borehole STHH 13 are higher than the background concentration of <200 mg/L (Section 3.2.1). This may indicate background contamination of groundwater at St Helena 10 Shaft by mining activities to the east, particularly the St Helena tailings dam on the east boundary of the assessment area.

Sulphate is a robust indicator of the dissolved load that enters groundwater from anthropogenic contaminant sources, especially where pyrite oxidation is significant. This is because sulphate is generally present in easily detectable concentrations in groundwater and is not significantly affected by geochemical processes under common aquifer conditions.

Sulphate is likely to be one of the least retarded contaminants in groundwater. Therefore, sulphate concentration downstream of a contaminant source is expected to be mainly a function of dilution and it is suitable as an early indicator of groundwater contamination. Other contaminants will have lower concentrations and are expected to travel more slowly in the aquifer.

4.1.3 Rock sample

The Acid-base accounting (ABA) results indicate that the sample from the 10 Shaft waste rock dump is not acid generating (copies of the laboratory reports are included in Appendix A).

The water extract results are discussed in Section 4.4.1 as part of the modelling of potential groundwater contamination from the WRD.

4.2 Conceptual model

Figure 6 presents a conceptual model of the groundwater environment in the St Helena 10 Shaft assessment area, based on the information review and hydrocensus results.

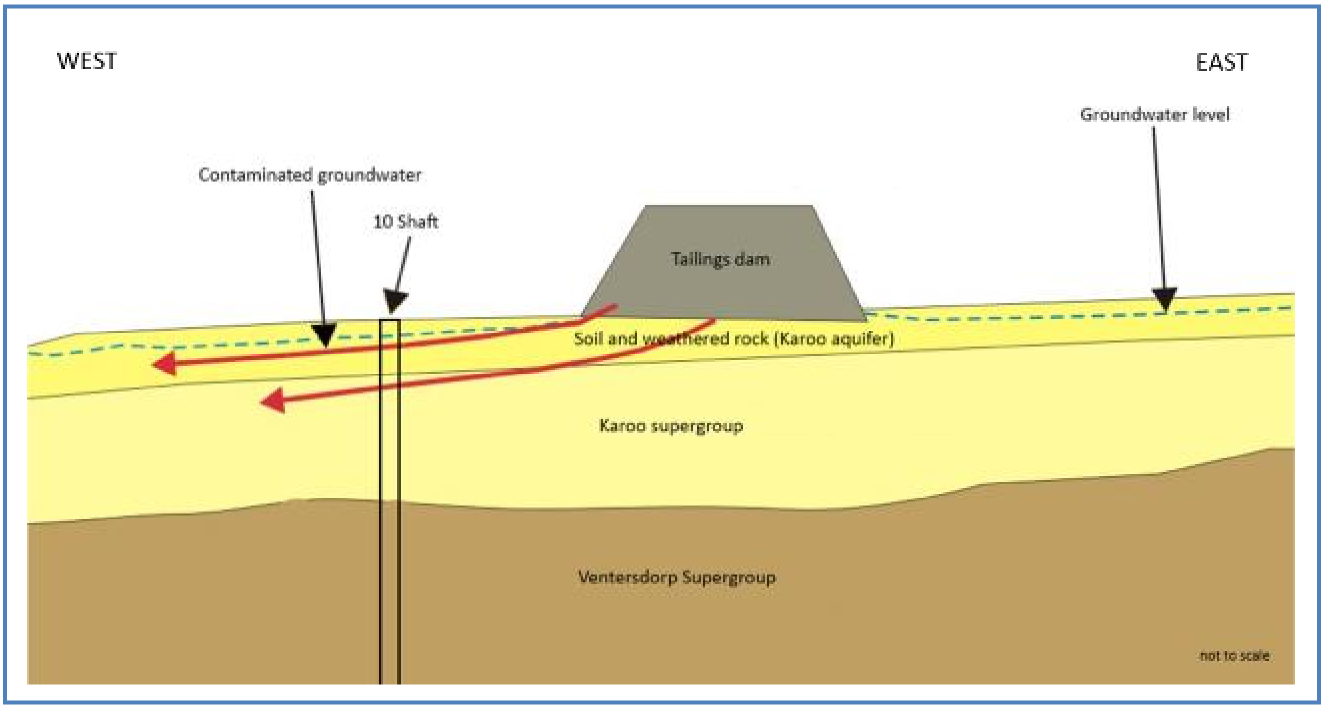

Figure 6: Conceptual model of the St Helena shaft groundwater system

Key features of the model include the following:

- The aquifer of interest consists of near-surface Karoo rocks (labelled as soil and weathered rock in Figure 6)
- The piezometric surface (groundwater table) is shallow (generally <10 m) in the assessment area
- The general direction (gradient) of groundwater flow is to the west
- The St Helena tailings dam east (that is, upgradient) of 10 Shaft is likely to be a significant source of shallow groundwater contamination.
- Groundwater contamination from decommissioning activities at 10 Shaft may include:
    - Spillages of liquid or solid waste from vehicles and machinery used in decommissioning
    - Seepage from the WRD
- The WRD has been (and continues to be) a large, near-constant source of seepage that started years before decommissioning. This is in contrast to spillages of liquid or solid waste, which are likely to have been infrequent, relatively small and of short duration. Therefore, WRD seepage is likely to be a conservative indicator of potential groundwater impacts.
- Any contamination from decommissioning activities at 10 Shaft is likely to be superimposed on the contamination from the upgradient tailings dam.

Numerical modelling of potential impacts from the 10 Shaft decommissioning activities is based on the above conceptual model.

4.3 Groundwater risk

Groundwater risks may be sub-divided into two categories:

- Risks to groundwater yield
- Risks to groundwater quality

The 10 Shaft rehabilitation activities do not include any activities that will result in significant changes to groundwater yield (such as groundwater abstraction, groundwater injection, or aquifer dewatering). Minor physical changes to the aquifer flow characteristics may occur in the form of changes in soil conditions due to compaction, importation of soil from other areas, and removal of buildings and paved areas. These may result in modest changes in rainfall infiltration and hence aquifer recharge. This is likely to be insignificant since the changes will occur over a limited surface area and, since groundwater recharge is generally less than 3% of mean annual rainfall, any changes in infiltration will be negligible.

The 10 Shaft RAP identifies the following significant risks to groundwater quality:

- Hydrocarbon spillages from vehicles and earthmoving machinery during the demolition, shaft backfilling, topographic shaping, topsoil placement, and revegetation processes. Spillages may result in soil contamination and subsequent leaching of contaminants to groundwater.
- Groundwater contamination from the slimes used to backfill the shaft. As the shaft fills with groundwater, contaminants may leach from the backfill and move with the local groundwater flow and possibly migrate offsite.

A further risk to groundwater quality not identified in the 10 Shaft RAP is seepage from the waste rock dump (WRD). As far as can be determined, the WRD is a legacy of original shaft development operations. Therefore, it has been present on the site for approximately 70 years. The WRD is likely to be removed as part of the site clearing and rehabilitation activities. However, the residual impact of 70 years of seepage on the underlying groundwater quality remains a risk associated with the 10 Shaft site. This risk is likely to significantly outweigh the risk of hydrocarbon spillages, since hydrocarbon contaminants will have lower concentrations and are expected to travel more slowly in the aquifer.

4.4 Numerical modelling

To assess the potential groundwater quality risk associated with decommissioning activities at St Helena 10 Shaft, Solution[H+] applied two numerical models:

- Geochemical modelling of WRD seepage quality was done using PHREEQC Interactive (PHREEQCI) version 3.1.6.9191 (20 January 2015). PHREEQCI is a computer program for performing low-temperature aqueous geochemical calculations, including speciation, saturation indices, batch reaction and 1-dimensional transport calculations. PHREEQCI can account for aqueous, mineral, gas, solid solution, surface complexation and ion exchange equilibria, as well as kinetic reactions (Parkhurst and Appelo 2013).
- The software code CONSIM (Contamination Impact on Groundwater: Simulation by Monte Carlo Method) was used to assess movement of groundwater contaminated by WRD seepage. CONSIM was developed on behalf of the UK Environment Agency to enable tiered risk assessments of impacts from surface contamination sources. Version 2.05.0004 was applied for this study. The model results were used to indicate potential contaminant travel times and concentrations at downstream receptors.

The following sections describe the development of each model and the results.

4.4.1 WRD drainage quality

As indicated in the conceptual model (Section 4.2), WRD seepage is likely to be a conservative indicator of potential groundwater impacts from decommissioning activities at 10 Shaft. Further, sulphate is a robust indicator of potential groundwater impact (Section 4.1.2). Therefore, this assessment develops an estimate of sulphate concentration in WRD seepage as a proxy for all decommissioning activities at 10 Shaft that may potentially contaminate groundwater.

4.4.1.1 Model approach

The waste rock dump (WRD) is conceptualised as a pile of coarse material, gravel size or larger, with few fines. Much of the rainfall on the WRD will infiltrate the porous surface; although evaporation in the upper zone will reduce the infiltration volume.

The composition of the laboratory water extractions on the ST H WRD sample is the starting point for estimating seepage quality from the WRD. Waste rock is non-PAG. Therefore, pyrite mineral oxidation processes are of minor significance to seepage quality and have not been considered in this assessment.

The water extractions were conducted at liquid to solid ratio (L/S) of 4/1. Based on field observations (Rohde and Williams 2009) and modelling studies (Noel and Ritchie 1999) drainage from waste rock occurs at moisture content (similar to L/S) of about 0.2. This is 20 times more concentrated than the water extraction.

Considering the above conceptualisation, geochemical modelling of WRD seepage involved the following general steps:

- Use the water extraction results as a starting solution
- Remove water to concentrate the solution 20-fold
- Equilibrate the concentrated solution with minerals that are likely to form under the *in situ* conditions

The resulting water quality is a conservative indicator of potential seepage quality from the WRD. “Conservative” because the laboratory water extraction measures the total flushing of soluble salts from the sample with an excess of water and does not measure the rate of long-term release of chemical elements from the sample.

4.4.1.2 Model inputs

Table 6 summarises the PHREEQC modelling inputs.

Table 6: PHREEQC model input parameters

Model input parameter	Value
Initial solution	Leach test results on sample St H WRD (4:1 liquid:solid ratio)
Thermodynamic database	phreeqc.dat
Equilibrium phases	CO2(g) Gibbsite Rhodochrosite

4.4.1.3 Assumptions and limitations

In the field, the waste rock will gradually be flushed by rainwater infiltration and the release of chemical elements will be constrained by many factors not accounted for in the laboratory analysis or the geochemical model. The following assumptions and limitations are relevant to the modelling of WRD drainage quality:

- Observed dynamics of water flow in mine waste rock piles indicates a rapid response between seepage volume and infiltrating rainfall. This is followed by a period of decreasing seepage flow. This suggests the presence of short flowpaths with a relatively high L/S; and longer flowpaths with a lower L/S. These can result in a broad range of WRD drainage quality.
- The St H WRD water extract composition is representative of interaction between infiltrating rainfall and rock in the St Helena WRD.
- Environmental water quality is influenced by the precipitation/dissolution of various minerals/gases. The geochemical model simulations included CO_2 (at atmospheric concentration) and gibbsite.
- Trace element concentrations are not significantly influenced by precipitation and dissolution of the pure mineral phases in the thermodynamic database. Therefore, they have not been included in the modelling.

Due to the inherent uncertainties of geochemical modelling, concentrations less than 0.1 mg/L have not been reported.

4.4.1.4 Model results

WRD drainage quality is modelled to have neutral pH (Table 7).

Table 7: Results of model simulation of WRD seepage quality

Aqueous component/ parameter	Description	Units	St H WRD	Model input	Input adjusted to achieve CBE <±10%	Model output (estimated WRD seepage)	SANS 241 (2015)[A]
pH	pH	pH unit	5.4	5.4	5.4	7.5	
Al	Aluminium	mg/L	0.176	0.176	0.176	<0.1	0.3
Alkalinity	Alkalinity	mg/L as $CaCO_3$	8	8	3.5	31	
Ca	Calcium	mg/L	<1	0.5	0.5	10	
Cl	Chloride	mg/L	<2	1	1	20	300
F	Fluoride	mg/L	<0.2	0.1	0.1	2	1.5*
Fe	Iron	mg/L	<0.025	0.0125	0.0125	0.25	2
K	Potassium	mg/L	1.6	1.6	1.6	32	
Mg	Magnesium	mg/L	<1	0.5	0.5	10	
Mn	Manganese	mg/L	0.071	0.071	0.071	1.4	0.4*
N(-3)	Ammonium	mg/L as N	1.3	1.3	1.3	5.6	1.5
N(5)	Nitrate	mg/L as N	<0.1	0.05	0.05	<0.1	11*
Na	Sodium	mg/L	1	1	1	20	
P	Phosphate	mg/L as P	<0.1	0.05	0.05	1	
S(6)	Sulphate	mg/L	7	7	7	92	500*
TDS[B]	Total Dissolved	mg/L	18	18	15	213	1200

Aqueous component/ parameter	Description	Units	St H WRD	Model input	Input adjusted to achieve CBE <±10%	Model output (estimated WRD seepage)	SANS 241 (2015)[A]
	Solids						
CBE	Charge Balance Error	%		-16	2.3	3.6	

Notes:
[A] South African National Standard 241 *Drinking water* (* signifies health-based guideline value)
[B] Calculated

Comparison of the model results with the SANS (241) 2015 standard suggest that concentrations of fluoride and manganese in WRD seepage may be a risk to groundwater quality. However, as discussed in Section 4.1.2 sulphate is likely to travel faster and further in groundwater than any other contaminant. Therefore, modelling of the groundwater quality risk in this assessment uses sulphate concentration as a “worst case” proxy for other groundwater contaminants. Based on the model results, the concentration of sulphate in WRD seepage is approximately 92 mg/L. Considering the assumptions, limitations, and uncertainties associated with the modelling, sulphate concentration in WRD seepage is estimated to range from 50 mg/L to 150 mg/L.

