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Groundwater Assessment for the Mponeng TSF Complex

Report

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GLOSSARY

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

ABA *- Acid Base Accounting*

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

Aquifer *– A body of rock, consolidated or unconsolidated, that is sufficiently permeable to conduct groundwater and to yield significant quantities of water to wells and springs.*

ARD *- Acid Rock Drainage*

Bedrock *– A general term for the rock that underlies soil or other unconsolidated superficial material.*

Cone of depression *– A depression in the potentiometric surface of a body of groundwater that has the shape of an inverted cone and develops around a well/mine shaft/open pit mine from which water is being withdrawn.*

Drawdown *– The decline of the water table or potentiometric surface as a result of withdrawals from wells or excavations.*

DW&S *- Department of Water and Sanitation (Used to be DWAF and then DWA)*

EC *- Electrical Conductivity (mS/m)*

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

Fault *– A fracture or fracture zone along which there has been displacement of the sides relative to one another parallel to the fracture.*

Fracture *– A crack, joint, fault or other break in rocks caused by mechanical failure.*

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

Heterogeneous *-indicates non-uniformity in a structure.*

Hydraulic conductivity (K) *- Measure of the ease with which water will pass through the earth's material; defined as the rate of flow through a cross-section of one square metre under a unit hydraulic gradient at right angles to the direction of flow.*

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

Hydraulic head *– Generally the altitude of the free surface of a body of water above a given datum.*

Interflow – *The lateral movement of water in the unsaturated zone during and immediately after precipitation. Interflow occurs when the zone above a low permeability horizon becomes saturated and lateral flow is initiated parallel to the barrier.*

Joint – *A fracture in rock along which there has been no visible movement.*

K *- Hydraulic Conductivity*

LOM *- Life of Mine*

mamsl *- Metres above mean sea level*

mbgl *- Metres below ground level*

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

NAG *- Net Acid Generation*

NGDB *- National Groundwater Database*

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

Perched Water Table *– The upper surface of a body of unconfined groundwater separated from the main body of groundwater by unsaturated material.*

Permeability *- the ease with which a fluid can pass through a porous medium and is defined as the volume of fluid discharged from a unit area of an aquifer under unit hydraulic gradient in unit time. Permeability is not to be confused with hydraulic conductivity. While similar, permeability considers the properties of the fluid being transmitted.*

pH *- is a measure of the acidity or alkalinity of a solution, numerically equal to 7 for neutral solutions, increasing with increasing alkalinity and decreasing with increasing acidity.*

Piezometric head *- is the sum of the elevation and pressure head. An unconfined aquifer has a water table and a confined aquifer has a piezometric surface, which represents a pressure head. The piezometric head is also referred to as the hydraulic head.*

Porosity *– The ratio of the aggregate volume of interstices in a rock or soil to its total volume. It is usually stated as a percentage.*

Pumping tests *- are conducted to determine aquifer or borehole characteristics.*

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

S *- Storativity*

SO_4 *- Sulphate (mg/l)*

Specific yield *- the ratio of the volume of water that drains by gravity to that of the total volume of the saturated porous medium. Specific yield is a ratio between 0 and 1 indicating the amount of water released due to drainage, from lowering the water table in an unconfined aquifer.*

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

Storativity *- the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head. It is a volume of water per volume of aquifer released as a result of a change in head. For a confined aquifer, the storage coefficient is equal to the product of the specific storage and aquifer thickness.*

TDS *- Total Dissolved Solids (mg/l)*

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

Transmissivity (T) *- is a measure of the ease with which groundwater flows in the subsurface. It is the two-dimensional form of hydraulic conductivity and is defined as the hydraulic conductivity multiplied by the saturated aquifer thickness.*

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

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

EXECUTIVE SUMMARY

GCS (Pty) Ltd was appointed by AngloGold Ashanti Limited to undertake a follow up groundwater study for the Mponeng TSF Projects.

The following concluding remarks can be made:

- The objectives of the hydrogeological assessment was to determine:
    - Potential groundwater seepage as a result of increasing the height of the upper compartment to 60m and the lower compartment to 66m;
    - To comment on the hydrogeological impact and management options; and
    - To look into ways to manage the spring in terms of water quality and flow.
- The completed geophysical field survey indicated that:
    - The location of the dolerite dyke which was indicated to the north of the Mponeng TSF running from north to south from the Gatsrand Area (Westrand Hills) is confirmed and in line with the available air magnetic data (Aquisim Consulting, 2001). The dyke position indicated on older geological maps used internally in Anglogold Ashanti is not correct.
    - Seepage areas were identified south and south east of the TSF.
- It was previously thought that the spring is controlled by the dolerite dyke, however the occurrence of the dolerite dyke and sills in the area appears to have limited hydrogeological influence on the spring flow. The spring appears to originate from deeper aquifer flow and connected via geological lineaments in the area.
- Seepage analyses indicated that current seepage rates are in the order of 0.3 m^3/day/ha or 12mm/annum for the lower compartment and 0.5 m^3/day/ha or 20mm/annum for the upper compartment. This will increase to 35 and 32 mm/annum respectively with the proposed increase in heights. This can be regarded as fairly low for gold tailings and can be attributed to the foundation geology (shales and andesites) and characteristics of the tailings material.
- Monitoring data indicates that typical sulphate concentrations for the tailings seepage is in the order of 2200mg/l. The 2002 geochemical data indicated sulphate concentrations to be lower. Neutral pH values were indicated for all the monitoring points. This implies that limited acid mine drainage currently occurred at the Mponeng TSF and that limited metal mobilization is in progress.
- Only two monitoring boreholes indicated higher sulphate seepage, above 500 mg/l. Most of the sites indicate sulphate concentrations to be less than 100mg/l.

- The numerical groundwater model was successfully calibrated with the observed monitoring data and it is predicted that a sulphate plume between 200 and 600 mg/l will develop to the south and south east of the TSF with the proposed increase in height. The sulphate plume will be limited to the Mponeng TSF area and return water dam area.
- However, the main impact of the sulphate plume will be evident in the Aquatic Dam, which indicated sulphate concentrations currently to be around 200 mg/l, generally 100mg/l higher than upstream sample sites. The sulphate concentration and salt load will increase to about 300 mg/l if the seepage is not controlled.
- The control mechanisms proposed will be:
  - Upgrade of the return water dams with suitable lining systems in place;
  - Upgrade of the southern toe seepage drains and solution trenches;
  - Management of the pond size on top of the TSF compartments;
  - Installation of shallow seepage drains at the identified shallow seepage areas;
  - Installation of interception boreholes to intercept deeper aquifer flow (in the order of 20 to 30m below surface;
  - Control over the release of any contaminated water by up-stream areas like the Mponeng mine and gold plant areas.
- The probability of the spring getting contaminated, if the upper and lower compartments are raised to the proposed levels, is higher. It is therefore recommended that the cut-off drain between the upper compartment and the spring be upgraded and that the spring is "ring-fenced" with drains and impermeable flow barriers. The spring water must be diverted in an easterly direction towards the clean natural flow path which drains into the aquatic dam. Furthermore, it is recommended that a trail study be initiated where the spring is intercepted by borehole MB20 and a potential 2nd borehole about 20 to 50m to the north-east. A 3rd borehole option can be considered further to the north but needs to be confirmed with additional infill geophysical survey.

In conclusion: No drastic increases in seepage volumes from the TSF via foundation geology into the underlying aquifer are therefore expected over the proposed life of mine and increased elevations. Shallow seepages will be more prominent within the direct vicinity of the TSF and these can be controlled by means of drains and trenches. Limited deeper aquifer seepage will occur and the identified geophysical anomalies can be tested through drilling to monitor the deeper environments.

Spring flow needs to be managed to prevent cross contamination due to increased heads from the lower and upper compartments.

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1 INTRODUCTION

GCS Pty Ltd (GCS) has been engaged by AngloGold Ashanti (AGA) to undertake a groundwater assessment for the Mponeng TSF Expansion Feasibility Study. The proposed expansion includes upgrade of the existing Tailings Storage Facility (TSF), including enlargement of the bottom and top TSF compartments. The AngloGold Ashanti's Mponeng Mine and TSF Complex is located approximately 75 km west of Johannesburg and 12 km south of Carletonville; the Elandsfontein Spruit is the main watercourse draining the site (Figure 2-1).

The Mponeng TSF Complex, commissioned in June 1986, is divided into an upper and lower compartment with a return water dam (RWD) facility to the south east of the Complex. The Aquatic Dam is situated to the east of the RWD and to the south of the TSF Complex.

This report presents the results of predictive groundwater modelling of seepage from the existing and proposed TSF outlay and the application of seepage recovery systems to mitigate potential impacts on the upstream fountain and shallow groundwater environments hydraulically down-gradient of the site.

The Mponeng rubble waste site is situated above and on top of the lower compartment of the TSF Complex, and the Old south dumping site to the west of the Complex.

The methodological approach involves:

- Review of proposed design parameters and available hydrogeological and TSF evaluation reports;
- Preliminary field applications which include ERT (Electric Resistivity Tomography) and magnetic geophysical surveys;
- Application of available water monitoring data;
- TSF seepage and numerical modelling; and
- Feasibility assessment of groundwater management applications.

2 PROPOSED TSF PARAMETERS FOR HYDROGEOLOGICAL ASSESSMENT

To evaluate additional storage capacity for the Mponeng TSF, different options for placing more tailings on the existing Mponeng TSF will be investigated to extend the life of the existing Mponeng TSF. The TSF operational characteristics can be described as follows:

- Area A, the currently active TSF (Figure 2-1).
- Area B, currently being used as a landfill site; there is a water fountain on the western side of the landfill site.
- Area C, currently being used to manage storm and return water – approved water storage facility.