4.4.2 Mass transport in groundwater

Once released from a source, contaminants may enter the groundwater and move in the direction of groundwater flow. This process was simulated using the CONSIM software.

4.4.2.1 Model approach

CONSIM is a source-pathway-receptor model. A potential risk may be realised if there is an unbroken path from contamination source to receptor. Figure 7 shows a plan view of the CONSIM model domain which indicates two sources:

- The St Helena tailings dam to the east of the 10 Shaft assessment area
- The St Helena 10 Shaft WRD

Both sources are assumed to have been placed 70 years ago, leaving a legacy of groundwater contamination that should be apparent in the chemistry of boreholes downgradient (“downstream”) of these sources.

Note that the St Helena 10 Shaft itself has not been identified as a source for the following reasons:

- Aquifer dewatering in the vicinity of the shaft will have prevented it from being a source of groundwater contamination during operations. This is because dewatering will direct groundwater flow towards, rather than away, from the shaft.
- The current groundwater level in the shaft is not known. However, recovery of the groundwater level is expected to take several years. Recovery may be further delayed if dewatering is continued at neighbouring mines with active underground operations. Therefore, it is likely that groundwater flow is still towards, rather than away, from the shaft.

- The rehabilitation plan indicates the shaft will be backfilled with inert (that is, chemically inert) waste material and slimes “suitable for rehabilitation” (the slimes will be neutralised through the addition of lime). Therefore, once groundwater levels have recovered and flow is away from the shaft, the potential for groundwater contamination from the backfill will be low.

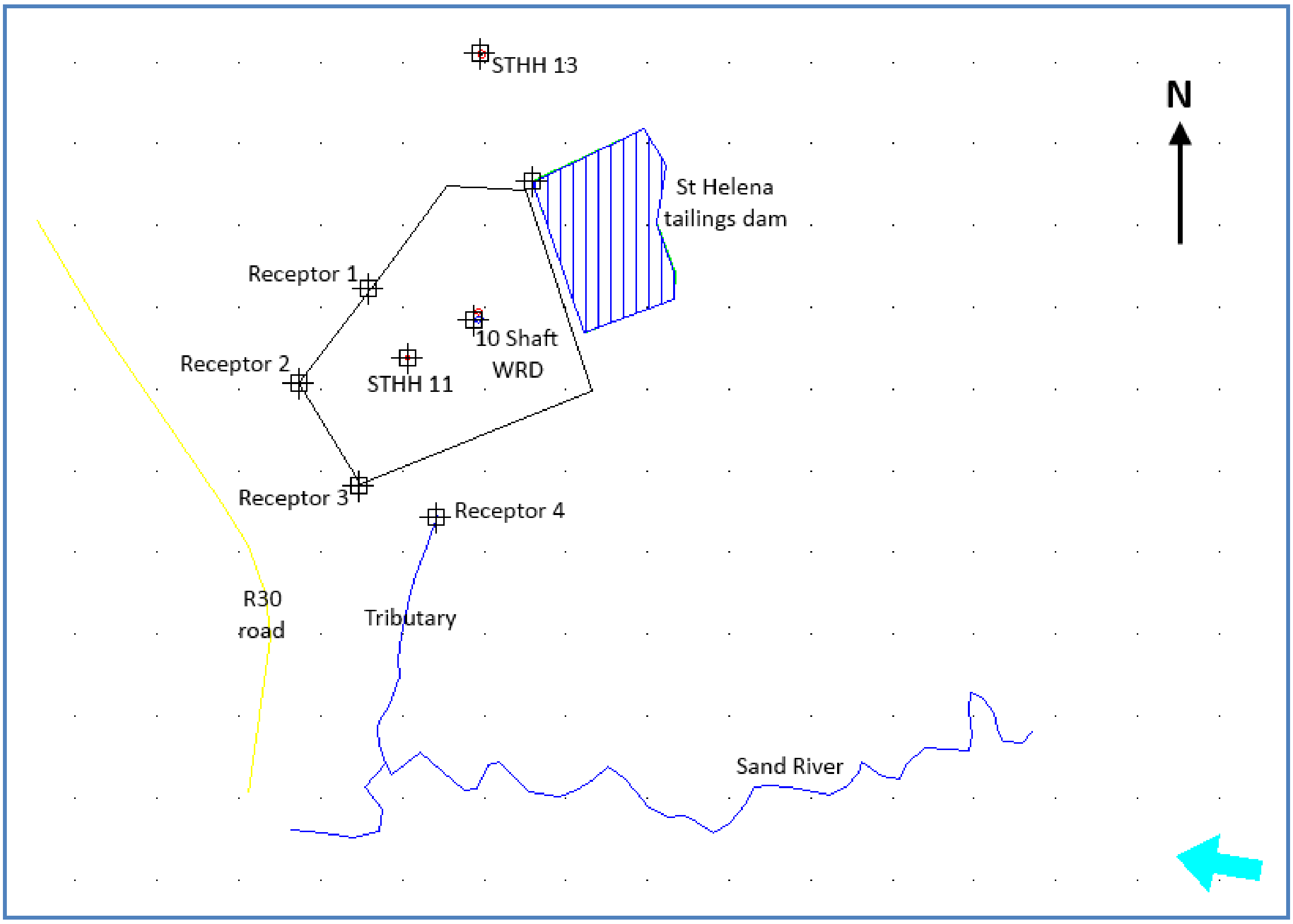

Figure 7: Plan view of the numerical transport model domain (grid points are 1 000 m apart, turquoise arrow shows groundwater flow direction)

CONSIM assumes a single-layer aquifer with uniform hydraulic gradient underlies the model domain. This is a simplification of reality. However, the model accounts for uncertainty by applying the Monte Carlo technique as follows:

- Ranges of parameters can be specified, including probability distributions for those parameters.
- A CONSIM “trial” consists of a series of simulations (typically 100 or more).
- During each simulation the value of each parameter is selected from the specified range using the specified probability distribution. Therefore, each simulation in a CONSIM run has a unique set of input parameters and a unique set of outputs.

The model allows definition of several “receptors”, that is, real or assumed boreholes where modelled impacts on groundwater quality from the sources can be observed (Figure 7).

At the end of each trial, CONSIM reports on the distribution of model outputs. For groundwater, this is typically the range of modelled contaminant concentrations at each specified receptor. CONSIM does not report actual concentrations at the receptor; it reports the distribution of concentrations, a synthesis of the results of multiple simulations. This is indicated as percentile values at 95, 90, 75, 50, 25, 10, and 5.

4.4.2.2 Model inputs

Table 8 summarises key CONSIM model input parameters.

Table 8: CONSIM model inputs

Model element	Item	Model input parameter	Unit	Value	Description/information source	Range
Source	St Helena WRD	Sulphate concentration	mg/L	92	As geochemically modelled (Section 4.4.1 of this report)	50 – 250
		Seepage rate	mm/yr	80	20% of annual rainfall	40 – 120
	St Helena tailings dam	Sulphate concentration	mg/L	1 500	Estimated from experience	1 000 – 2 000
		Seepage rate	mm/yr	40	Estimated from experience	20 – 80
Pathway	Aquifer	Thickness	m	35	From background geology	10 – 80
		Hydraulic conductivity	m/s	2.5×10^{-6}	General for fractured siltstone	2.5×10^{-7} – 2.5×10^{-5}
		Effective porosity	%	3	General for Karoo rocks	1 – 5
		Hydraulic gradient	m/m	0.01	From hydrocensus	0.008 – 0.012
		Groundwater flow direction	°	270	From hydrocensus	
		Longitudinal dispersivity	m	100	General 1/10th of path length	30 – 300
		Lateral dispersivity	m	10	10% of longitudinal dispersivity	3 – 30

4.4.2.3 Assumptions and limitations

Summarised in the following points:

- Initial model parameters were selected from the information review and modified as required during model validation to obtain the input values indicated in Table 8. The parameter ranges in Table 8 were then applied during the impact modelling to account for parameter variation and uncertainty. The ranges were applied as triangular distributions.
- The model represents the aquifer as a single-layer, which may oversimplify reality. However, this is offset by the use of a range of potential aquifer parameters. The combined behaviour of two or three aquifers can often be reasonably simulated by a single aquifer with average parameters. The Karoo aquifer is generally consistent over a wide geographic area of South Africa. Therefore, the single-layer simplification is considered reasonable.
- The groundwater flow direction is fixed for each CONSIM trial. Therefore, the combined impact of the westward and inferred southward component of groundwater flow (see Section 4.1.1) has not been considered. However, a separate trial was run considering southward flow at a flatter gradient as an indicator of “worst case” impact.
- Groundwater gradient is considered uniform across the entire model domain.

4.4.2.4 Model results

The model provided three sets of results:

- Evaluation of model credibility
- Evaluation of current groundwater quality impact
- Evaluation of future situation

These are discussed separately below

4.4.2.4.1 Model credibility

A model is considered "useful" if it can reproduce observed results. Solution[H+] evaluated the model's ability to reproduce the measured sulphate concentrations in groundwater samples from boreholes STHH 11, STHH 12, and STHH 15 under the assumption that the St Helena tailings dam and 10 Shaft WRD are the only sources of dissolved sulphate.

As indicated in the evaluation of groundwater risk factors (Section 4.3), the St Helena tailings dam and the 10 shaft WRD sources have been active since St Helena mine was established in the 1940s, a period of approximately 70 years. Therefore, the initial model input parameters were modified until a general correspondence was obtained between the measured sulphate concentrations and the modelled sulphate concentrations at 70 years (Figure 8).

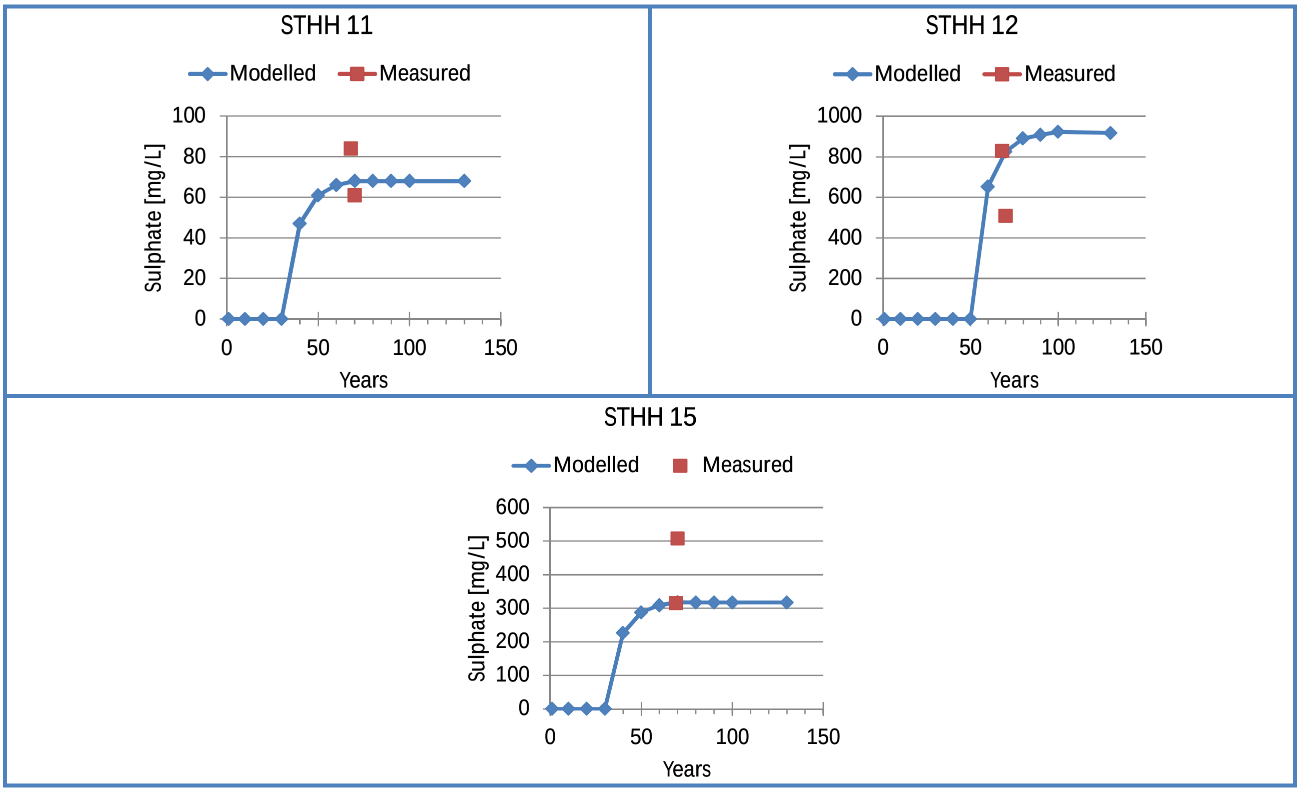

Figure 8: Reproduction of measured sulphate concentrations by the CONSIM model for selected boreholes. Year 70 is the year of this report (2018).