Two options are being evaluated for the additional storage capacity to accommodate the Mponeng Life of Mine shortfall at Mponeng TSF Complex – namely Option 2a and 2b.

1. The first option (Option 2a) comprises extending the height of the active compartment Area A of the Mponeng TSF to above the approved 60 meter height. Area A will be raised to a maximum height before stability is compromised, the shortfall will be placed onto the inactive compartment Area C. It's unlikely that the raising of the active Area A to above 60 meters will exceed 70 meters height.
2. The second option (Option 2b) consists of re-commissioning inactive compartment Area C and depositing all the tailings tonnages to the height of the active compartment (approximately 60m).
3. Currently Area C is utilized as the Holding Dam due to insufficient capacity of the existing Return water dams. Therefore, both Option 2a and Option 2b will require the design of a new return water dam (RWD) to accommodate return water from the TSF, runoff and legislated stormwater provisions.

The following TSF design parameters were applied for the hydrogeological assessment:

Table 2-1: Proposed design parameters

Mponeng TSF Compartment	Current Elevation (mamsl)	Current Height (m)	Proposed Elevation (mamsl)	Proposed Height (m)	Time From	Time to (LoM)
Mponeng lower TSF	1540	25	1581	66	1937	2065
Mponeng upper TSF	1577	38	1599	60	2019	2036

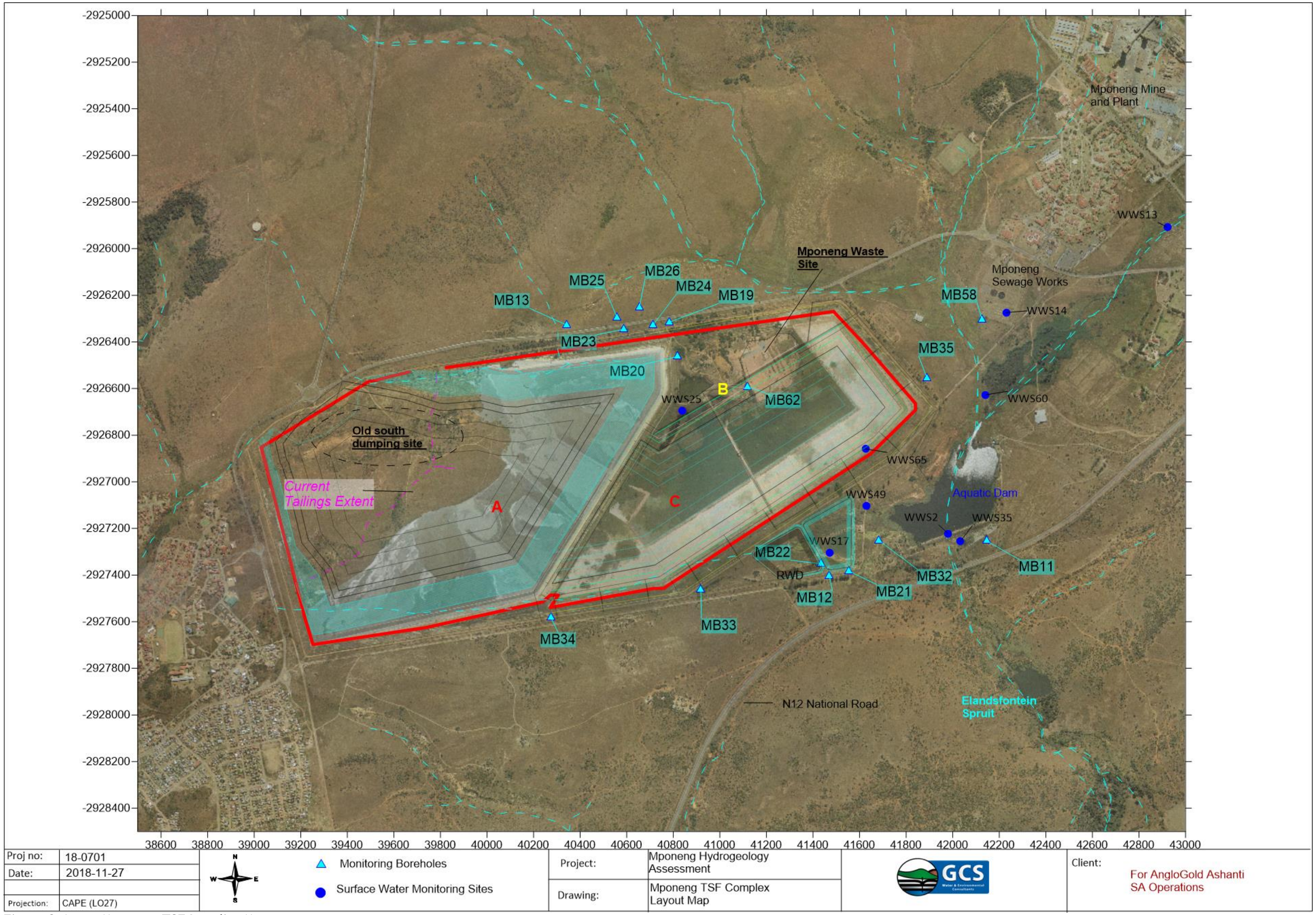


Figure 2-1: Mponeng TSF Locality Map

3 BACKGROUND AND BASELINE DATA

The following historical reports were considered:

- The geology and geohydrology is described by Barnard (1995), Wagener (1976 & 1979), Hearne & Bush (1994), Van Rensburg & Bush (2001) and Vivier et al. (2001).
- Phase 2 Groundwater investigation: Drilling and Pump testing Programme - AATS 1996.
- Hydrological investigation in the vicinity of the South Slimes Dam – AATS; South Complex return water Dam - Environmental Impact Assessment Study - ATD 1998.
- Determination of the Origin of the Spring Water at the Slimes dam of AngloGold at Mponeng Mine - Aquisim Consulting 2001. Geological interpretations from 8 boreholes drilled in the vicinity, an aero-magnetic survey and structural interpretations found that the spring is located on identified lineaments that are interpreted to be fracture zones that allow for the upward movement of groundwater to the surface from confined or semi-confined strata.
- Ground Water Pollution Investigation Maas Boreholes – South Slimes Dam - KLM Consulting Services ; 1999. Resistivity surveys performed by Engineering and Exploration Geophysical Services in June 1999 indicated that seepage from the South Tailings Complex is restricted to a very shallow near surface zone of weathering.
- AngloGold Ashanti's West Wits Sulphate Groundwater Plume Update Report, GCS 2011, 2013 and 2015.
- SLR, 2017: Mponeng and Savuka Tailings Storage Facilities – Field Investigations and Side Slope Stability Assessments SLR Project No.: 710.01003.00015.
- SLR, 2013: Mponeng and Savuka Tailings Storage Facilities – Field Investigations and Side Slope Stability Assessments SLR Project No.: 710.01003.00006.

3.1 Regional Geology

The geology and geohydrology is described by Barnard (1995), Wagener (1976 & 1979), Hearne & Bush (1994), Van Rensburg & Bush (2001) and Vivier et al. (2001).

The Mponeng TSF Area is underlain by Pretoria Group sediments belonging to the Transvaal Supergroup (Figure 3-1). The Timeball Hill quartzite formation forms the Gatsrand, also known as the West Witwatersrand ridge. To the south of the ridge the ground slopes away under the Timeball hill shales towards the Wadela valley. The Hekpoort andesite discordantly overlies the sedimentary formations on the southern perimeter of the Mponeng TSF property.

3.2 Structural Geology

According to Van Rensburg & Bush (2001) several fault related lineaments can be observed in the area (refer to Figure 3-1 and Figure 3-2). These structures crosscut the sedimentary successions in a mainly north north-westerly direction – perpendicular to the general strike direction. Several other lineaments were derived from previous remote sensing and mapping exercises and area associated with the strike direction of dyke intrusions. Several lineaments in the vicinity of the Bank Dyke in the east of the area, follow the same north-north-western direction while north-south trending lineaments are common in the vicinity of the central twin-dyke intrusion which occurs directly north of the South Tailings Dam Complex.

It can be seen from available data that the exact locality of the Bank Dyke is uncertain and discrepancies occur in the various datasets. GCS undertook detailed geophysical surveys in this area to attempt to map the exact locality of the dyke (refer to Section 7 below).

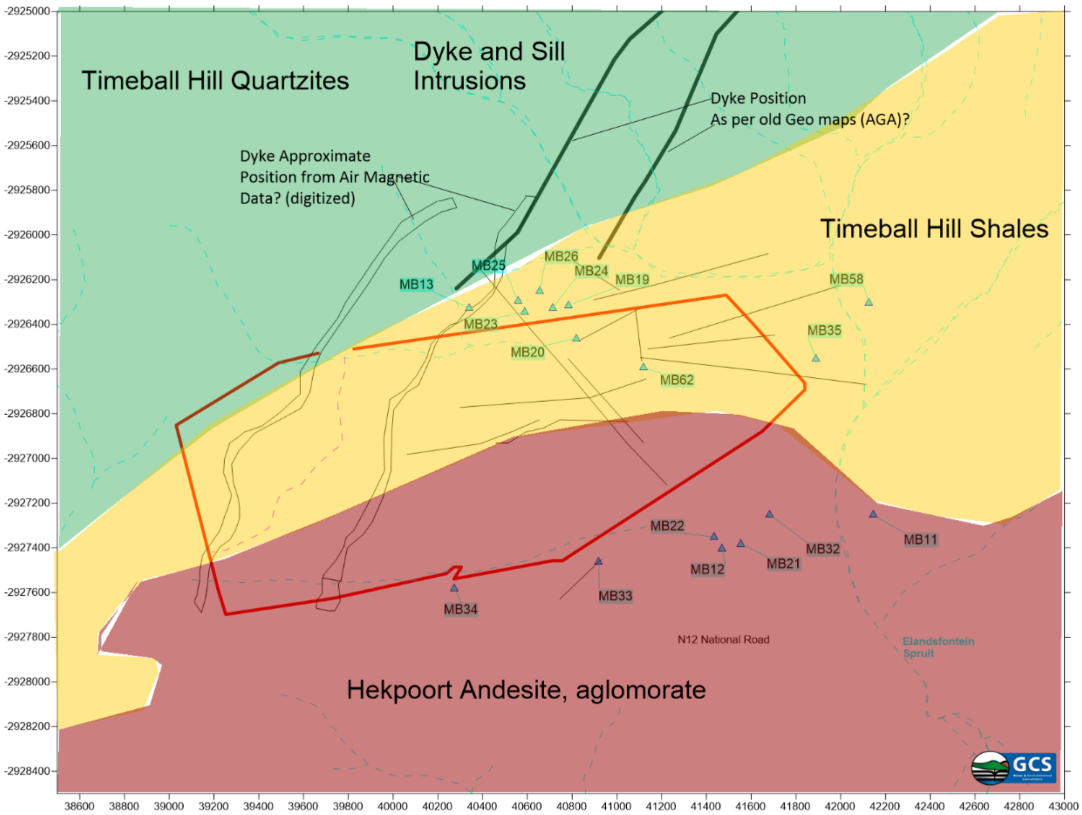


Figure 3-1: Regional Geological Setting

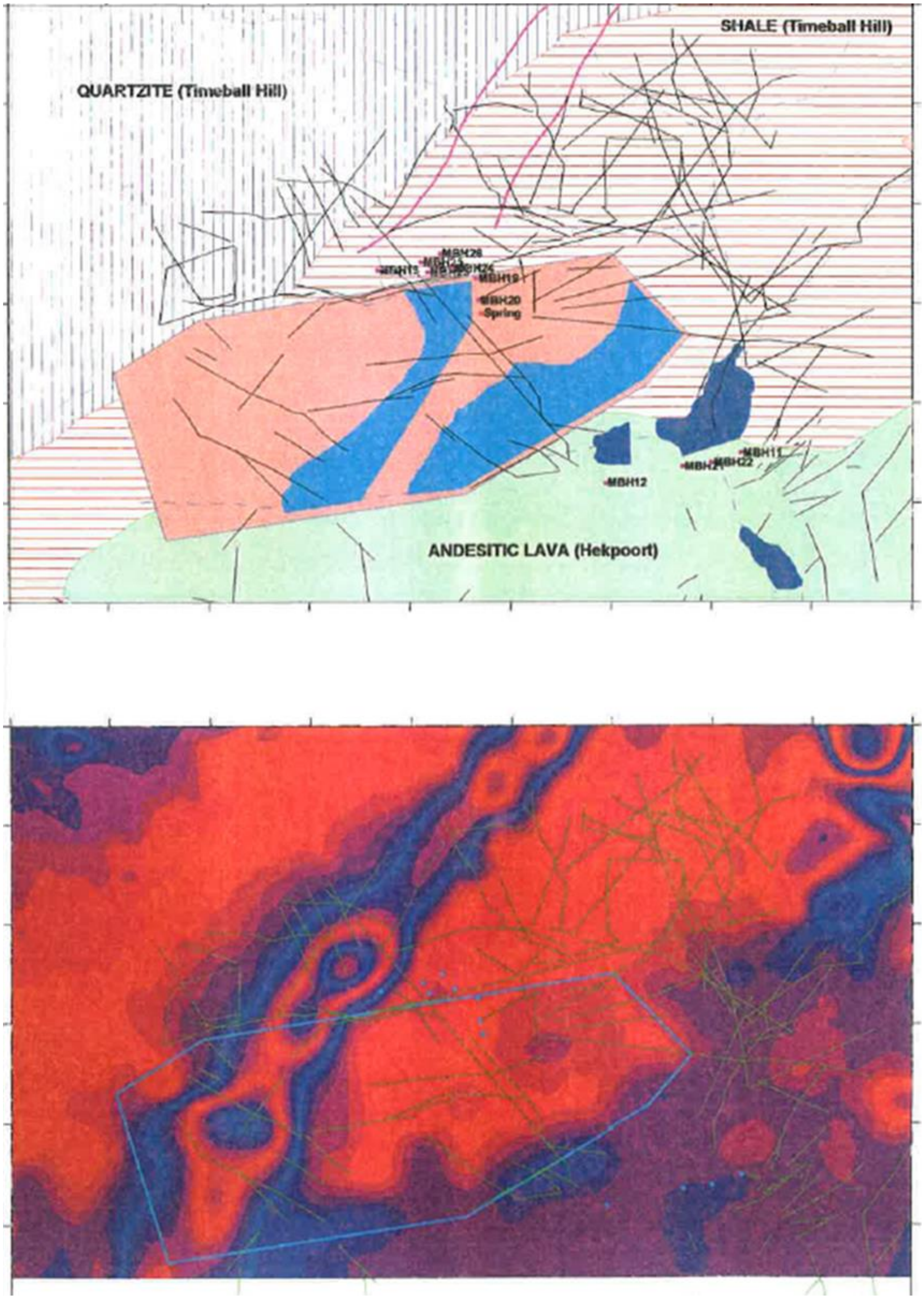


Figure 3-2: Structural lineaments mapped and site specific aeromagnetic data (Van Rensburg, 2001)

3.3 Hydrology

The Aquatic dam is a clean water dam with the main objective of diverting clean catchment run-off and aquifer/spring flow away from the Mponeng TSF towards the Elandsfontein Spruit.

The Elandsfontein Spruit drains the Mponeng catchment area through the Aquatic dam from where it flows south again into the Loopspruit, Leeuspruit and the Klipdrift dam, ultimately discharging into the Mooi River. The Mooi River, in turn, is a tributary of the Vaal River.

The “Mponeng Spring” is situated to the north of the TSF Complex, in between the Upper and Lower compartments. The “Farmer’s Spring” is situated to the east of the Complex. Farmer’s spring is registered as a servitude for the downstream farming community, and discharges from the West Wits property via the Aquatic dam and Elandsfontein Spruit.

The Elandsfontein Spruit system is monitored at seven different sites (Figure 2-1).

4 GROUNDWATER CHARACTERISTICS OF THE MPONENG TSF SITE

The Mponeng TSF Complex is situated on Timeball Hill Quartzites and shales of the Pretoria Group. The four (4) boreholes drilled additionally during the 1998 site hydrogeological investigation (boreholes MBH19 to MBH22) intersected shales and a few meters of andesite were encountered in MB22. The site investigation was completed by the Civil Engineering Department of Anglo-American Corporation to determine groundwater flow and seepage into the South TSF and to determine the aquifer characteristics south of the Aquatic Dam, February 1998, Report number CED/021/98. Generally, the sediments of the Pretoria Group exhibit poor aquifer characteristics. In the vicinity of the TSF these shales are however, jointed and fractured to such an extent that high yielding aquifers exist along lineaments and shear zones.

Groundwater flow is in a southern direction and any pollution transport will eventually end up in the lower Elandsfontein Spruit basin area. The Aquatic dam is situated at the lowest point within the spruit and is therefore also vulnerable to any pollution migration.

As drilling at borehole MBH20 extended only to 30m and did not intersect dolerite, uncertainty remains as to whether dolerite underlies the shales intersected or not. It is however evident that the spring and both boreholes MBH20 and MBH13 are located on identified or extrapolated lineaments. These are interpreted to be fracture zones that allow for the movement of groundwater towards the surface from confined or semi-confined strata (Van Rensburg, 2001). The source of the water at the spring and adjacent borehole MBH20 is not derived from TSF seepage (Aquasim, 2001). It is most likely that this water is derived from recharge occurring through the quartzites that makes out the Westrand Hills.

4.1 Aquifer Parameters

Aquifer testing was completed at 7 boreholes and the data can be viewed in Table 4-1. Hydraulic conductivity is quite variable and mainly controlled by geological structures (lineaments, dykes) and geological contact zones. Generally the shales and andesites along the majority of the TSF's footprint consist of low permeabilities and are very similar to the permeabilities of the tailings; also refer to the Seepage Analyses in Section 8.2.2 where the foundation material is discussed in more detail. Groundwater flow is therefore very low within the majority of the underlying aquifer with increased flow along the identified geological structures.

4.2 Groundwater Levels

Figure 2-1 above shows the locations of the Mponeng area groundwater monitoring sites and Table 4-1 the descriptions of the boreholes.

Figure 4-1 supplies an overview of the groundwater level trend data for boreholes MB35 and MB32, shallow levels were observed around the TSF with seepage daylighting along the southern area upstream of the return water dams. **Figure 4-2** supplies an overview of the groundwater flow direction and elevation contours for the Mponeng TSF area.