The correspondence between measured and modelled results is considered approximate as the sulphate concentration data from boreholes STHH 11, STHH 12, and STHH 15 is limited and the measured values from the same boreholes are not consistent. However, the approximate correspondence suggests there is a general level of agreement with current reality. Therefore, the model is assumed to provide a credible indicator of future groundwater sulphate concentration downstream of the St Helena tailings dam and 10 Shaft WRD.

4.4.2.4.2 Current impact

Figure 9 shows the approximate extent of the modelled plume of contaminated groundwater from the 10 Shaft WRD after a simulation period of 70 years, that is, an indicator of current impact. The offsite impact (that is, outside of the 10 Shaft assessment area) appears to be of the order of 1 mg/L or less. Note that the plume from the St Helena tailings dam has been excluded from Figure 9 for clarity, since it dominates the impact on local groundwater quality, as shown in Figure 10, which includes both sources.

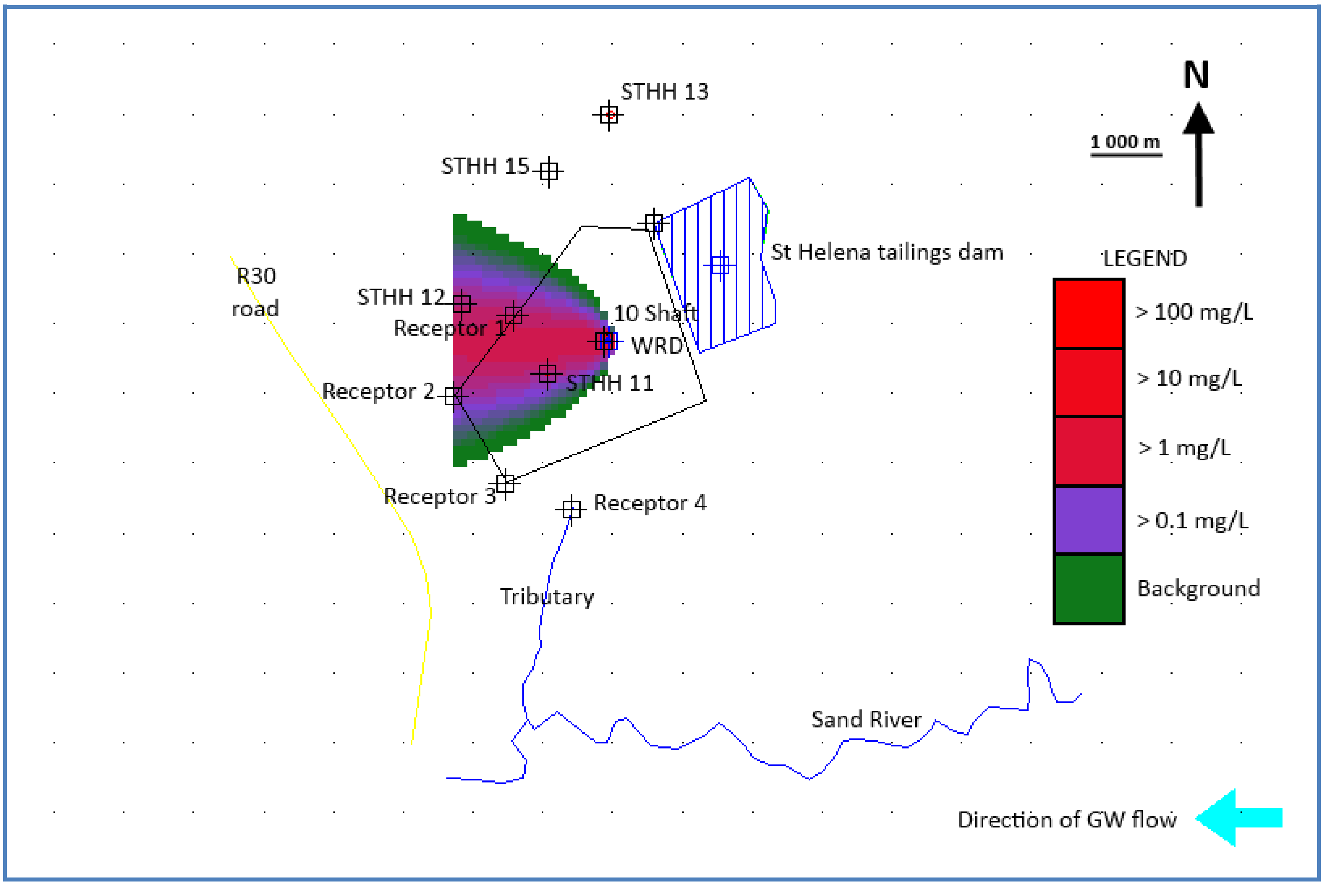

Figure 9: Modelled extent of sulphate concentrations in groundwater from the St Helena 10 Shaft WRD up to 2018

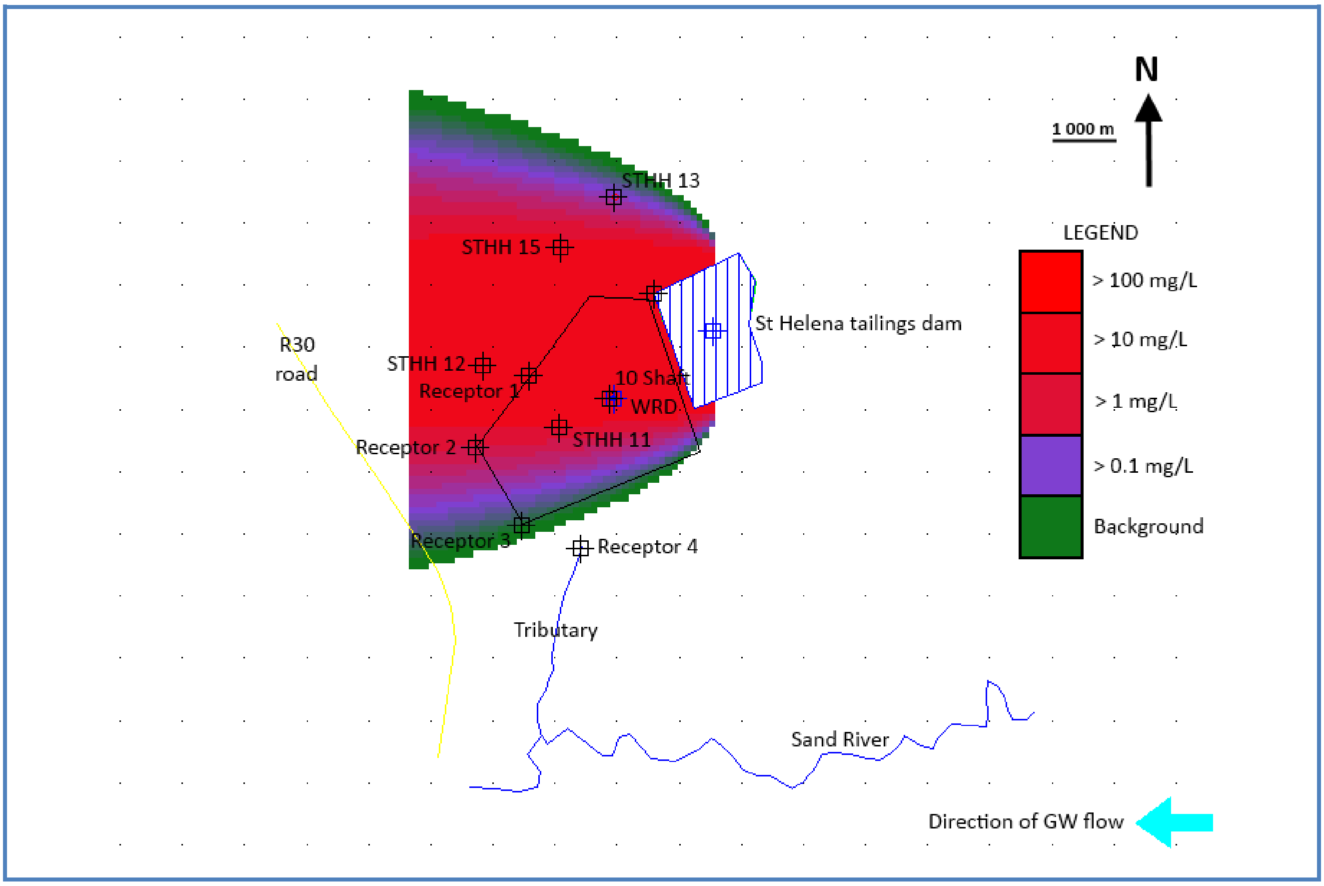

Figure 10: Modelled extent of sulphate concentrations in groundwater from the St Helena 10 Shaft WRD and St Helena tailings dam up to 2018

Figure 10 shows that the groundwater quality impact from the St Helena tailings dam obscures the relatively smaller impact from the 10 Shaft WRD. Model results show that the relative contribution of the WRD to groundwater sulphate concentration at STHH 11, STHH 12, and Receptor 1 is significantly less than 1%. The modelled 90 percentile groundwater sulphate concentration downstream of the 10 Shaft WRD is less than 1 mg/L (Figure 11). Stated differently, 90% of simulated sulphate concentrations originating from the WRD are less than 1 mg/L. This suggests that the impact of the WRD alone on groundwater outside the 10 Shaft assessment area is likely to be indistinguishable from background groundwater sulphate concentration.

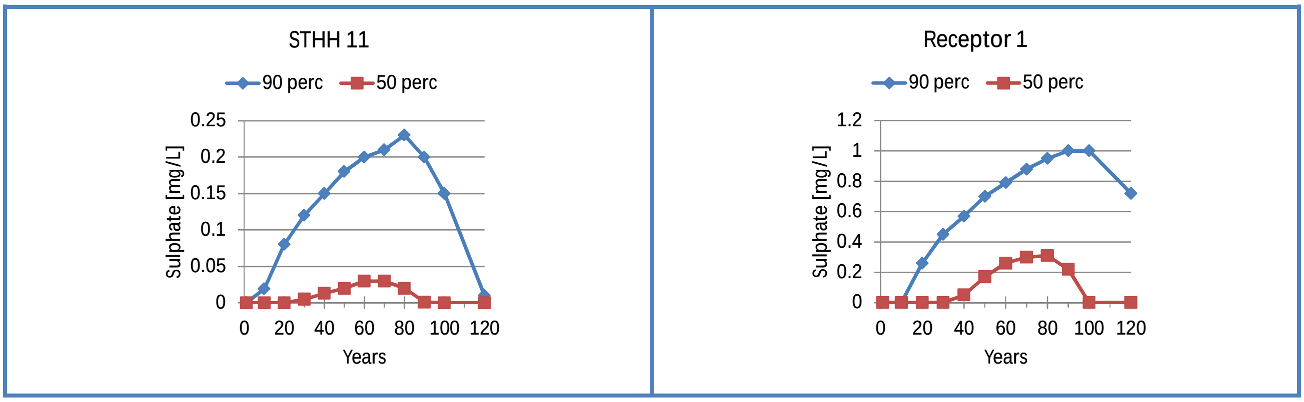

Figure 11: Modelled distribution of offsite impact of the 10 Shaft WRD alone on groundwater sulphate concentration at selected receptors. Year 70 is the year of this report (2018).

4.4.2.4.3 Future impact

Effectively, the 10 Shaft WRD source will be "switched off" as part of the decommissioning. Assuming this happens around 2018, Figure 12 shows the residual groundwater quality impact after 50 years.

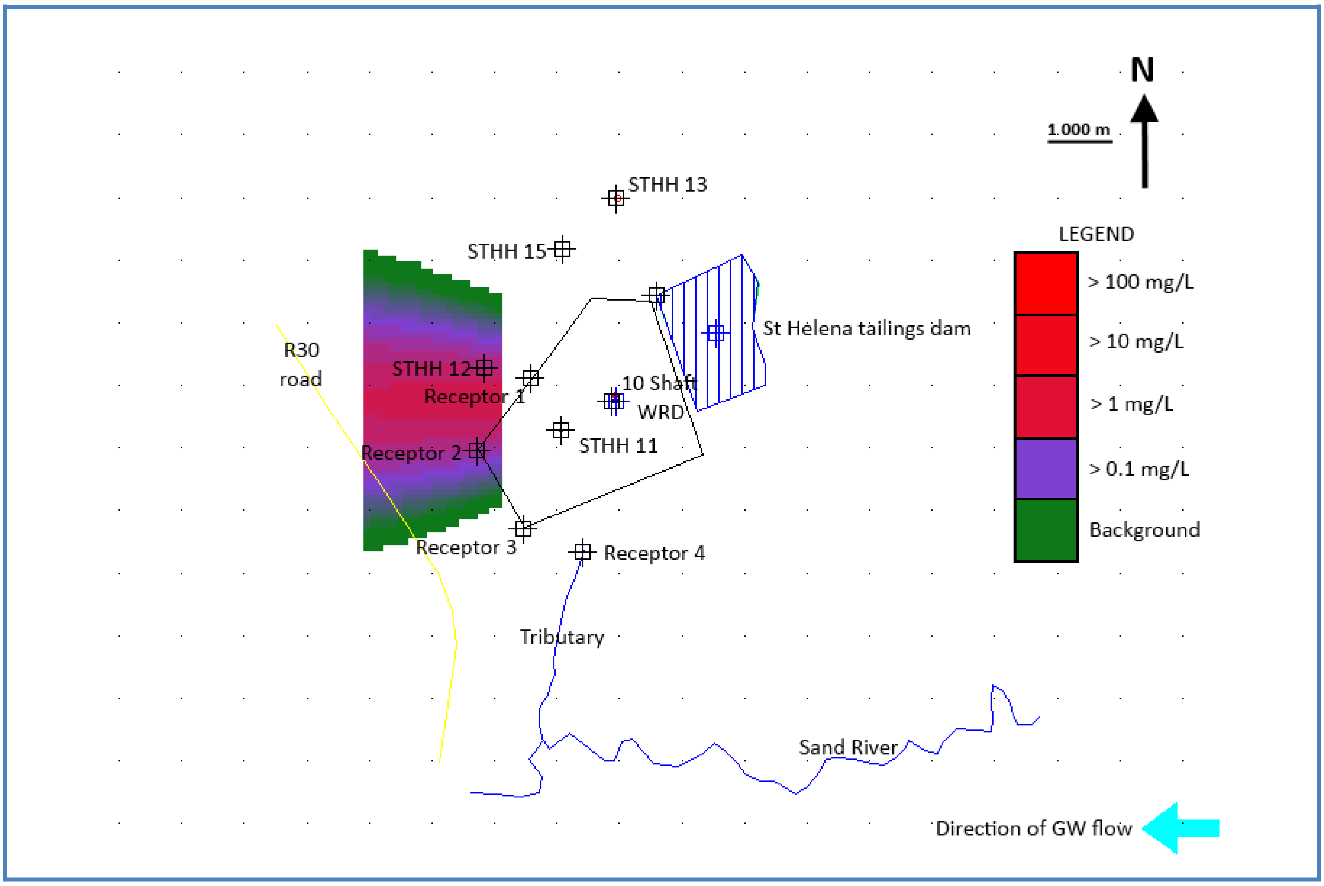

Figure 12: Modelled extent of sulphate concentrations in groundwater from the St Helena 10 Shaft WRD up to 2068

The sulphate mass from the WRD in the groundwater continues to move westward, but the plume is no longer connected to the source. In fact, groundwater in the aquifer between the source and the east side of the plume has been replaced by groundwater from upgradient (that is, from the east).

While Figure 12 suggests the existence of a body of sulphate-contaminated groundwater west of the assessment area, in reality, it will be indistinguishable from the greater impact of the St Helena tailings dam (Figure 13).

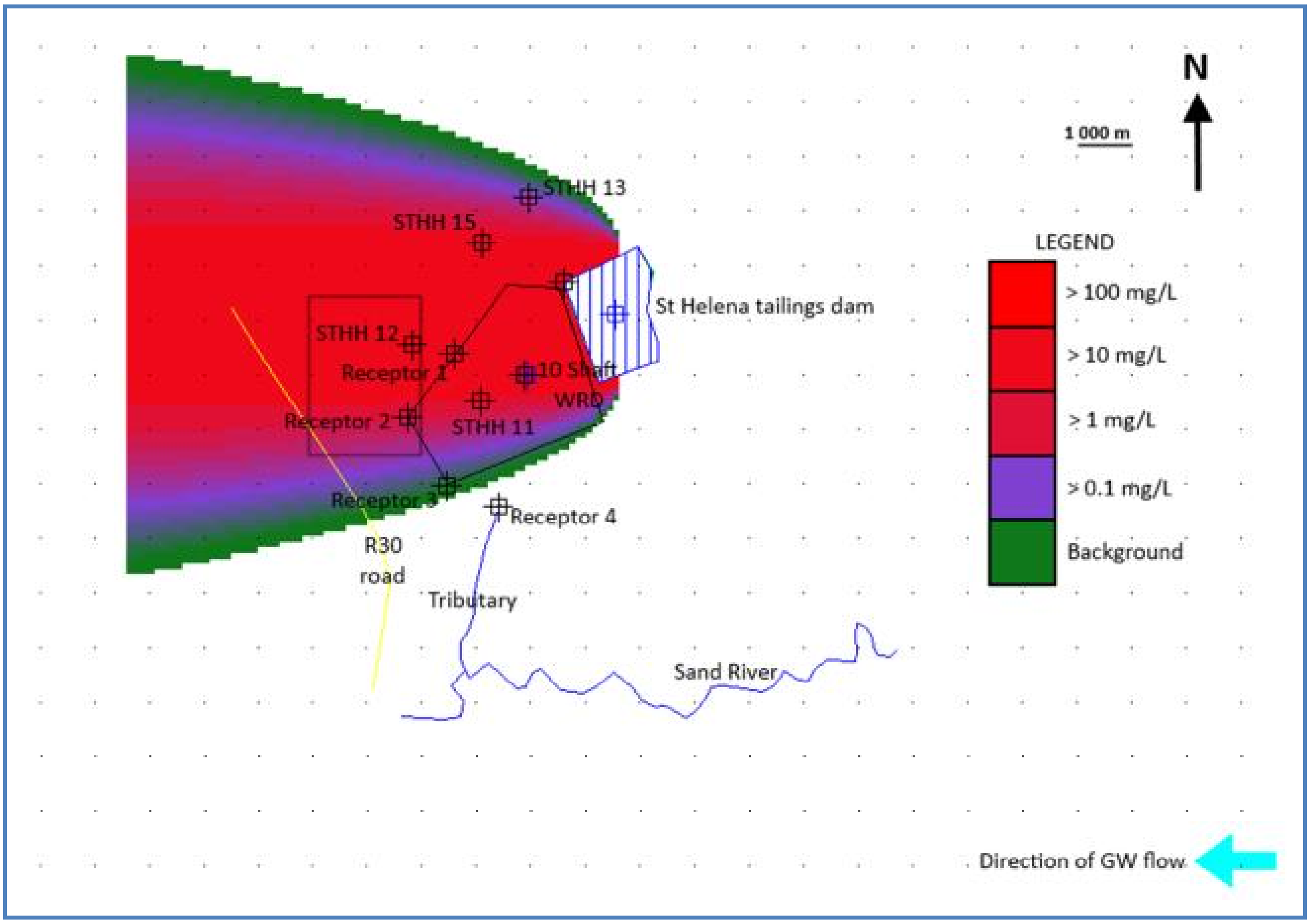

Figure 13: Modelled extent of sulphate concentrations in groundwater from the St Helena 10 Shaft WRD and St Helena tailings dam together up to 2068 (Black rectangle shows approximate location of WRD-impacted groundwater, which is indistinguishable in the greater impact from the tailings dam)

The modelled sulphate concentration from the 10 Shaft WRD alone outside of the assessment area is less than 1 mg/L (Figure 14).

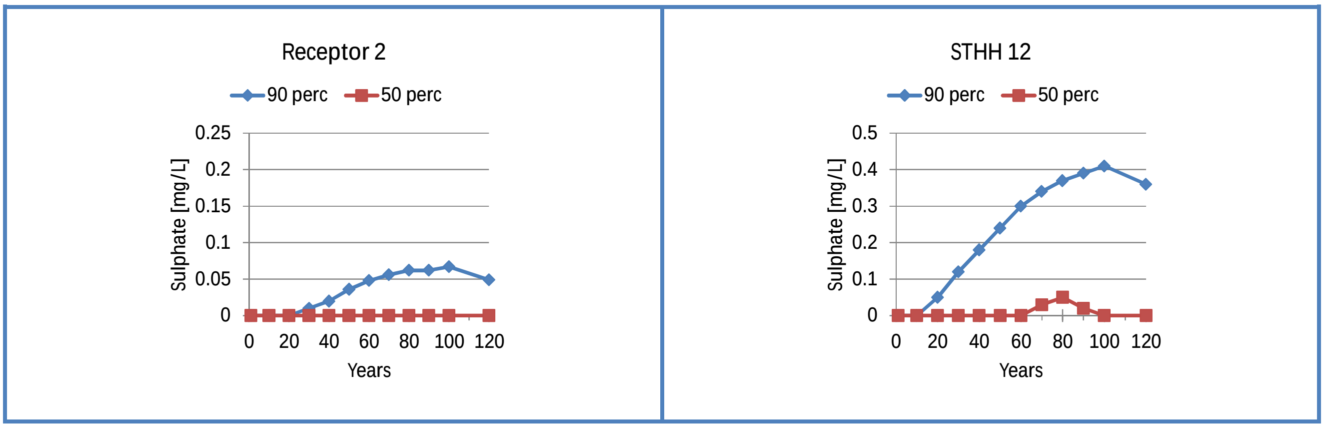

Figure 14: Modelled distribution of sulphate concentrations in groundwater from the St Helena 10 Shaft WRD alone up to 120 years after placement (2068).Year 70 is the year of this report (2018).

The potential impact of the inferred southward component of groundwater flow was assessed in a separate CONSIM trial. The modelled 90 percentile of sulphate concentration attributed to the WRD at the Sand River tributary (Receptor 4) is less than 5 mg/L 50 years from the present (Figure 15).

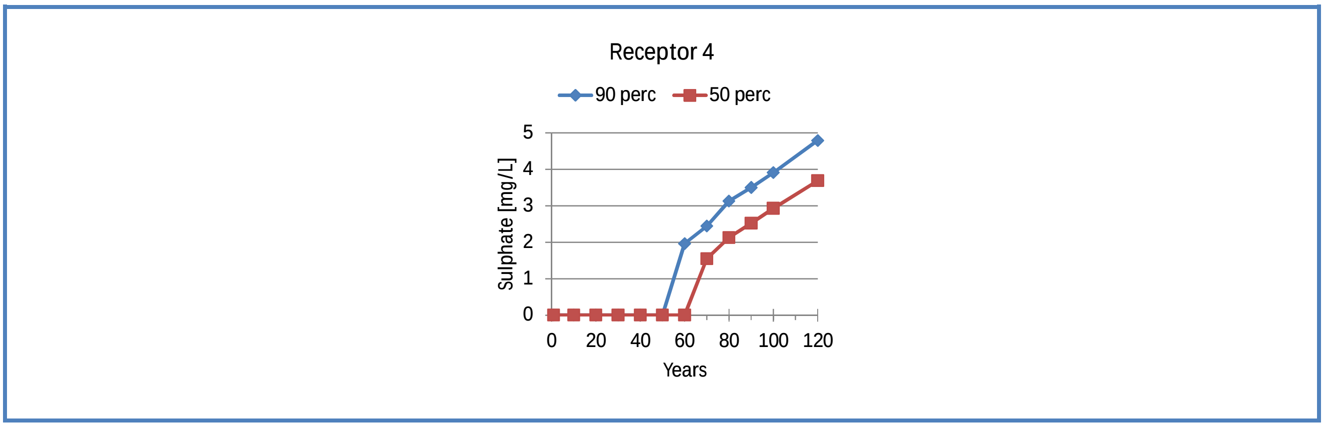

Figure 15: Modelled extent of groundwater impact from the St Helena 10 Shaft WRD up to 2068 assuming southward groundwater flow. Year 70 is the year of this report (2018).

5 IMPACT ASSESSMENT

The impact assessment methodology is described in detail in Appendix . Table 9 presents the results of the groundwater impact assessment.

Table 9: Groundwater impact assessment results of the 10 Shaft decommissioning.

Impact	Mitigation	Nature	Extent	Duration	Magnitude	Reversibility	Consequence	Probability	Environmental Risk	Significance class	Public response	Cumulative impact	Loss of resources	Priority score	Prioritisation factor	Overall Significance	Environmental Significance rating
Groundwater levels	Pre	-1	2	2	1	1	-1.5	2	-3	Low							
	Post	-1	2	2	1	1	-1.5	2	-3	Low	1	1	1	3	1	-3	Low
Groundwater quality	Pre	-1	2	4	1	5	-3	1	-3	Low							
	Post	-1	2	4	1	5	-3	1	-3	Low	1	1	1	3	1	-3	Low

As discussed in Section 4.3, no significant impacts on groundwater levels are expected from the decommissioning activities. Therefore, the assessed significance class of the impact is low, no mitigations are required, and the impact with mitigation remains low (Table 9).

Regarding groundwater quality, the long-term impact of the 10 Shaft WRD has been modelled under the assumption that it is a conservative proxy for potentially groundwater contaminating activities associated with the 10 Shaft decommissioning, including hydrocarbon spillages and seepage from the WRD.

The model results have indicated that the current groundwater impact from the WRD is indistinguishable from background groundwater quality, which is extensively contaminated by the St Helena tailings dam. Further, removing the WRD source, one outcome of shaft decommissioning activities, results in a low level (as indicated from the modelled distribution of sulphate concentrations) of offsite groundwater impact. This is true for both the inferred groundwater flow directions: west and south.

The above model results are assumed to hold valid for hydrocarbon spillages, as these are expected to be:

- Low volume because there will be little vehicle and machinery maintenance on the site and the maximum spillage from a single vehicle/machine is likely to be significantly less than, say 20 L.
- Short duration because spillages will no longer occur after the decommissioning is complete and residual soil contamination with hydrocarbons is assumed to biodegrade before significant leaching to groundwater.

Therefore, the post-decommissioning distribution of the sulphate contamination from the WRD is indicative of the potential distribution of hydrocarbon-contaminated groundwater (refer back to Figure 12). In fact, hydrocarbons are significantly retarded in groundwater due to biodegradation and physical impedance in the aquifer. Therefore, the modelled sulphate distribution in Figure 12 probably overestimates the potential distribution of hydrocarbons.