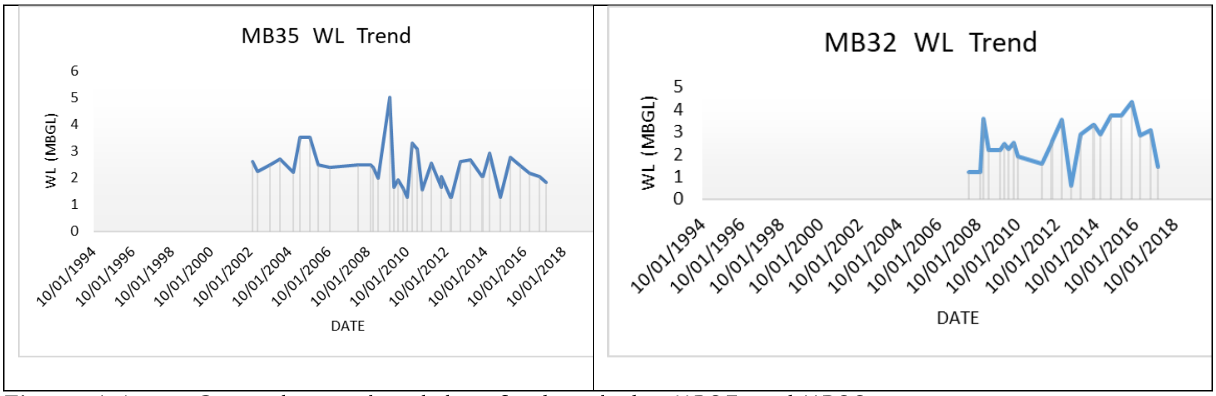


Figure 4-1: Groundwater level data for boreholes MB35 and MB32

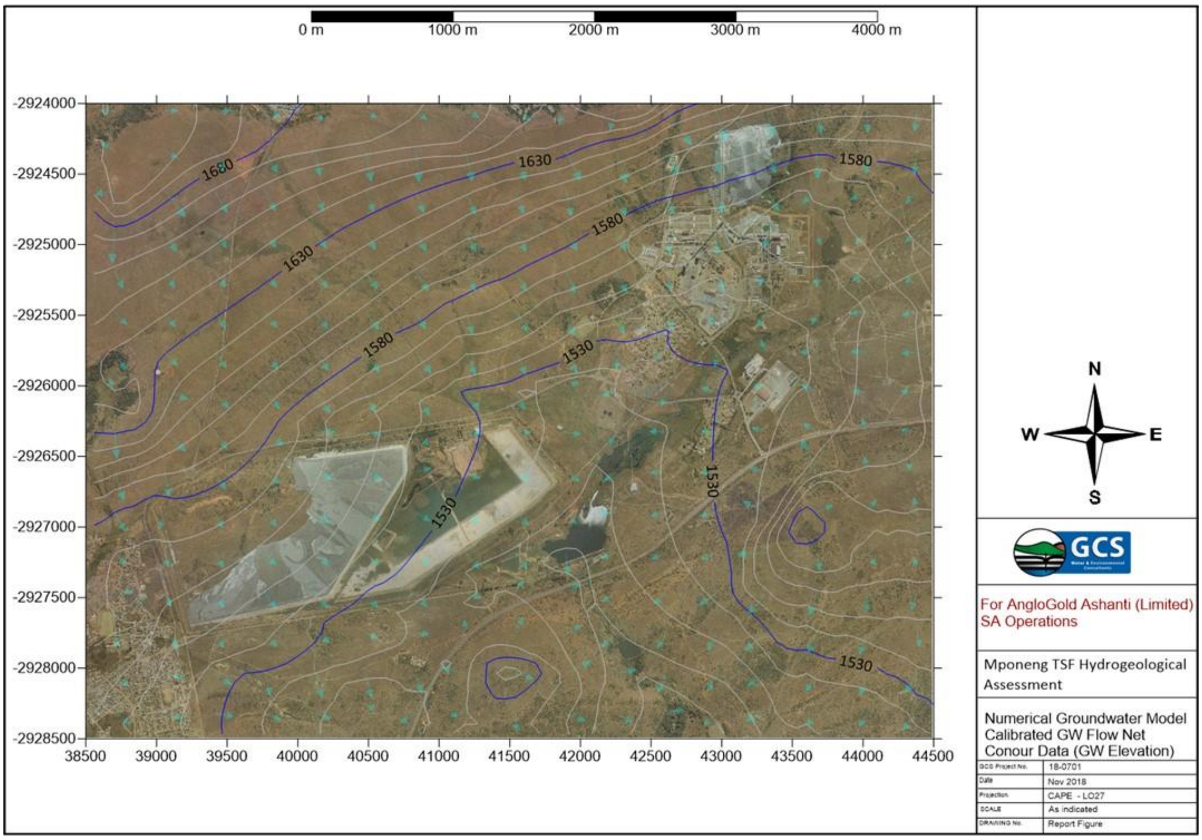


Figure 4-2: Regional groundwater flow elevation and direction

Table 4-1: Groundwater Monitoring Site Descriptions

	ID	X	Y	Z	Description	Borehole depth (m)	Date Drilled	Geology	Dept to water strike (m)	Blow Yield (lt/hour)	T	K (CD)	K (Rec)
1	MB10	43602.454	-2924760.85	1567.172	SE of Mponeng RD; N of Mponeng GP	29.66	1996	Timeball Hill Shale and Quartzite	15, 17	23000		12.9	6.08
2	MB11	42144.88	-2927252.917	1499.27	SE of Mponeng TSF and Below aquatic Dam	30	1996	Shales	19	150	0.07		
2	MB12	41469.851	-2927402.294	1511.919	S of Mponeng TSF and below return water dams	30.1	1996	Shales	20	400	0.01	0.052	0.0303
3	MB13	40341.609	-2926327.188	1560.333	N of Mponeng TSF, N road,	33.5	1996	Timeball Hill Shale and Quartzite	29	1190	0.7	0.1194	0.0363
	MB19	40783.138	-2926315.376	1548.889	N of Mponeng TSF	30	06-Jan-98	Shales	17	100			
4	MB20	40817.786	-2926462.637	1542.922	Next eye,	30	07-Jan-98	Shales (weathered /fractured)	18, 20, 21, 22	100000	337	11.6	14.38
	MB21	41554.497	-2927382.621	1511.25	SE of Mponeng TSF, SE Mponeng RWD	30	08-Jan-98	Shales	18	1600	2		
5	MB22	41434.92	-2927351.213	1515.6	SE of Mponeng TSF, SE Mponeng RWD	30	09-Jan-98	Shales and andesite lava	10	3600	13	0.5573	0.4645
6	MB23	40588.34	-2926345.591	1552.262	North, Upstream of Mponeng TSF	91		Timeball Hill Shale and Quartzite					
7	MB24	40713.433	-2926326.416	1549.807	North, Upstream of Mponeng TSF	100		Timeball Hill Shale and Quartzite					
8	MB25	40558.218	-2926296.015	1556.949	N of Mponeng TSF	100		Timeball Hill Shale and Quartzite					
9	MB26	40654.167	-2926251.919	1557.33	N of Mponeng TSF,	100		Timeball Hill Shale and Quartzite					
12	MB32	41682.655	-2927251.169	1504.987	S of S Mponeng RWD								
13	MB33	40918.33	-2927461.42	1525.01	S of Mponeng TSF								
14	MB34	40273.52	-2927580.86	1537.73	S of Mponeng TSF								
15	MB35	41889.51	-2926555.03	1516.79	E of S s/dam next to soccer field	30		Timeball Hill Shale and Hekpoort andesite				0.47	1.86
16	MB39	39696.64	-2924618.90	1703.90	On Gatsrand up from Wadela circle to Savuka	114	2002	Timeball Hill Shale				0.04	
17	MB50	42984.729	-2924929.963	1562.884	South-west (down gradient) of Mponeng waste dump	35	2003	Timeball Hill Shale and Quartzite	19	seepage			

	ID	X	Y	Z	Description	Borehole depth (m)	Date Drilled	Geology	Dept to water strike (m)	Blow Yield (lt/hour)	T	K (CD)	K (Rec)
18	MB51	43223.784	-2924710.261	1571.453	South-east (down gradient) of Mponeng Waste dump	35	2003	Timeball Hill Shale and Quartzite	18	seepage			
19	MB58	42125.811	-2926303.935	1515.707	Downstream Mponeng (south) sewage works	40	2004	Timeball Hill Shale and Quartzite	35	3000			
20	MB62				Downstream Mponeng Solid Waste Site at TSF Compartment		2008						