Therefore, the impact on groundwater quality is low, and mitigation is not required. However, in the decommissioning RAP, Harmony indicates the risk of hydrocarbon spillages will be managed by the following:

- Spill kits will be placed on site
- Spill kits will be used immediately when there is a spill on site
- The contaminated soil will be properly handled and placed in hazardous waste skips
- The contaminated soil will be sent to a licenced hazardous waste disposal facility
- Drip trays will be used to capture hydrocarbon spillages during on-site repairs of machinery

In addition, the RAP indicates that the Department of Water and Sanitation (DWS) have reached an agreement with Harmony regarding the following measures to manage groundwater contamination from shaft backfilling:

- Backfilling of St Helena 10 shaft with tailings will stop at a safe level below the Karoo aquifer to prevent slimes leachate from contaminating groundwater in the aquifer.
- The slimes will be neutralised with lime and mixed with a thickener and binding agent. This will solidify the material, prevent free flowing of slime underground, and reduce leaching of the slimes by groundwater.
- Continuous monitoring of groundwater 10 years post closure in existing Harmony monitoring boreholes.

The 10 Shaft RAP (Harmony 2016) includes the following instruction from DWS to monitor groundwater:

> "…implement a groundwater monitoring plan around the areas of impact to detect any impact or deterioration of the quality of the water resource. The mine must first determine the groundwater baseline quality and conduct quarterly monitoring. The results thereof must be submitted to [DWS]"

The effect of these mitigations will be to lower the already low assessed impact on groundwater quality.

6 CONCLUSIONS

As indicated in Section 1.3, this groundwater assessment has the following objectives:

- Establish baseline groundwater conditions at the site
- Identify potential groundwater impacts due to decommissioning activities
- Recommend actions to mitigate significant groundwater impacts

The following sections summarise key conclusions associated with each of the above objectives.

6.1 Baseline groundwater conditions

- The aquifer of concern is the weathered and fractured Karoo aquifer.
- Baseline groundwater levels are generally less than 10 m below surface.
- Groundwater levels generally mimic the topography.
- Groundwater flow from the 10 Shaft assessment area is generally to the west (similar to topography), with an inferred component of flow to the south that is relatively minor (that is, lower gradient and lower groundwater flow velocity).
- The southward flow component is associated with a tributary of the Sand River that starts south of the assessment area and extends southwards.
- Baseline groundwater has less than 200 mg/L sulphate, although the available background water quality data is limited and no consistent trends could be identified.

6.2 Potential groundwater impacts

The following groundwater quality risks were identified:

- Hydrocarbon spillages from vehicles and earthmoving machinery during the demolition, shaft backfilling, topographic shaping, topsoil placement, and revegetation processes. Spillages may result in soil contamination and subsequent leaching of contaminants to groundwater.
- Seepage from the waste rock dump (WRD). The WRD is a legacy of original shaft development operations and has been present on the site for approximately 70 years. The residual impact of 70 years of seepage on the underlying groundwater quality remains a groundwater risk associated with the site.
- The WRD risk is likely to significantly outweigh the risk of hydrocarbon spillages, since hydrocarbon contaminants will have lower concentrations and are expected to travel more slowly in the aquifer.

Numerical modelling was conducted to assess the magnitude, extent, and duration of groundwater quality impacts. This involved geochemical and hydrogeological modelling. The models were based on conceptual models of the WRD and Karoo aquifer developed from professional experience, available information, and the results of a limited hydrocensus conducted at the site.

The numerical modelling results suggest that current and future impacts on groundwater quality at 10 Shaft are indistinguishable from the elevated background resulting from ongoing contamination from the St Helena tailings dam. Even if the St Helena tailings dam were not present, model results suggest that the offsite impact from the 10 Shaft WRD (and by assumption, hydrocarbon-contaminated soil) is likely to be undetectable.

6.3 Mitigations

The impact assessment methodology indicated that the 10 Shaft decommissioning activities would have “low” category impacts on groundwater levels and quality. Therefore, no mitigation is required. However, The RAP for the decommissioning commits Harmony to several mitigation measures to manage potential groundwater quality impacts, including groundwater monitoring. A groundwater monitoring programme is recommended in the next section of this report.

7 RECOMMENDATIONS

Solution[H+] recommends the following groundwater monitoring plan for the 10 Shaft site:

- Harmony should commission an experienced hydrogeologist (who is registered with the South African National Council for Natural Scientific Professions) to site, drill, and install three (3) monitoring boreholes in the 10 Shaft assessment area. General locations for these boreholes are:
  - one borehole upstream (east) of 10 Shaft, and
  - two boreholes downstream (west and south) of 10 Shaft.
- The boreholes should be sited by an experienced hydrogeologist using aerial imagery and a site geophysical survey to increase the probability of obtaining useful groundwater intersections in the aquifer.
- The boreholes should be drilled to a depth of at least 35 m, although final depths should be decided by the appointed hydrogeologist.
- The boreholes should be screened, constructed, and equipped as long-term monitoring boreholes.
- The new boreholes should be added to Harmony's routine groundwater monitoring programme.
- The three new boreholes and the existing borehole STHH 11 should be monitored as follows:
  - Quarterly measurement of groundwater levels
  - Quarterly measurement of groundwater quality
- Groundwater samples should be collected using the procedure of Weaver et al (1996), including purging prior to sampling, field measurement of alkalinity, field filtering and preservation of a sample for metals analysis, and collection of an undisturbed sample for hydrocarbon analysis.
- Groundwater samples should be analysed for the following:
  - Analytes as indicated in the RAP: pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Sulphate (SO_4) and Chloride (Cl)
  - Major anions: Fluoride (F), Nitrate (NO3)
  - Major cations: Sodium (Na), Potassium (K), Calcium (Ca), Magnesium (Mg)
  - Trace elements of environmental concern:
  - Hydrocarbons: Petroleum range organics (C4-C10), Diesel range organics (C10-C40), Volatile organic hydrocarbons (Benzene, Toluene, Ethylbenzene, Xylene)
- The groundwater montiroing results should be periodically evaluated by an experienced hydrogeologist (who is registered with the South African National Council for Natural Scientific Professions) to provide an opinion on the status of groundwater at the site and the need for further monitoring.

Terry Harck (Pr.Sci.Nat 400088/95)

Hydrogeochemist

8 REFERENCES

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Appendix A: Laboratory reports

WATERLAB

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sanas Testing Laboratory T0391

CERTIFICATE OF ANALYSES
GENERAL WATER QUALITY PARAMETERS

Date received: 2018 - 05 - 17		**Date completed:** 2018 - 05 – 30
Project number: 1000	**Report number: 74569**	**Order number: PMM18-301**
Client name: Solution H+		**Contact person: Mr. T. Harck**
Address: P.O Box 39546 Moreleta Park 0044		**e-mail:** terry.harck@solutionhplus.com
Telephone: 083 521 3711	**Facsimile:**	**Mobile: 083 521 3711**

Analyses in mg/ℓ (Unless specified otherwise)	**Method Identification**	**Sample Identification**	
		STHH13	**STHH11**
Sample Number		30547	30548
pH – Value at 25°C *	WLAB065	7.9	7.5
Electrical Conductivity in mS/m at 25°C	WLAB002	201	137
Total Dissolved Solids at 180°C *	WLAB003	1 322	914
Total Alkalinity as $CaCO_3$	WLAB007	220	252
Chloride as Cl	WLAB046	326	248
Sulphate as SO_4	WLAB046	358	61
Fluoride as F	WLAB014	<0.2	0.4
Nitrate as N	WLAB046	0.2	15
Ortho Phosphate as P	WLAB046	<0.1	<0.1
Free & Saline Ammonia as N	WLAB046	1.1	0.7
ICP-MS Scan *	WLAB050	See Attached Report: 74569-A	
% Balancing *	---	96.1	96.4

*** = Not SANAS Accredited**
Tests marked "Not SANAS Accredited" in this report are not included in the SANAS Schedule of Accreditation for this Laboratory.

Ard van de Wetering

Technical Signatory

WATERLAB (PTY) LTD

CERTIFICATE OF ANALYSIS

WATERLAB

Project Number : 1000
Client : Solution H+
Report Number : 74569-A

Sample Origin	Sample ID	Ag (mg/L)	Al (mg/L)	As (mg/L)	Au (mg/L)	B (mg/L)	Ba (mg/L)	Be (mg/L)	Bi (mg/L)	Ca (mg/L)	Cd (mg/L)	Ce (mg/L)	Co (mg/L)
STHH13	30547	< 0.010	< 0.100	< 0.010	< 0.010	0.167	0.061	< 0.010	< 0.010	60	< 0.010	< 0.010	< 0.010
STHH11	30548	< 0.010	< 0.100	< 0.010	< 0.010	0.086	0.114	< 0.010	< 0.010	120	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	Cr (mg/L)	Cs (mg/L)	Cu (mg/L)	Dy (mg/L)	Er (mg/L)	Eu (mg/L)	Fe (mg/L)	Ga (mg/L)	Gd (mg/L)	Ge (mg/L)	Hf (mg/L)	Hg (mg/L)
STHH13	30547	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.430	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
STHH11	30548	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.025	0.014	< 0.010	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	Ho (mg/L)	In (mg/L)	Ir (mg/L)	K (mg/L)	La (mg/L)	Li (mg/L)	Lu (mg/L)	Mg (mg/L)	Mn (mg/L)	Mo (mg/L)	Na (mg/L)	Nb (mg/L)
STHH13	30547	< 0.010	< 0.010	< 0.010	32	< 0.010	0.040	< 0.010	87	0.193	< 0.010	194	< 0.010
STHH11	30548	< 0.010	< 0.010	< 0.010	10.5	< 0.010	0.055	< 0.010	49	< 0.025	< 0.010	70	< 0.010

Sample Origin	Sample ID	Nd (mg/L)	Ni (mg/L)	Os (mg/L)	P (mg/L)	Pb (mg/L)	Pd (mg/L)	Pr (mg/L)	Pt (mg/L)	Rb (mg/L)	Rh (mg/L)	Ru (mg/L)	Sb (mg/L)
STHH13	30547	< 0.010	< 0.010	< 0.010	0.019	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010
STHH11	30548	< 0.010	0.035	< 0.010	0.126	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010

Sample Origin	Sample ID	Sc (mg/L)	Se (mg/L)	Si (mg/L)	Sm (mg/L)	Sn (mg/L)	Sr (mg/L)	Ta (mg/L)	Tb (mg/L)	Te (mg/L)	Th (mg/L)	Ti (mg/L)	Tl (mg/L)
STHH13	30547	< 0.010	0.076	3.3	< 0.010	< 0.010	0.859	< 0.010	< 0.010	< 0.010	< 0.010	0.048	< 0.010
STHH11	30548	< 0.010	0.059	14.6	< 0.010	< 0.010	1.48	< 0.010	< 0.010	< 0.010	< 0.010	0.104	< 0.010

Sample Origin	Sample ID	Tm (mg/L)	U (mg/L)	V (mg/L)	W (mg/L)	Y (mg/L)	Yb (mg/L)	Zn (mg/L)	Zr (mg/L)
STHH13	30547	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	0.258	< 0.010
STHH11	30548	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	< 0.010	1.30	< 0.010

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CERTIFICATE OF ANALYSES
ACID – BASE ACCOUNTING
EPA-600 MODIFIED SOBEK METHOD

Date received: 2018-05-18
Project number: 1000
Report number: 74598
Date completed: 2018-06-18
Order number: PMM18-301

Client name: Solutions H Plus
Address: PO Box 39546, Moreleta Park, 0044
Telephone: -----
Facsimile: -----
Contact person: Terry Harck
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Acid – Base Accounting Modified Sobek (EPA-600)	Sample Identification	
	STHWRD	STHWRD
Sample Number	30627	30627 D
Paste pH	6.8	6.9
Total Sulphur (%) (LECO)	0.10	0.10
Acid Potential (AP) (kg/t)	3.07	3.07
Neutralization Potential (NP)	-1.95	-1.46
Nett Neutralization Potential (NNP)	-5.02	-4.53
Neutralising Potential Ratio (NPR) (NP : AP)	0.636	0.476
Rock Type	II	II

* Negative NP values are obtained when the volume of NaOH (0.1N) titrated (pH: 8.3) is greater than the volume of HCl (1N) to reduce the pH of the sample to 2.0 – 2.5 Any negative NP values are corrected to 0.00.