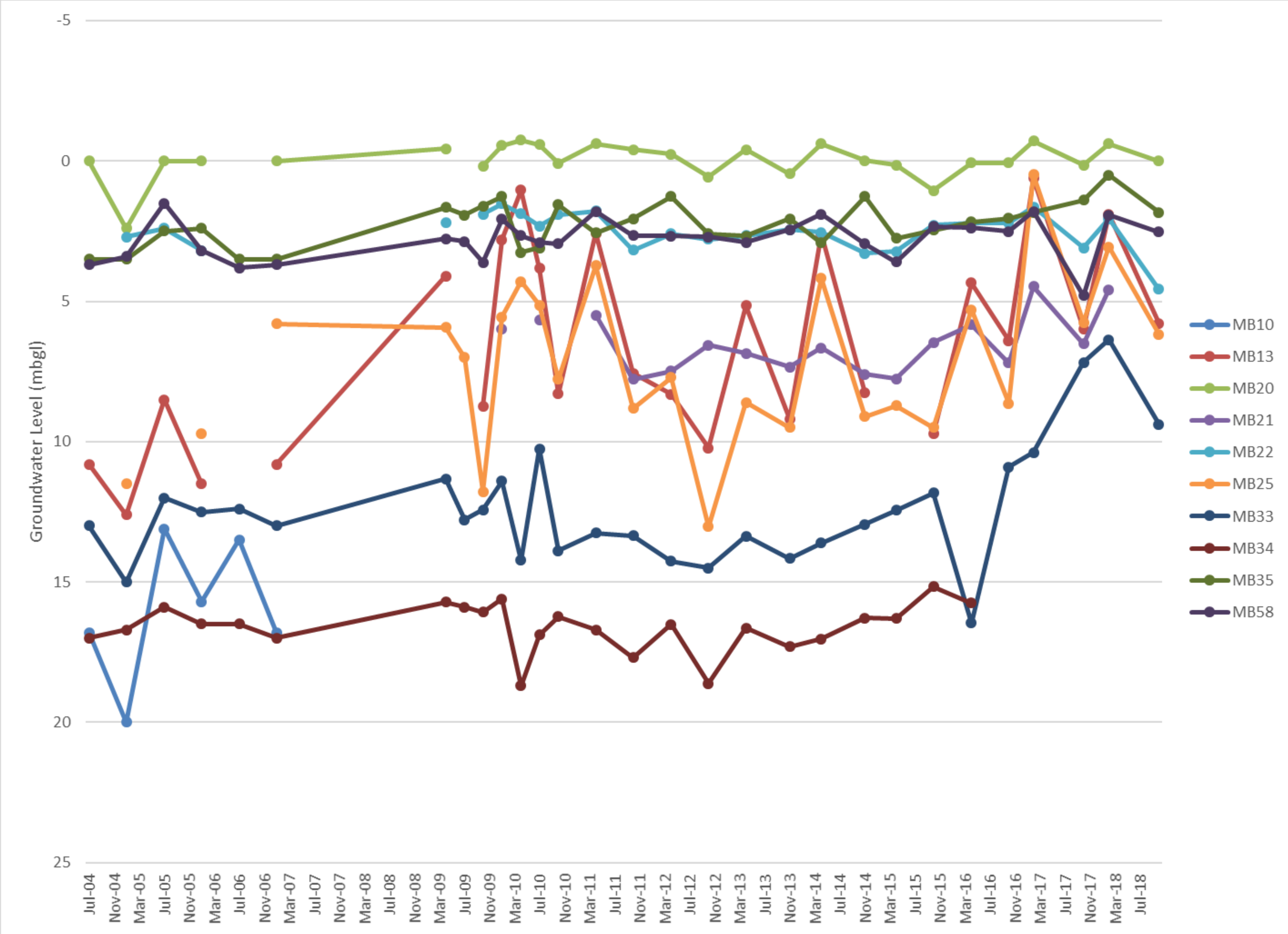


Figure 4-3: Groundwater Levels for the Mponeng Area

5 GROUNDWATER QUALITY

Table 6-2 supplies sulphate and pH trend graphs for the Mponeng TSF monitoring boreholes. These graphs were selected as indicators for areas of concern. All boreholes showed fairly low concentrations of sulphate except for boreholes MB32 and MB35. It should be noted that these boreholes were located in areas where seepage was observed during the field visit. The pH levels were predominantly neutral at most sites with the exception of boreholes MB32 and MB35 where once off acidity anomalies were measured.

6 SURFACE WATER QUALITY

Table 6-1 supplies a list of the surface water monitoring sites at the Mponeng TSF area and Table 6-3 an overview of the sulphate and pH time graphs.

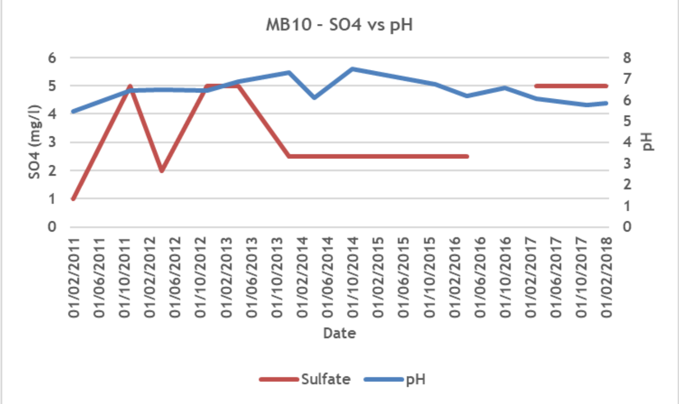
Return Water from the TSF indicates sulphate concentrations in the order of 1500mg/l. Water sampled from the Aquatic Dam overflow indicate sulphate concentrations around 600mg/l. This is a clear indication of up-stream influence from the mining activities.

The inlet to the aquatic dam however showed improvement as well as the spring outflow monitoring sites.

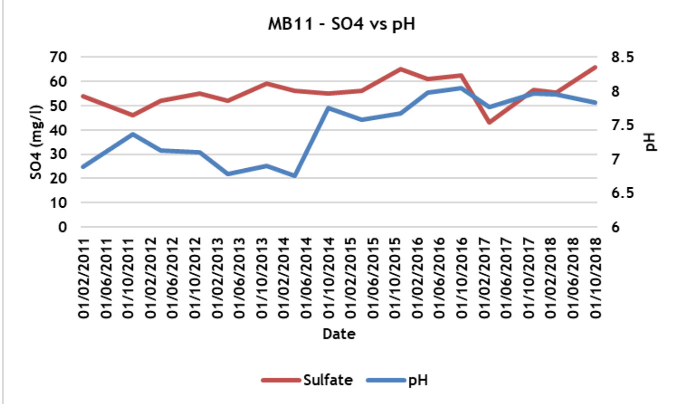
Table 6-1: Existing surface water monitoring sites for the south sub-catchment area

ID	X	Y	Description
WWS2	2927221.34	-41980.02	Aquatic Dam
WWS12	2925136.05	-43730.63	Kennedy Dam
WWS13	2925908.38	-42921.53	Elandsfonteinspruit 1 Below Holding dam (Mponeng Mine)
WWS14	2926274.00	-42230.70	Mponeng Water Care Works purified sewage effluent
WWS17	2927303.21	-41470.86	Mponeng TSF Return Water Dam
WWS25	2926695.14	-40836.92	van Eeden Dam
WWS27	2925662.00	-43401.49	Elandsfonteinspruit 2
WWS35	2927254.74	-42033.61	Aquatic Dam Overflow
WWS43	2925749.41	-43061.17	Inside South Holding Dam
WWS49	2927103.53	-41628.47	Spring Dam outlet
WWS54	2925566.40	-43251.45	
WWS60	2926626.92	-42141.82	Inlet to Aquatic Dam
WWS61	2925717.50	-43053.56	PSE Holding Dam
WWS63	2925533.23	-43131.54	Mponeng Shaft Water to PSE Holing Dam
WWS65	2926858.61	-41625.96	Mponeng TSF underdrains South 15
WWS70	2925818.59	-43023.86	South PSE discharge below bridge before Elandsfontsp.
WWS68	2924547.03	-44050.10	Biesiesvlei Dam
WWS74			Van Eden Spring Dam (Clean)
WWS85			Holding Dam

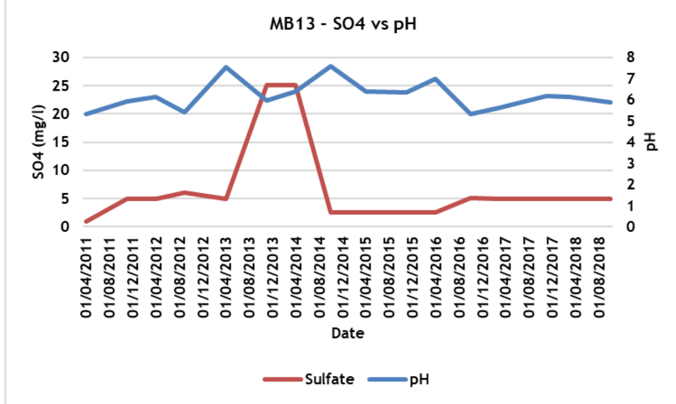
Table 6-2: Sulphate and pH time graphs for the Mponeng Area groundwater monitoring sites



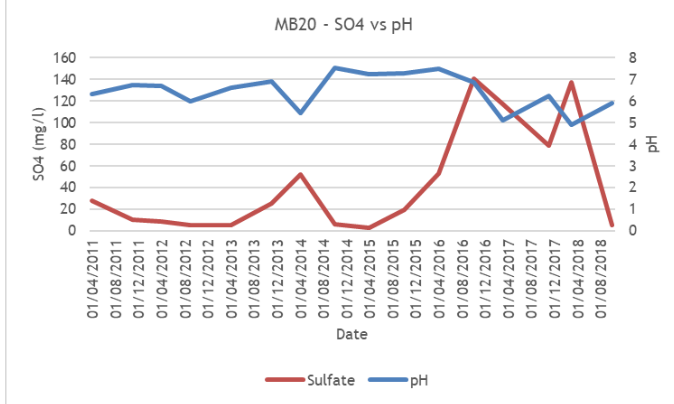
South East of Mponeng Rock Dump; North of Mponeng GP



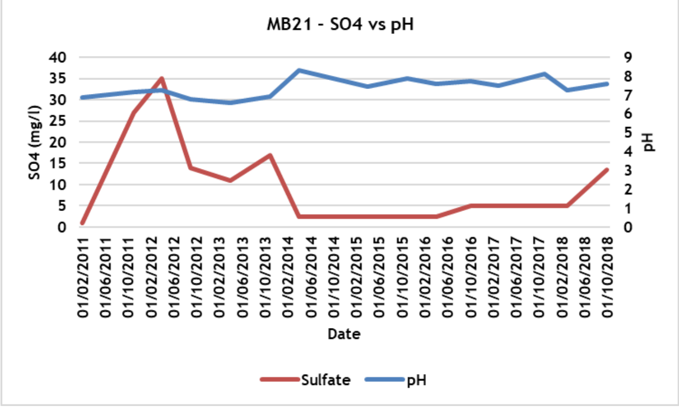
South of Aquatic Dam



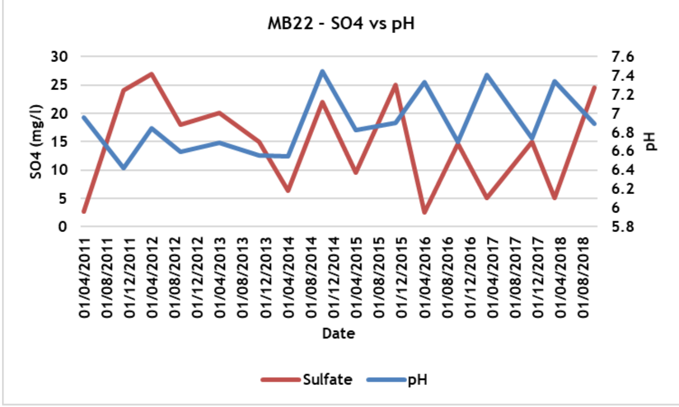
North of South TSF, North of the road, West borehole up gradient of the waste site



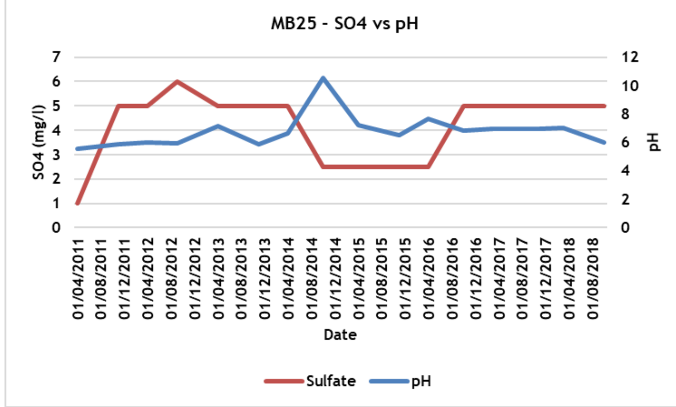
Next to eye, next Spring Water Dam at South Complex TSF



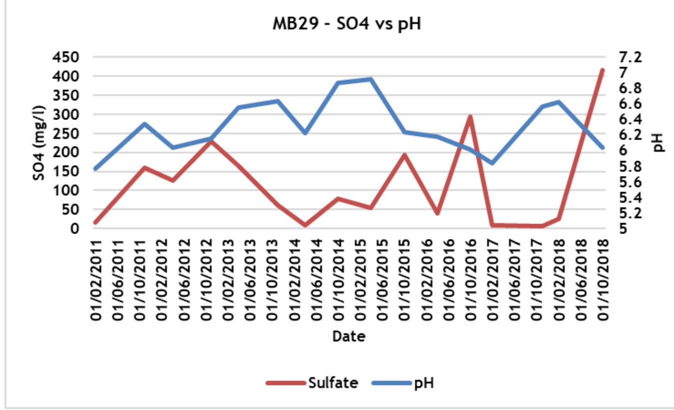
South of Mponeng RWD



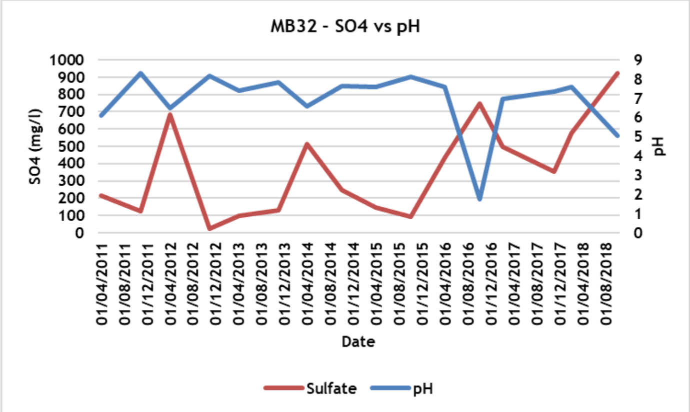
South West of Mponeng RWD



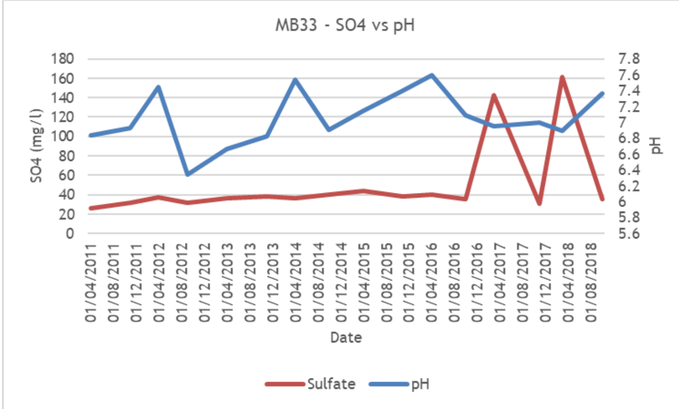
North of South Complex TSF, North of road, middle of 3 BHs



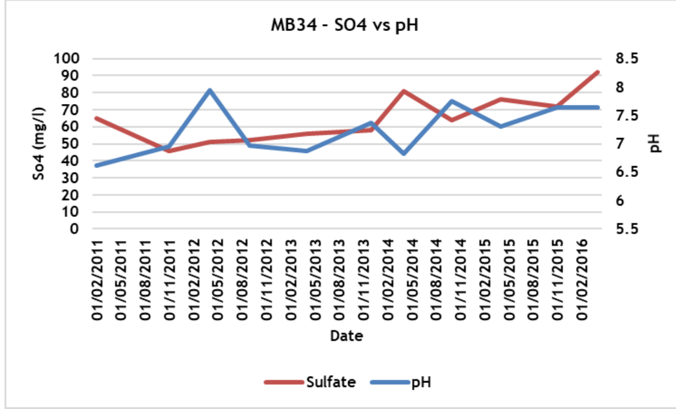
South of anti pollution dams Mponeng Plant



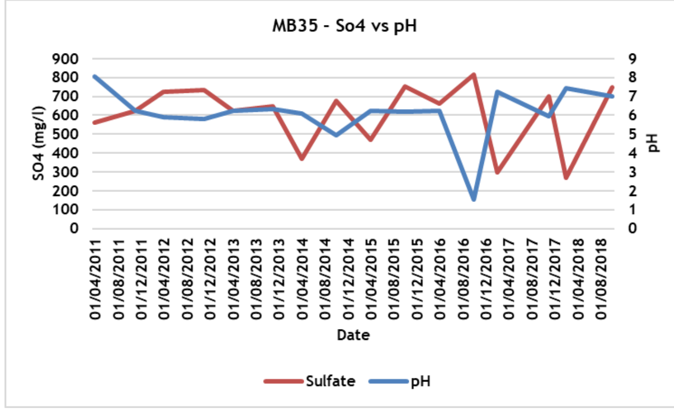
South of South Mponeng RWD



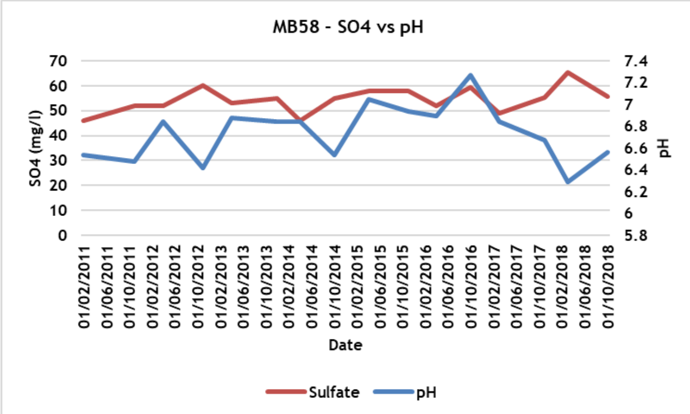
South of South TSF below van Eeden dam



South of South TSF below partition of 2 dams



East of South TSF next to soccer field



Downstream Mponeng (south) sewage works

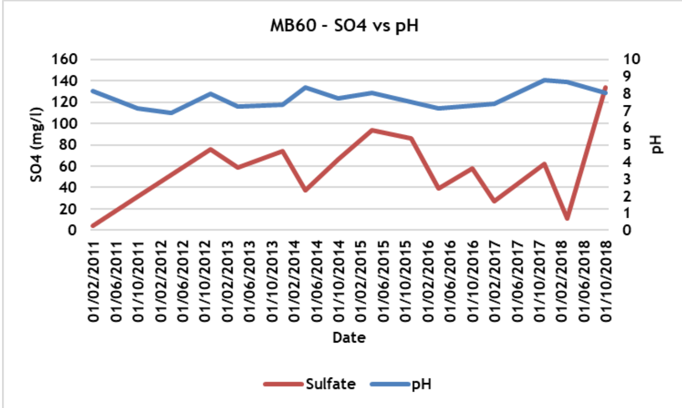
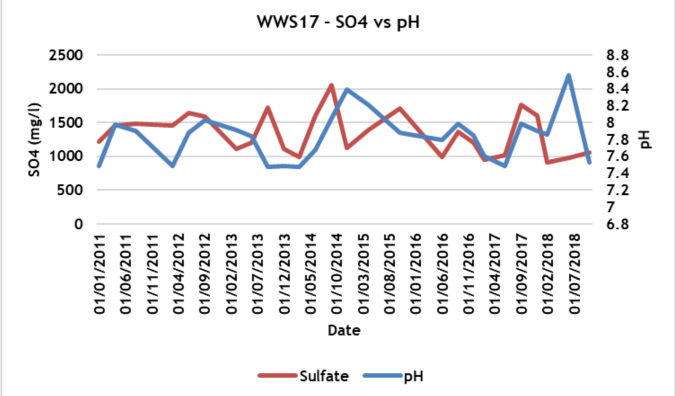
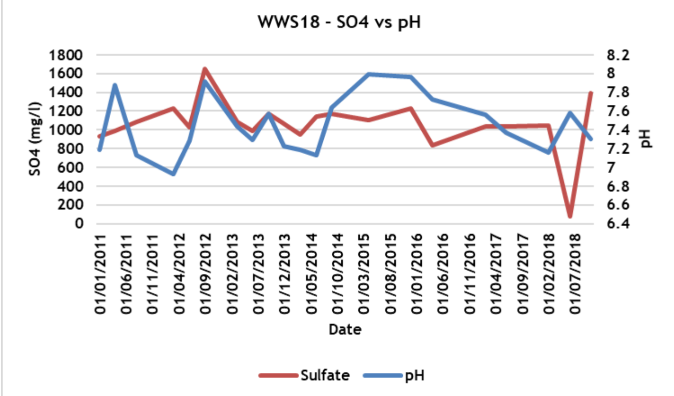