Please refer to Appendix (p.2) for a Terminology of terms and guidelines for rock classification

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APPENDIX: TERMINOLOGY AND ROCK CLASSIFICATION

TERMINOLOGY (SYNONYMS)

- Acid Potential (AP) ; *Synonyms:* Maximum Potential Acidity (MPA)
  Method: Total S(%) (Leco Analyzer) x 31.25
- Neutralization Potential (NP) ; *Synonyms:* Gross Neutralization Potential (GNP) ; *Syn:* Acid Neutralization Capacity (ANC) (The capacity of a sample to consume acid)
  Method: Fizz Test ; Acid-Base Titration (Sobek & Modified Sobek (Lawrence) Methods)
- Nett Neutralization Potential (NNP) ; *Synonyms:* Nett Acid Production Potential (NAPP)
  Calculation: NNP = NP – AP ; NAPP = ANC – MPA
- Neutralising Potential Ratio (NPR)
  Calculation: NPR = NP : AP

CLASSIFICATION ACCORDING TO NETT NEUTRALISING POTENTIAL (NNP)

If NNP (NP – AP) < 0, the sample has the potential to generate acid
If NNP (NP – AP) > 0, the sample has the potential to neutralise acid produced

Any sample with NNP < 20 is potentiall acid-generating, and any sample with NNP > -20 might not generate acid (Usher *et al.*, 2003)

ROCK CLASSIFICATION

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

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CLASSIFICATION ACCORDING TO NEUTRALISING POTENTIAL RATIO (NPR)

Guidelines for screening criteria based on ABA (Price *et al.*, 1997 ; Usher *et al.*, 2003)

Potential for ARD	Initial NPR Screening Criteria	Comments
Likely	< 1:1	Likely AMD generating
Possibly	1:1 – 2:1	Possibly AMD generating if NP is insufficiently reactive or is depleted at a faster rate than sulphides
Low	2:1 – 4:1	Not potentially AMD generating unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP
None	>4:1	No further AMD testing required unless materials are to be used as a source of alkalinity

CLASSIFICATION ACCORDING TO SULPHUR CONTENT (%S) AND NEUTRALISING POTENTIAL RATIO (NPR)

For sustainable long-term acid generation, at least 0.3% Sulphide-S is needed. Values below this can yield acidity but it is likely to be only of short-term significance. From these facts, and using the NPR values, a number of rules can be derived:

1) Samples with less than 0.3% Sulphide-S are regarded as having insufficient oxidisable Sulphide-S to sustain acid generation.
2) NPR ratios of >4:1 are considered to have enough neutralising capacity.
3) NPR ratios of 3:1 to 1:1 are consider inconclusive.
4) NPR ratios below 1:1 with Sulphide-S above 3% are potentially acid-generating. (Soregaroli & Lawrence, 1998 ; Usher *et al.*, 2003)

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Assistant Geochemistry Project Manager

Appendix B: Impact assessment methodology

Method of Assessing Impacts:

The impact assessment methodology is guided by the requirements of the NEMA EIA Regulations (2010). The broad approach to the significance rating methodology is to determine the environmental risk (ER) by considering the consequence (C) of each impact (comprising Nature, Extent, Duration, Magnitude, and Reversibility) and relate this to the probability/likelihood (P) of the impact occurring. This determines the environmental risk. In addition other factors, including cumulative impacts, public concern, and potential for irreplaceable loss of resources, are used to determine a prioritisation factor (PF) which is applied to the ER to determine the overall significance (S).

Determination of Environmental Risk:

The significance (S) of an impact is determined by applying a prioritisation factor (PF) to the environmental risk (ER).

The environmental risk is dependent on the consequence (C) of the particular impact and the probability (P) of the impact occurring. Consequence is determined through the consideration of the Nature (N), Extent (E), Duration (D), Magnitude (M), and reversibility (R) applicable to the specific impact.

For the purpose of this methodology the consequence of the impact is represented by:

$$\boldsymbol{C} = \frac{\boldsymbol{E} + \boldsymbol{D} + \boldsymbol{M} + \boldsymbol{R}}{\boldsymbol{4}} \times \boldsymbol{N}$$

Each individual aspect in the determination of the consequence is represented by a rating scale as defined in Table .

Table 1: Criteria for Determining Impact Consequence

Aspect	Score	Definition
Nature	- 1	Likely to result in a negative/ detrimental impact
	+1	Likely to result in a positive/ beneficial impact
Extent	1	Activity (i.e. limited to the area applicable to the specific activity)
	2	Site (i.e. within the development property boundary),
	3	Local (i.e. the area within 5 km of the site),
	4	Regional (i.e. extends between 5 and 50 km from the site
	5	Provincial / National (i.e. extends beyond 50 km from the site)
Duration	1	Immediate (<1 year)
	2	Short term (1-5 years),
	3	Medium term (6-15 years),
	4	Long term (the impact will cease after the operational life span of the project),
	5	Permanent (no mitigation measure of natural process will reduce the impact after construction).
Magnitude/ Intensity	1	Minor (where the impact affects the environment in such a way that natural, cultural and social functions and processes are not affected),

Aspect	Score	Definition
	2	Low (where the impact affects the environment in such a way that natural, cultural and social functions and processes are slightly affected),
	3	Moderate (where the affected environment is altered but natural, cultural and social functions and processes continue albeit in a modified way),
	4	High (where natural, cultural or social functions or processes are altered to the extent that it will temporarily cease), or
	5	Very high / don't know (where natural, cultural or social functions or processes are altered to the extent that it will permanently cease).
Reversibility	1	Impact is reversible without any time and cost.
	2	Impact is reversible without incurring significant time and cost.
	3	Impact is reversible only by incurring significant time and cost.
	4	Impact is reversible only by incurring prohibitively high time and cost.
	5	Irreversible Impact

Once the C has been determined the ER is determined in accordance with the standard risk assessment relationship by multiplying the C and the P (refer to **Error! Reference source not found.**). Probability is rated/scored as per Table .

Table 2: Probability Scoring

Probability	1	Improbable (the possibility of the impact materialising is very low as a result of design, historic experience, or implementation of adequate corrective actions; <25%),
	2	Low probability (there is a possibility that the impact will occur; >25% and <50%),
	3	Medium probability (the impact may occur; >50% and <75%),
	4	High probability (it is most likely that the impact will occur- > 75% probability), or
	5	Definite (the impact will occur),

The result is a qualitative representation of relative ER associated with the impact. ER is therefore calculated as follows:

$$ER = C\ x\ P$$

Table 3: Determination of Environmental Risk

Consequence						
	5	5	10	15	20	25
	4	4	8	12	16	20
	3	3	6	9	12	15
	2	2	4	6	8	10
	1	1	2	3	4	5
		1	2	3	4	5
	Probability					

The outcome of the environmental risk assessment will result in a range of scores, ranging from 1 through to 25. These ER scores are then grouped into respective classes as described in Table .

Table 4: Significance Classes

Environmental Risk Score	
Value	**Description**
< 9	Low (i.e. where this impact is unlikely to be a significant environmental risk),
≥9; <17	Medium (i.e. where the impact could have a significant environmental risk),
≥ 17	High (i.e. where the impact will have a significant environmental risk).

The impact ER will be determined for each impact without relevant management and mitigation measures (pre-mitigation), as well as post implementation of relevant management and mitigation measures (post-mitigation). This allows for a prediction in the degree to which the impact can be managed/mitigated.

Impact Prioritisation:

In accordance with the requirements of Regulation 31 (2)(l) of the EIA Regulations (GNR 543), and further to the assessment criteria presented in the Section above it is necessary to assess each potentially significant impact in terms of:

- Cumulative impacts; and
- The degree to which the impact may cause irreplaceable loss of resources.

In addition it is important that the public opinion and sentiment regarding a prospective development and consequent potential impacts is considered in the decision making process.

In an effort to ensure that these factors are considered, an impact prioritisation factor (PF) will be applied to each impact ER (post-mitigation). This prioritisation factor does not aim to detract from the risk ratings but rather to focus the attention of the decision-making authority on the higher priority/significance issues and impacts. The PF will be applied to the ER score based on the assumption that relevant suggested management/mitigation impacts are implemented.

Table 5: Criteria for Determining Prioritisation

Public response (PR)	Low (1)	Issue not raised in public response.
	Medium (2)	Issue has received a meaningful and justifiable public response.
	High (3)	Issue has received an intense meaningful and justifiable public response.
Cumulative Impact (CI)	Low (1)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is unlikely that the impact will result in spatial and temporal cumulative change.
	Medium (2)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is probable that the impact will result in spatial and temporal

		cumulative change.
	High (3)	Considering the potential incremental, interactive, sequential, and synergistic cumulative impacts, it is highly probable/definite that the impact will result in spatial and temporal cumulative change.
Irreplaceable loss of resources (LR)	Low (1)	Where the impact is unlikely to result in irreplaceable loss of resources.
	Medium (2)	Where the impact may result in the irreplaceable loss (cannot be replaced or substituted) of resources but the value (services and/or functions) of these resources is limited.
	High (3)	Where the impact may result in the irreplaceable loss of resources of high value (services and/or functions).

The value for the final impact priority is represented as a single consolidated priority, determined as the sum of each individual criteria represented in Table 11. The impact priority is therefore determined as follows:

$$\boldsymbol{Priority} = \boldsymbol{PR} + \boldsymbol{CI} + \boldsymbol{LR}$$

The result is a priority score which ranges from 3 to 9 and a consequent PF ranging from 1 to 2 (Refer to Table).

Table 6: Determination of Prioritisation Factor

Priority	Ranking	Prioritisation Factor
3	Low	1
4	Medium	1.17
5	Medium	1.33
6	Medium	1.5
7	Medium	1.67
8	Medium	1.83
9	High	2

In order to determine the final impact significance the PF is multiplied by the ER of the post mitigation scoring. The ultimate aim of the PF is to be able to increase the post mitigation environmental risk rating by a full ranking class, if all the priority attributes are high (i.e. if an impact comes out with a medium environmental risk after the conventional impact rating, but there is significant cumulative impact potential, significant public response, and significant potential for irreplaceable loss of resources, then the net result would be to upscale the impact to a high significance).

Table 7: Final Environmental Significance Rating

Environmental Significance Rating	
Value	**Description**
< 10	Low (i.e. where this impact would not have a direct influence on the decision to develop in the area),
≥10 <20	Medium (i.e. where the impact could influence the decision to develop in the area),
≥ 20	High (i.e. where the impact must have an influence on the decision process to develop in the area).

Appendix C: Curriculum Vitae of Terry Harck

CURRICULUM VITAE
Terry Harck

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PROFESSIONAL PROFILE

Environmental Geochemist. Mine drainage quality prediction. Acid Mine Drainage (AMD) assessment. Mine water management. Integration of geochemistry, groundwater and surface water studies.

BIOGRAPHY

Terry advises Southern African and international clients on the management of acid rock drainage and contaminated seepage at mine sites. He has been practicing as a consultant for 25 years. He was the manager and lead consultant of a team of 11 specialists before going solo as Solution[H+].

Terry is a member of the International Mine Water Association (IMWA), the Groundwater Division of the Geological Society of South Africa (GWD-GSSA), and the South African chapter of the International Association of Hydrogeologists (IAH-SA).

PROFESSIONAL EXPERIENCE

Solution[H+], Pretoria, South Africa
Principal Consultant — **February 2012 – present**
Environmental Geochemist

Golder Associates Africa, Johannesburg, South Africa
Senior Geochemist and Divisional Leader — **May 2004 – February 2012**
Specialist impact prediction studies with special reference to the geochemistry and groundwater aspects of mining impacts. Integration of hydrogeological and geochemical aspects of contamination assessment projects for the mining and related industries.

Responsible for 10 professionals: internal coordination, marketing, developing proposals, project management, report development, client liaison and budget management.

Coffey Geosciences, Sydney, Australia
Senior Geoscientist — **July 1997 – December 2003**
Led a business unit comprising four employees. Project managed mine environmental specialist studies. Business development. Internal auditor for office Quality Management System

Wates, Meiring and Barnard, Johannesburg, South Africa
Contaminant Geohydrologist/Geochemist — **July 1996 – June 1997**
Specialist hydrogeological and geochemical studies for mining and industrial clients.

Steffen, Robertson and Kirsten, Johannesburg, South Africa
Contaminant Hydrogeologist/Geochemist — **May 1995 – June 1996**
Specialist hydrogeological and geochemical studies for mining and industrial clients.

E Martinelli and Associates, Johannesburg, South Africa
Geologist — **January 1991 – December 1993**
Geophysical surveys, contractor supervision, groundwater development work.

EDUCATION

University of Cape Town, Cape Town, South Africa
M.Sc. in Environmental Geochemistry **1995**
Thesis: "A Geochemical Investigation of the Aquatic Sediments, Groundwater and Surface water of the Verlorenvlei Coastal Lake, With Special Reference to Nitrate Transformations."

University of the Witwatersrand, Johannesburg, South Africa
M.Sc. in Geology **1994**
Thesis: "Depositional Systems and Syndepositional Tectonics of the Basal Griqualand West Sequence, Northern Cape"

University of the Witwatersrand, Johannesburg, South Africa
B.Sc. Honours in Geology **1987**

PUBLICATIONS AND PAPERS

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Harck T and M Peters *Reprocessing Kimberlite tailings: A square contaminant source in a big hole?* 11th International Mine Water Association Congress. October 2009, Pretoria, South Africa

Harck T et al *Impact prediction of the reactivation of an unused tailings dam*. 11th International Mine Water Association Congress. October 2009, Pretoria, South Africa

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Harck T *Managing the Groundwater Impact of Mine Water Treatment Waste*. 10th International Mine Water Association Congress. June 2008, Karlovy Vary, Czech Republic.

Harck T *Are biodiversity offsets a licence to plunder natural resources?* IAIAsa Newsletter. August 2005, South Africa.