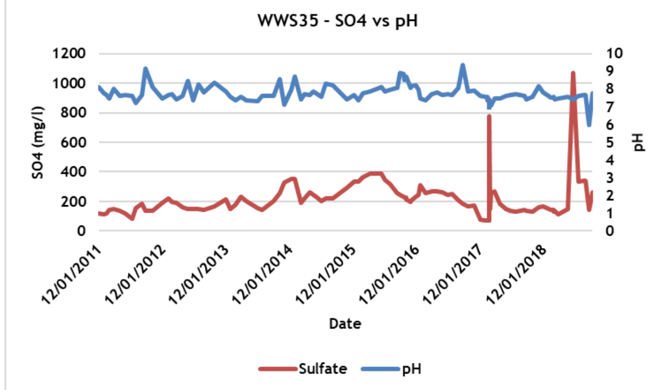
Table 6-3: Sulphate and pH time graphs for the Mponeng Area surface water monitoring sites



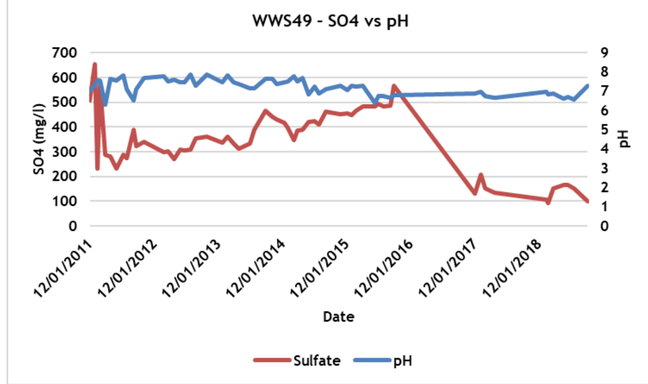
South Dam - South Return Water Dam



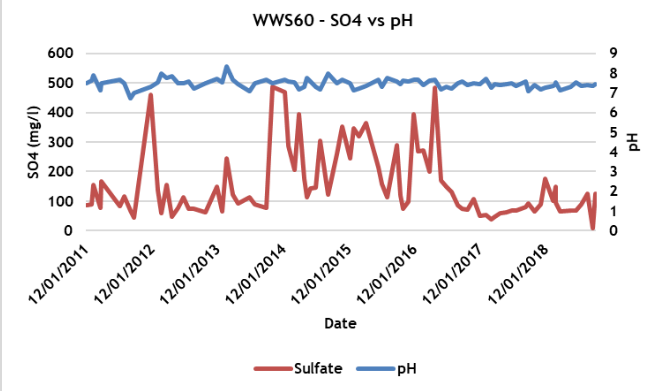
Aquatic Dam - seepage from Mponeng TSF



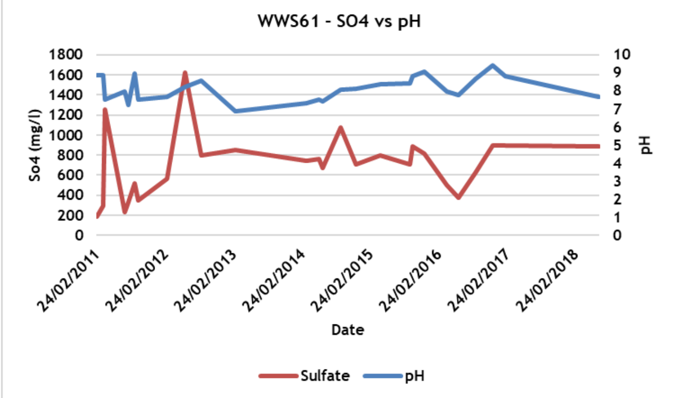
Aquatic Dam overflow into the Elandsfontein Spruit (discharge to the valley)



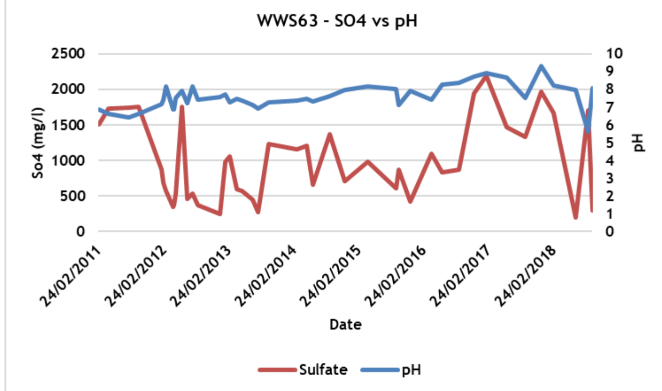
Spring Dam outlet



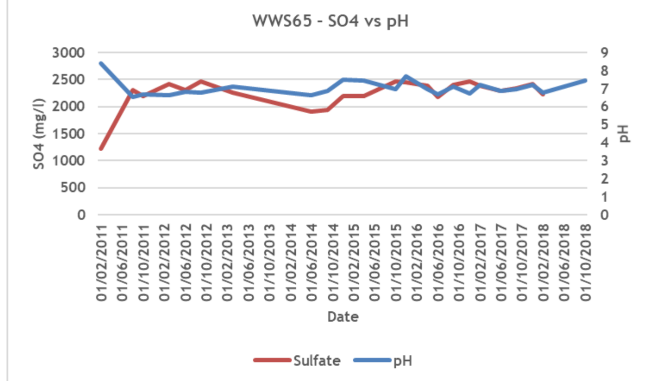
Inlet to Aquatic Dam



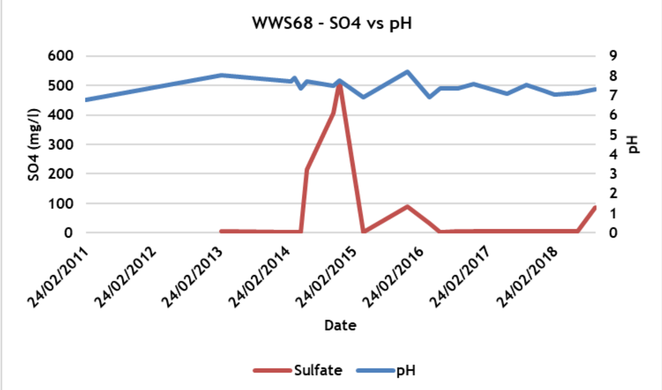
PSE Holding Dam



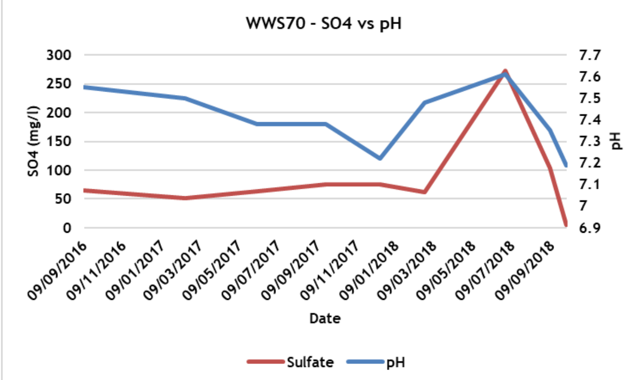
Mponeng Shaft Water to PSE Holing Dam



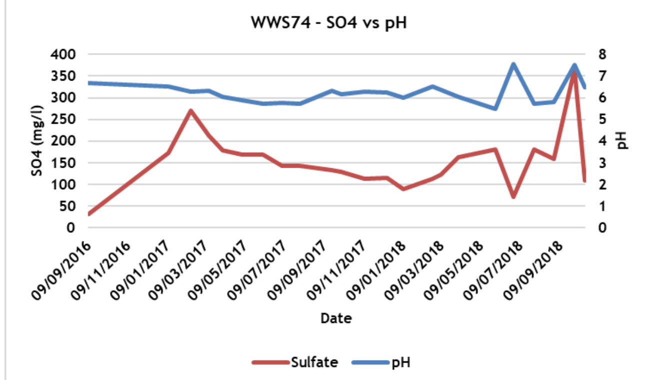
Mponeng TSF underdrains South 15



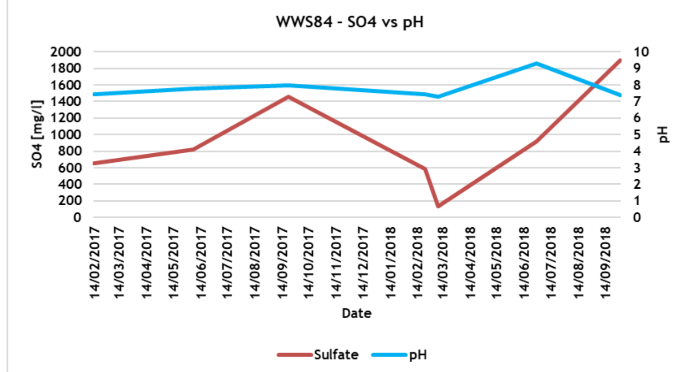
Biesiesvlei Dam



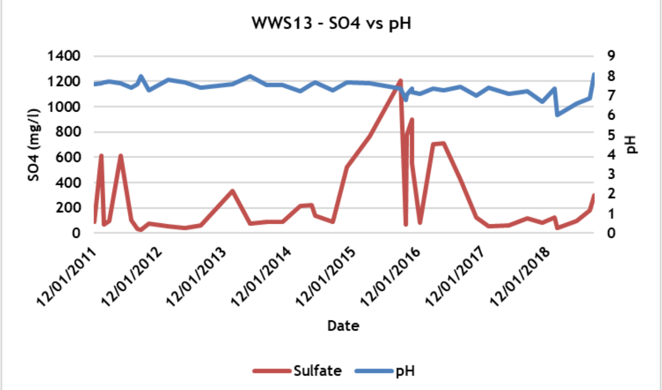
South PSE discharge below bridge before Elandsfontsp



van Eeden Spring Dam clean dam



Mponeng Holding Dam



Below Holding dam (Mponeng Mine)

7 GEOPHYSICAL SURVEY

The geophysical survey at the site was undertaken by conducting an Electrical Resistivity Tomography (ERT) survey as well as a magnetic survey. The ERT survey was conducted using a LS2 terrameter by ABEM and the magnetic survey was conducted using a G5 magnetometer. Table 7-1 supplies an overview of the geophysical line descriptions and Figure 7-1 shows the localities of the lines.