Harck T *Old mines yield history*. Australian Geographic. July – September 2002, Australia

Harck T, Willis JP, and Fey MV *Denitrification of nitrate-rich ground water entering Verlorenvlei Lake on the west coast of South Africa*. Proceedings of the 4th International symposium on Environmental Geochemistry, Oct. 5-10 1997, Vail, CO, United States

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SOLUTION H+

PROJECT EXPERIENCE
Terry Harck

Terry's project experience has been separated into two sections:

- **Geochemistry** – projects focussed on geochemistry (acid and metalliferous drainage assessment and prediction, contaminant source terms, salt balances)
- **Hydrogeology and Geochemistry** – projects which integrate geochemistry and hydrogeology (groundwater quality risk assessments, specialist studies for Environmental Impact Assessments and site contamination assessments)

PROJECT EXPERIENCE – GEOCHEMISTRY

Coffey-Pivot Mining Kingamyambo project, Democratic Republic of Congo (DRC)	Proposed tailings facility to store reprocessed and recycled copper tailings. Geochemical analysis of tailings sample from metallurgical testing. Development of a contaminant source term to be applied in numerical groundwater model
Beric Robinson Tailings Withok TSF, Gauteng Province, South Africa	Proposed new tailings storage facility. Conducted water and tailings sampling, coordinated geochemical analysis. Evaluated the data and developed a geochemical model to simulate chemical evolution of tailings seepage over time. The model was partially validated against field measurements. The model results were applied as a source term to predict the potential groundwater quality impact
AngloGold Ashanti Siguiri Gold Mine, Guinea	Developed a hydrogeochemical mixing model to predict tailings pool water quality and potential impact of flow through an artificial wetland
METS Engineering Rampura-Agucha Mine, India	Shaft sinking at open cast lead zinc mine as a prelude to underground mining. Evaluated water quality results from shaft water to determine potential corrosion risks and likely source of the contamination. Found that the shaft water is probably brine circulated from deep crustal rocks.
Petra Diamonds Finsch Mine, Northern Cape Province, South Africa	Waste classification and waste type assessment of kimberlite residues in terms of the National Environmental Management: Waste Amendment Act (NEMWA) and SANS 10234. Geochemically analysed samples of waste rock and slimes
Delta H for Anglo American Thermal Coal South African Coal Estates (SACE), Mpumalanga, South Africa	Evaluated mine water quality and geochemistry data to develop contaminant source terms for 10 open cast backfill and three coal discard facilities. Developed geochemical models to indicate progressive oxidation and seepage quality over time from backfill and discard
SLR Consulting for AngloGold Ashanti Sadiola Mine, Mali	Concept and feasibility studies of tailings placement in mined out open cast pits. Evaluated water quality and geochemistry data to predict interstitial water quality in the tailings. Integrated with engineering design team to indicate discharge of tailings water during and after tailings placement.
Delta H for Mafube Coal Mine Mpumalanga Province, South Africa	Evaluated geochemistry data to develop a contaminant source terms for open cast pit backfill and coal discard residue facility.
Knight Piesold for MMG Limited Kinsevere Mine, Democratic Republic of Congo (DRC)	Conducted a study to estimate post closure water quality in two open cast pits of an operating copper mine. Included coordinating the development of a numerical water balance model incorporating daily time step estimates. Evaluated geochemical data to estimate the water quality of pit inflows (groundwater, rainfall, pit wall runoff and seepage). Developed a hydrogeochemical mixing model to indicate potential pit water quality up to 1 000 years after closure. Evaluated the impact of tailings disposal in the pits on pit water quality.

PROJECT EXPERIENCE – GEOCHEMISTRY

AngloGold Ashanti Siguiri Mine, Guinea	Evaluated the potential environmental risk associated with waste rock dumps at open cast pits. Included laboratory analysis of 70 samples, acid drainage potential assessment. Assessed water quality risk by integrating surface water monitoring and geochemistry data. Input to closure plan for the mine.
SLR Consulting for Xtract Resources Mozambique	Proposed underground and open cast gold mine, including mining of alluvial gravel eroded from the deposits. Conducted technical review and input to sampling plan, laboratory analysis, data interpretation, source term estimation and reporting. Waste rock was sampled from geological exploration borehole core, tailings was supplied from metallurgical testing. Assessment of potential risk due to alluvial mining in river.
SLR Consulting for Tharisa Minerals Northwest Province, South Africa	Proposed open pit platinum mining operation. Conducted technical review and input to the geochemical assessment and waste type assessment in terms of the National Environmental Management: Waste Amendment Act (NEMWA). Sampling included tailings, waste rock, smelter slag and scrubber slurry. Assessed metal leaching potential and potential risk to water quality resources.
Knight Piesold for Lethabo Power Station Free State, South Africa	Waste classification and waste type assessment of residues in terms of the National Environmental Management: Waste Amendment Act (NEMWA) and SANS 10234. Geochemically analysed 4 samples of sludge and ash from power station residue facilities
AngloGold Ashanti Siguiri Mine, Guinea	Provided geochemistry inputs to the Definitive Feasibility Study (DFS) for the proposed mining of sulphidic gold ore. Developed sampling plan, coordinated sample collection and laboratory analysis, data interpretation, water quality risk assessment associated with waste rock facilities adjacent to open cast pits. Risks associated with urban settlements in close proximity to mine operations.
Agreenco for Anglo American Thermal Coal New Vaal Colliery, Free State, South Africa	Proposed scheme to irrigate treated mine water onto open cast pit backfill. Developed a geochemical model to estimate the potential migration of dissolved salts through the backfill material. Combined inputs from irrigation system designers and soil quality investigations.
SLR Consulting for Taung Gold Jeanette project, Free State, South Africa	Geochemical sampling of tailings and waste rock, development of contaminant source term for proposed waste rock dump and tailings storage facility.
SLR Consulting for Rappa Holdings Germiston, South Africa	Geochemical sampling, waste type assessment in terms of NEMWA, assessment of water quality risks, development of contaminant source term for a proposed new tailings storage facility. Assessment needed to consider the potential effect of historical underground workings beneath the site.
Anglo American Thermal Coal Kleinkopje Colliery, Witbank, South Africa	Sampling of open cast pit overburden material from geological core. Geochemical characterisation. Waste assessment in terms of NEMWA. Assessment of acid drainage potential.
Petra Diamonds Kimberley, Northern Cape Province, South Africa	Waste classification and waste type assessment of kimberlite residues in terms of the National Environmental Management: Waste Amendment Act (NEMWA) and SANS 10234. Collected and geochemically analysed 11 composite samples of tailings and slimes from five residue facilities
WSP Environment and Energy for Anglo Platinum Union Platinum Mine, Limpopo Province, South Africa	Advice on environmental management and rehabilitation of the Mortimer slag facility. The work included a review of available information to develop a conceptual model of the slag facility and underlying geology. A conceptual model was developed. Numerical modelling of the slag water balance and groundwater transport of seepage from the slag
Knight Piesold for Hotazel Manganese Mine Northern Cape Province, South Africa	Conducted geochemical and physical characterisation of a tailings sample to inform design of a new tailings storage facility TSF. The characterisation results were used to determine the waste type according to the National Environmental Management: Waste Act and develop a contaminant source term to determine potential groundwater contamination impact downstream of the proposed tailings facility.
Worley-Parsons RSA for Wafi-Golpu Joint Venture Wafi-Golpu Mine, Papua New Guinea	Feasibility and water management study of a proposed porphyry copper-gold mine. Reviewed and interpreted geochemical characterisation data to develop estimates of mine drainage quality for the tailings storage facility, ore stockpile, decline development, block cave, and subsidence zone lake. Follow-up: Revision of drainage quality estimates based on additional laboratory data

PROJECT EXPERIENCE – GEOCHEMISTRY

Delta H for Anglo Coal New Vaal Colliery, Free State Province, South Africa	Developed a geochemical model to inform water management at an open cast mine adjacent to a major river. Considered acid rock drainage generation from kinetic testwork on spoils. Work was conducted as part of the numerical groundwater model developed for the site. Included salt balance for various closure scenarios.
Knight Piesold for RBPM Styldrift Platinum Mine, Northwest Province, South Africa	Geochemical characterisation of two samples of tailings as part of the design of a tailings facility expansion. Interpreted the results in the context of potential water quality impacts.
Bigen Africa Overvaal Coal Mine, Mpumalanga Province, South Africa	Developed a salt balance for the proposed coal mine according to Best Practice Guidelines for Water Resource Protection in the South African Mining Industry.
Agreenco for Petra Diamonds Cullinan Diamond Mine, Gauteng Province, South Africa	Assessment of the hydrochemistry of the Premierspruit. Presented conclusions regarding management of dissolved fluoride concentrations and developed conceptual design of a passive treatment system
AngloGold Ashanti Siguiri Gold Mine, Guinea	Geochemical and soil contamination assessment for proposed mine expansion projects, including development of a new return water dam, tailings dam expansion, and new open cast pits. Investigated the potential water quality risks associated with the change from mining of the oxide resource to the sulphide resource.
Golder Associates Africa Townlands Chrome Project, Rustenburg, Northwest Province, South Africa	Geochemical and physical characterisation of rock samples for a proposed chromite mining project. The results were used to indicate the contaminant loading of ore stockpiles, the waste rock dump, and the tailings storage facility (TSF) on local water resources.
Agreenco for Sumo Coal Eerstelingsfontein Coal Mine, Mpumalanga, South Africa	The rehabilitated open cast is decanting into local watercourses. Conducted numerical modelling to predict potential water quality impact from the decant and how a proposed constructed wetland may reduce the impact.
Water Hunters for Lonmin Marikana, Northwest Province, South Africa	Conducted a detailed source term study on a platinum tailings dam. Confirmed that the tailings are a sink for dissolved salts in the mine water circuit and pose a lower risk to groundwater quality than originally anticipated
Knight Piesold Consulting Tarkwa Gold Mine, Ghana	Coordinated geochemical analysis of tailings to predict seepage quality and potential environmental risk
Fraser Alexander Tailings Khutala Colliery, Mpumalanga, South Africa	Conducted sampling of open cast coal mine backfill material, geochemical assessment for Acid Rock Drainage potential and provided recommendations for management of mine drainage quality risks
SLR Consulting Tshipi Borwa Manganese Mine, Northern Cape, South Africa	Conducted a preliminary geochemical assessment and mine drainage quality prediction for proposed pit backfill.
Delta H for MMG Limited Kinsevere Copper Mine, DRC	Developed an Acid Rock Drainage management strategy for the mine based on geochemical characterisation results, GARD Guide principles and the MMG sustainability policy
Knight Piesold Consulting Styldrift, Northwest Province, South Africa	Geochemical analysis and interpretation of pilot test tailings samples for a mine feasibility study
SLR Consulting Mkuju River Project, Tanzania	Prediction of water qualities at key locations downstream of proposed mine residue management facilities. Included geochemical modelling of uranium transport in groundwater
AngloGold Ashanti Iduapriem Gold Mine, Ghana	Conducted a Pre-feasibility Study (PFS) geochemistry assessment for a proposed open cast gold mine pit expansion
Golder Associates Tulu Kapi, Ethiopia	Acid Mine Drainage (AMD) assessment of proposed open cast gold mining project. Interpretation of baseline water quality.

PROJECT EXPERIENCE – GEOCHEMISTRY

Kimberley Underground Mines JV Northern Cape, South Africa	Sampling of diamond mining tailings residue, geochemical analysis, assessment of water quality risks and liability associated with tailings drainage.
Water Hunters for Lonmin Northwest Province, South Africa	Developed a salt balance for three platinum mining companies incorporating a dozen shafts, five concentrators and nine tailings dams. Assessed environmental monitoring results and integrated them with numerical water balance results to develop a mine water salt balance. Follow up sampling to address gaps in data. Development of detailed salt balance and geochemical modelling of processes in mine water circuit
Coal of Africa Ltd Mpumalanga, South Africa	Geochemical sampling, analysis and interpretation of open cast coal mine backfill to inform mine closure and rehabilitation planning
Alamos Gold Agi Dagi Project, Turkey	Conducted interpretation of geochemical sampling and analysis results, predicted mine drainage quality for a proposed gold mine and heap leach operation
Vanchem Mpumalanga, South Africa	Conducted detailed geochemical sampling of a fine residue and developed a block model to estimate available tonnages and grades for reprocessing.
Optimum Colliery Mpumalanga, South Africa	Evaluation of co-disposal options for open cast pit backfilling. Considered spoil, water treatment plant gypsum sludge and coal fines. The study included an assessment of the dissolved salt load that would report to a local receptor.
Cooke Plant Gauteng, South Africa	Geochemical assessment of pyrite and estimation of the leachate quality and groundwater risk arising from storage of the pyrite in a lined facility. This involved geochemical testing of the pyrite and modelling of leachate quality. Leachate volumes through the facility liner were modelled to indicate the potential groundwater impact for the licencing process.
Millsite Randfontein, South Africa	Geochemical assessment of gold tailings to be reclaimed and redeposited on other facilities. The tailings were found to be highly sulphidic and the client was assisted in the feasibility study of sulphide removal from the tailings. The potential groundwater impacts from the reclaimed tailings were modelled and used to inform the EIA.
Mispah Orkney, South Africa	Geochemical assessment of a gold tailings facility comprising two daywall tailings dams and a cyclone dam. Tailings and underlying soils were sampled and analysed. The data were used to estimate seepage volumes and qualities using numerical geochemical and unsaturated flow modelling. The study indicated the contaminant load to groundwater and recommendations to reduce the load during tailings dam operation.
Kansanshi Zambia	Specialist geochemical study of a proposed new sulphide tailings facility. Included geochemical and mineralogical analysis of tailings, development of anticipated seepage qualities and documenting the results in a specialist study report for the EIA.
Beatrix, South Deep, Kloof and Driefontein Mines South Africa	Baseline ARD assessment of approximately 20 waste rock dumps. Included sampling, laboratory analysis and data interpretation. Study presented client with a conceptual model illustrating the ARD risk of the dumps and recommendations to manage potential ARD impacts should the dumps be reclaimed.
Tweefontein Colliery Mpumalanga, South Africa	Used information in EIA specialist studies to develop a conceptual geochemical model of a proposed coal tailings dam to be located on a backfilled open cast pit. The study assessed the potential AMD risk from the system and made recommendations to the client for the management of the risk.
Coalbrook Free State, South Africa	Conducted geochemical sampling and analysis of an abandoned coal discard dump. Developed an estimate of contaminant loads from the dump and recommendations to manage groundwater contamination after closure.
Water Research Commission Gauteng, South Africa	Chaired a workshop to discuss aspects of underground brine disposal in South Africa. Wrote the workshop proceedings which were published.

PROJECT EXPERIENCE – GEOCHEMISTRY

New Denmark Colliery Mpumalanga, South Africa	Client proposes to store AMD treatment brine in underground compartments. The project included review of groundwater and brine chemistry from a brine storage trial study to assess the potential risk of groundwater contamination. The review indicated no mixing of deep groundwater and brine.
Himmetdede Turkey	Baseline geochemical assessment of a gold deposit for input to the EIA. Included development of a sampling-analysis plan, interpretation of the data and development of a specialist study report for the EIA. Study concluded that the AMD risk was moderate.
Kimberley Mines Northern Cape, South Africa	Project to develop source-terms for over 50 diamond tailings deposits scattered across the city of Kimberley. Coordination of an extensive geochemical sampling and analysis programme, data interpretation, geochemical and unsaturated flow modelling. Study ranked the tailings deposits in terms of relative risk to groundwater and proposed a management strategy that significantly reduces the potential groundwater contamination impact.
Mucanha-Vuzi Mozambique	Baseline Acid Rock Drainage assessment of a coal resource on the shores of Lake Cahora-Bassa. Coordinated sampling of exploration borehole core, geochemical analysis programme, and data interpretation. Study concluded that significant potential for AMD is present and further detailed geochemical work required to develop management plan.
Mafube Coal Mine Mpumalanga, South Africa	Conducted baseline geochemical assessment, including sampling of exploration borehole core and preliminary drainage quality estimation
Kamoa Dem. Rep. Congo	Baseline Acid Rock Drainage assessment of Cu prospect. Conducted sampling of exploration borehole core, laboratory analysis, interpretation of the results. Study concluded that there is a significant potential AMD risk.

PROJECT EXPERIENCE – HYDROGEOLOGY AND GEOCHEMISTRY

WSP Environment and Energy for Samancor Turffontein Project, Northwest Province, South Africa	Groundwater study for EIA of proposed underground chrome mine. Included evaluation of available data and development of a numerical groundwater model to assess impacts associated with mining, and other underground workings above the proposed workings.
WSP Environment and Energy for Anglo Platinum Union Platinum Mine, Limpopo Province, South Africa	Advice on environmental management and rehabilitation of the Mortimer slag facility. The work included a review of available information to develop a conceptual model of the slag facility and underlying geology. A conceptual model was developed. Numerical modelling of the slag water balance and groundwater transport of seepage from the slag
WSP for Atha Mining Yzermyn Coal Mine, Mpumalanga, South Africa	Coordinated the hydrogeology and geochemistry specialist studies for the EIA of a proposed underground coal mine. Mine in environmentally sensitive location on the escarpment and source area for several KZN rivers. Included presenting the results at public meetings.
ERM Marampa Mine, Sierra Leone	Developed the hydrogeology specialist study report. Consolidated data collected from site, including groundwater quality sample results, isotope analysis and groundwater drilling.
Kansanshi Copper Mine Kansanshi, Zambia	Evaluated the potential contaminant load leached from a proposed new tailings dam and the potential groundwater impact.
Tweefontein Colliery Mpumalanga, South Africa	Conducted a desktop evaluation of the potential impact on local water quality of a proposed fine residue and discard disposal facility placed over a backfilled open cast pit. This was informed by a limited sampling programme to fill gaps in the available geochemical data. The evaluation integrated the preliminary design of the facility, geochemisty, hydrogeology and surface water hydrology to evaluate the potential water quality risk. The evaluation was aligned with document G4 of the Best Practice Guidelines for Water Resource Protection in the South African Mining Industry
Manganese Metal Company Krugersdorp, South Africa	Developed a source-pathway-receptor model for the site which took into account the geochemical leaching behaviour of various waste sources, flow in the unsaturated zone, surface water hydrology and groundwater hydrology to estimate the potential impact on water quality in the nearby Wonderfonteinspruit watercourse.
Harmony Welkom, South Africa	Co-ordination of the hydrogeology and geochemistry specialist studies of the EIA of proposed gold tailings reclamation project. Included baseline hydrogeology and geochemistry assessments, fieldwork programme, laboratory analysis and modelling of the potential leachate qualities during tailings reclamation and deposition and the potential downgradient groundwater level and quality impacts.
Kupane Liqhobong, Lesotho	Co-ordination of the hydrogeology and geochemistry specialist studies to inform the Bankable Feasibility Study (BFS) of a proposed diamond mine. Geochemical sampling and hydrogeological drilling of kimberlite and basalt, numerical modelling to assess likely seepage qualities and groundwater impacts from the proposed Tailings Storage Facility. Integration of study results into the EIA of the proposed project.
Rand Uranium Randfontein, South Africa	Co-ordination of the hydrogeology and geochemistry specialist studies of the EIA of a proposed gold tailings Aμ/U reclamation project. Included baseline hydrogeology and geochemistry assessments, field geochemical sampling of tailings hydrogeological drilling and testing programme, laboratory analysis, numerical modelling of seepage qualities (including Acid Rock Drainage), numerical groundwater modelling.
Riversdale Tete, Mozambique	Geochemistry specialist study of the EIA of a proposed 10 000 ha open-cast coal mine and coal-fired power station. Proposed pit depth is 350 m. Sampling of drill core, coal, fine discard, ash laboratory analysis including static and kinetic geochemical testing. Numerical modelling of likely seepage and pit water qualities from overburden/ash stockpile and the open-cast pit. Development of contaminant source-terms for groundwater and surface water impact assessments.
De Beers, Kimberley Mine Kimberley, South Africa	Development of a contaminant source term for kimberlite tailings and slimes material proposed as backfill for open-cast pits. Sampling of tailings material, laboratory analysis and geochemical modelling.

PROJECT EXPERIENCE – HYDROGEOLOGY AND GEOCHEMISTRY

Vanchem Witbank, South Africa	Geochemical characterisation of hazardous calcine waste based on previous work, limited sampling and analysis. Use of geochemical characterisation results to conduct probabilistic modelling of groundwater quality impacts on downgradient receptors over time.
Mafube Macro Mine Middelburg, South Africa	Acid rock drainage assessment for a proposed open-cast coal mine. Sampling of exploration borehole core, static and kinetic geochemical testing, assessment of acid seepage potential.
SLR Consulting for Cradle Resources Panda Hill, Tanzania	Proposed rare earth element (REE) mine on an alkaline igneous intrusion. Conducted groundwater baseline studies in the vicinity of the proposed project. Boreholes drilled into thick (150 m+) sequence of lacustrine sediments targeting sandy clay aquifers. Testing and sampling of completed boreholes.
Exxaro Coal, Grootegeluk Mine Lephalale, South Africa	Assessment of downgradient groundwater quality impacts from proposed backfill placement in the open cast pit. Co-ordination and integration of numerical modelling task which included: pit water balance (GoldSim), unsaturated flow (Vadose W), geochemical (Geochemists Workbench) and groundwater flow and mass transport (Medflow, MT3D).
Manganese Metal Company, Pappas Quarry Nelspruit, South Africa	Extension of groundwater monitoring network including geophysical survey, borehole drilling, borehole testing and sampling. Integration of results and update of numerical groundwater model of the site to assess likely compliance with regulator requirements over time.
Metalloys Gauteng, South Africa	Source characterisation and groundwater contamination assessment at a 400ha industrial site used for manganese smelting and related industries.
Finsch Diamond Mine Northern Cape, South Africa	Groundwater contamination assessment at a diamond mine tailings disposal complex. Co-ordination of geophysical surrey, borehole drifting, borehole testing and sampling. Development of a hydrogeological conceptual model and monitoring plan.
Majuba UCG Mpumalanga, South Africa	Hydrogeological services in support of the development of a pilot plant for underground coal gasification.
African Chrome North West, South Africa	Assessment of soil and groundwater contamination by Hexavalent chrome at an abandoned chrome processing facility.
Ferrometals Mpumalanga, South Africa	Conducted a groundwater situation assessment at a Ferrochrome plant near Witbank. The review involved sampling over 20 potential contamination sources preliminary geochemical assessment and review of 4 years of monitoring data from over 30 boreholes.
Manganese Metal Company Mpumalanga, South Africa	Conducted the installation and testing of six dewatering wells located in the manganese waste body at Pappas Quarry. The purpose of the dewatering system is to mitigate groundwater contamination by reducing the driving head in the waste body.
United Colliery NSW, Australia	Hydrogeological and geochemical input to feasibility assessment of proposed new long wall block. Input to Environmental Impact Assessment. Considered potential subsidence effects associated with proposed longwalls.
Lachlan River Valley NSW, Australia	Specialist hydrogeological input to a land dispute and associated court case for the NSW Department of Land and Water Conservation.
Kimberley Mines Northen Cape, South Africa	Hydrogeological investigation, numerical modelling of former open cast diamond mine, tailings facility and associated groundwater contamination plume
Finsch Mine Northern Cape, South Africa	Hydrogeological investigation, numerical groundwater modelling of an open cast diamond mine, tailings facility and associated groundwater contamination plume.
Black Range Minerals NL NSW, Australia	Input to mine feasibility assessment. Design of wellfield to supply process water to a prospective nickel mine.

PROJECT EXPERIENCE – HYDROGEOLOGY AND GEOCHEMISTRY

Hunter Water Corporation NSW, Australia	Computer modelling of impact of proposed municipal water supply wells on industrial development. Site investigation and feasibility assessment of a water supply wellfield. Developed a conceptual design to yield 30ML/day, including well design, pipeline design, low-voltage power distribution and telemetry considerations. Development of tender documents to cover acquisition of pumps, pump motors, and installation and commissioning of new groundwater wells and pipework.
Barnawatha STP Victoria, Australia	Groundwater studies and specialist input to public participation programme for regional water supply utility.
Auspine Ltd Tasmania, South Australia, Australia	Assessment of surface water and groundwater quality at three timber treatment plants, including CCA treatment and sawmilling. Design and maintenance of monitoring network.
Yerranderie Silver Mining Field NSW, Australia	Project for the NSW Department of Mineral Resources. Investigated, costed, planned rehabilitation of historic silver mining field including over 100 abandoned shafts, pits and adits. Development of tender specifications. Assessed tenders and appointed sub-consultants and sub-contractors.
Sydney Catchment Area NSW and Victoria, Australia	Identified orphan/derelict mine sites in the Sydney Catchment. Preliminary risk screening. Developed an assessment methodology using remote sensing and GIS technology to estimate the environmental risk associated with derelict mine sites. Environmental site assessment to assess water quality impacts on Sydney's water supply. Developed preliminary rehabilitation plans and costs.
Tottenham Mining Field NSW, Australia, NSW, Australia	Project for the NSW Department of Mineral Resources. Reviewed environmental issues for seventeen derelict copper mines. Prioritised mines for rehabilitation. Developed mine rehabilitation plans and indicative costing and scheduling.
Zeehan Slag Dumps Tasmania, Australia, Tasmania, Australia	Developed environmental management plan to recover saleable minerals during dump reclamation. Input to feasibility assessment.
Savage River Mine Tasmania, Australia	Rehabilitation design options for a pyritic iron ore mine. Assessed hydrogeology, hydrology and environmental management at the site which included three tailings dams, nine waste rock dumps and four open pits.
Pasminco Hobart Smelter Tasmania, Australia	Investigated subsurface conditions and groundwater quality. Designed and did preliminary costing of hydrocarbon contamination interception trench. Developed contractor specifications. Assessed tenders. Monitored construction of trench.
Hebburn No 2 Colliery NSW, Australia	Assessed environmental impacts of a coal washery waste reprocessing operation. Consulted with regulators on behalf of client.
Cordeaux Colliery NSW, Australia	Conducted an audit of surface water quality, analysis of results and analytical modelling of the water quality impact of proposed discharge of mine water into a local watercourse. Consulted with regulators and assessed impact of local laws and regulations on the proposed discharge.
Kurnell Peninsula NSW, Australia	Assessed groundwater impacts and developed groundwater management strategies associated with master planning studies for a proposed luxury residential development.
Sydney City Council NSW, Australia	Investigation and assessment of heavy metal and hydrocarbon soil and groundwater contamination at an inner city depot site to be redeveloped for commercial/residential use. Development of remedial strategies and costs.
Wyong Shire Council NSW, Australia	Managed the assessment of groundwater contamination associated with a decommissioned domestic landfill and nightsoil disposal site adjacent to a residential subdivision.
Shell Australia NSW, Australia, NSW, Australia	Groundwater contamination assessment at seven service station sites in Sydney, Central Coast and South Coast. Included hydrocarbon analysis of more than 100 monitoring wells.

PROJECT EXPERIENCE – HYDROGEOLOGY AND GEOCHEMISTRY

United Dairies Parramatta, NSW, Australia	Assessed soil/groundwater contamination at a dairy product factory for property managers, included assessment of contamination from USTs.
Khutala Colliery Mpumalanga, South Africa	Input to feasibility of proposed opencast pit. Computer modelling of pit hydrogeology.
Gardinia Colliery Natal, South Africa	Hydrogeological data collection, monitoring and computer modelling of an opencast coal mining pit undergoing rehabilitation.
Freegold Ltd Free State, South Africa	Investigated shallow groundwater contamination from AMD downstream of a surface water catchment dam. Design of remediation system
Sasol Coal Mpumalanga, South Africa	Detailed hydrogeological study of Secunda coal mines with particular emphasis on defining the recharge dynamics responsible for excessive groundwater inflow to the mine workings. Developed a mine water balance. Desktop study of mine subsidence effects. Compilation of hydrogeological aspects of Environmental Management Programme Reports. Extensive consultation with client
Lerokis Mine Wetar island, Indonesia	Technical study to assess environmental impacts from an unmined massive sulphide body exposed during open cast mining.