The ERT lines can be viewed in Figure 7-2 to Figure 7-4 and the magnetometer lines in Figure 7-5.

Table 7-1: Description of geophysical lines completed

Line Id	Description	Anomalies
Line 1 Mag	North of Mponeng TSF, from west to east	200m from start
Line 2 Mag	South of Mponeng TSF, from west to east	Only infrastructure noise
Line 3 Mag	North of Mponeng TSF, from west to east	300 to 400m and 700m
RES WW01	ERT Line 1, North of Mponeng TSF, from west to east	240 and 400
RES WW02	ERT Line 2, South of Mponeng TSF, from west to east	Seepage between 800m and 1600m Several localized high resistance anomalies
RES WW03	ERT Line 3, South East of Mponeng TSF, from NE to SW	Seepage zone between 800 and 1400m.

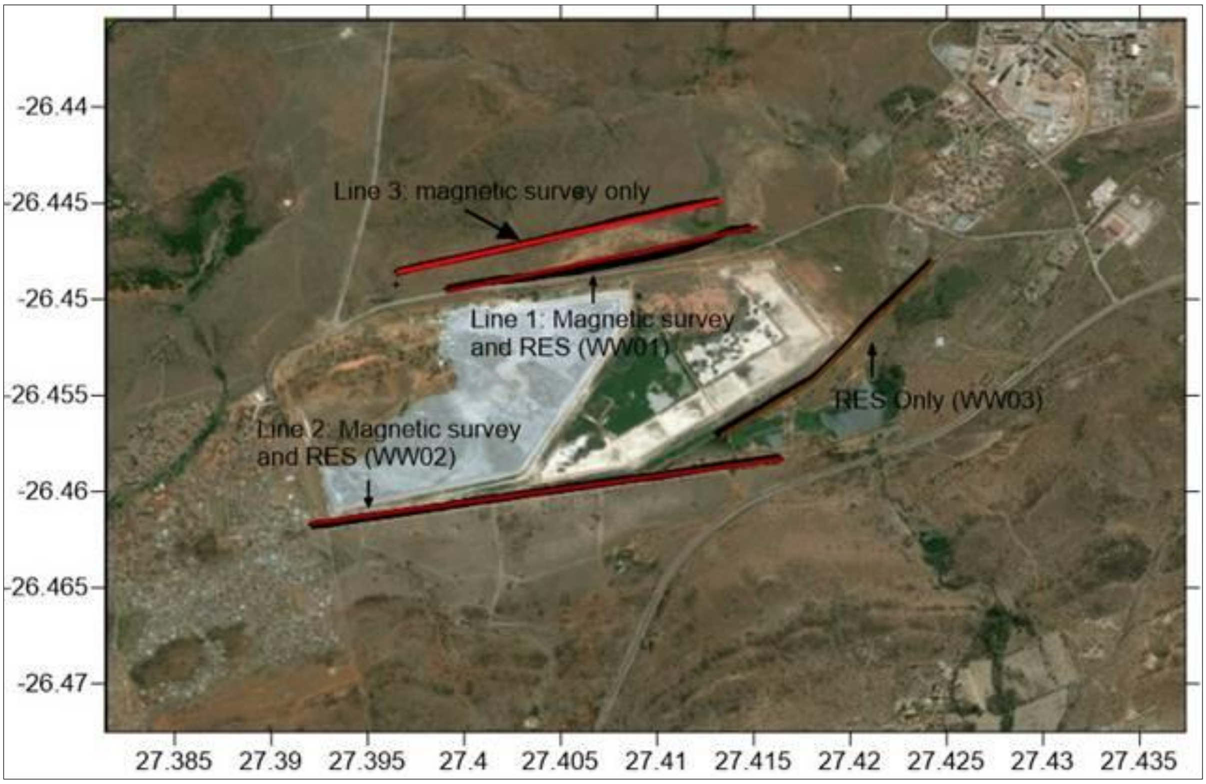


Figure 7-1: Locality of the 2018 geophysical survey

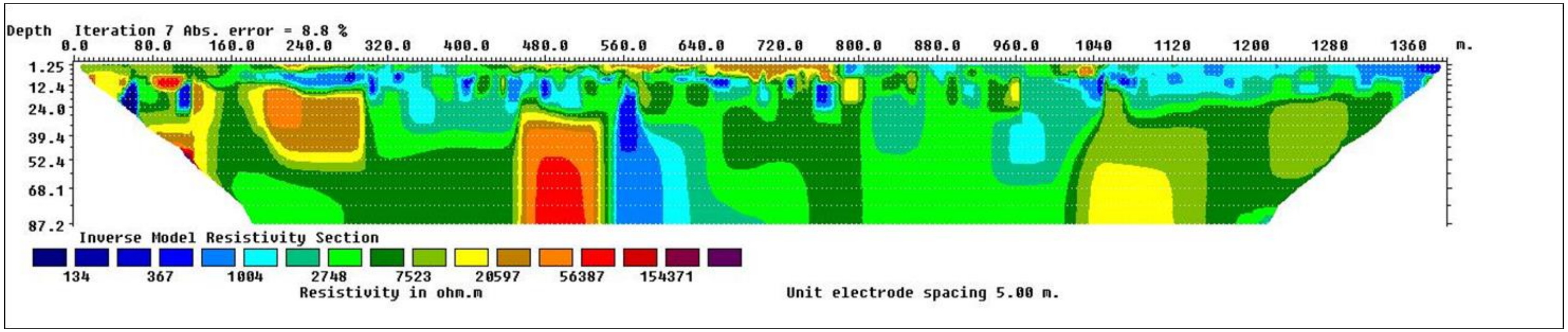


Figure 7-2: ERT Line 1, north of Mponeng TSF, from west to east

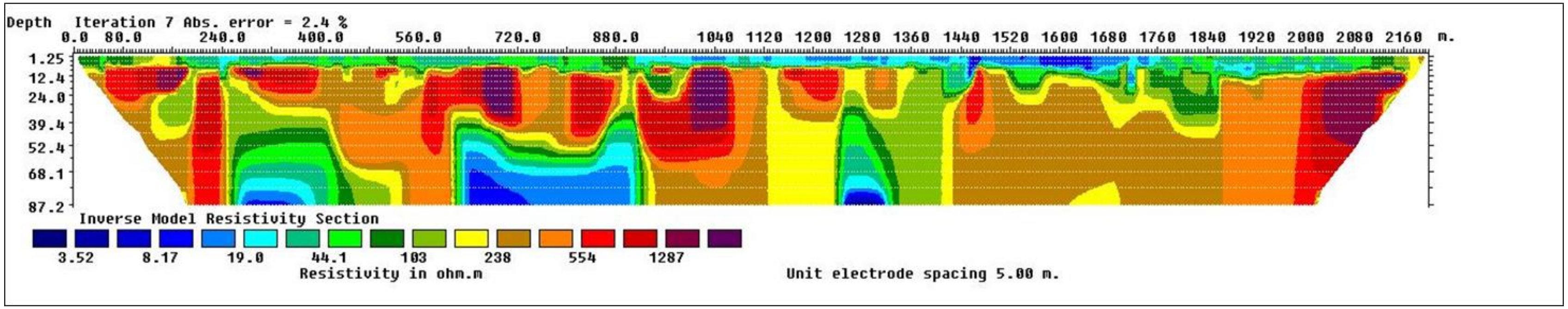


Figure 7-3: ERT Line 2, south of Mponeng TSF, from west to east

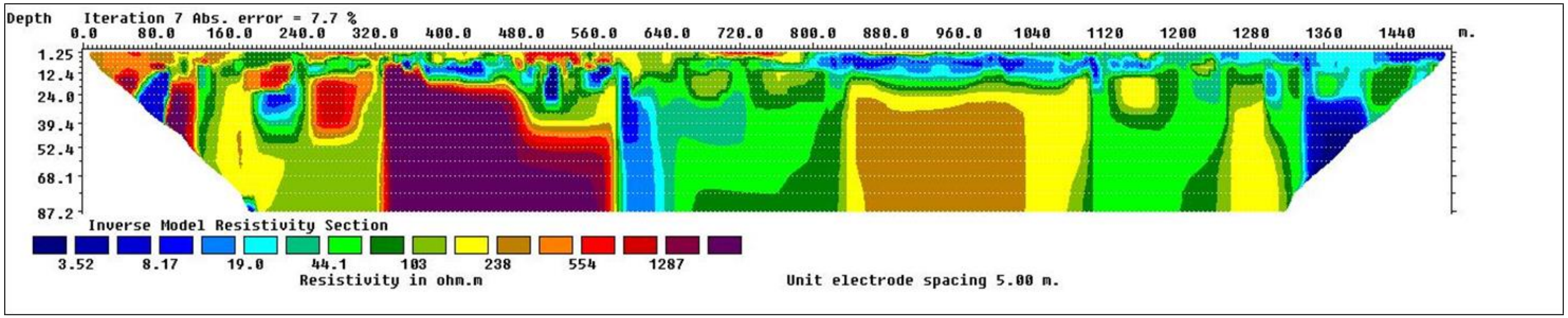


Figure 7-4: ERT Line 3, east of Mponeng TSF, from north-east to south-west

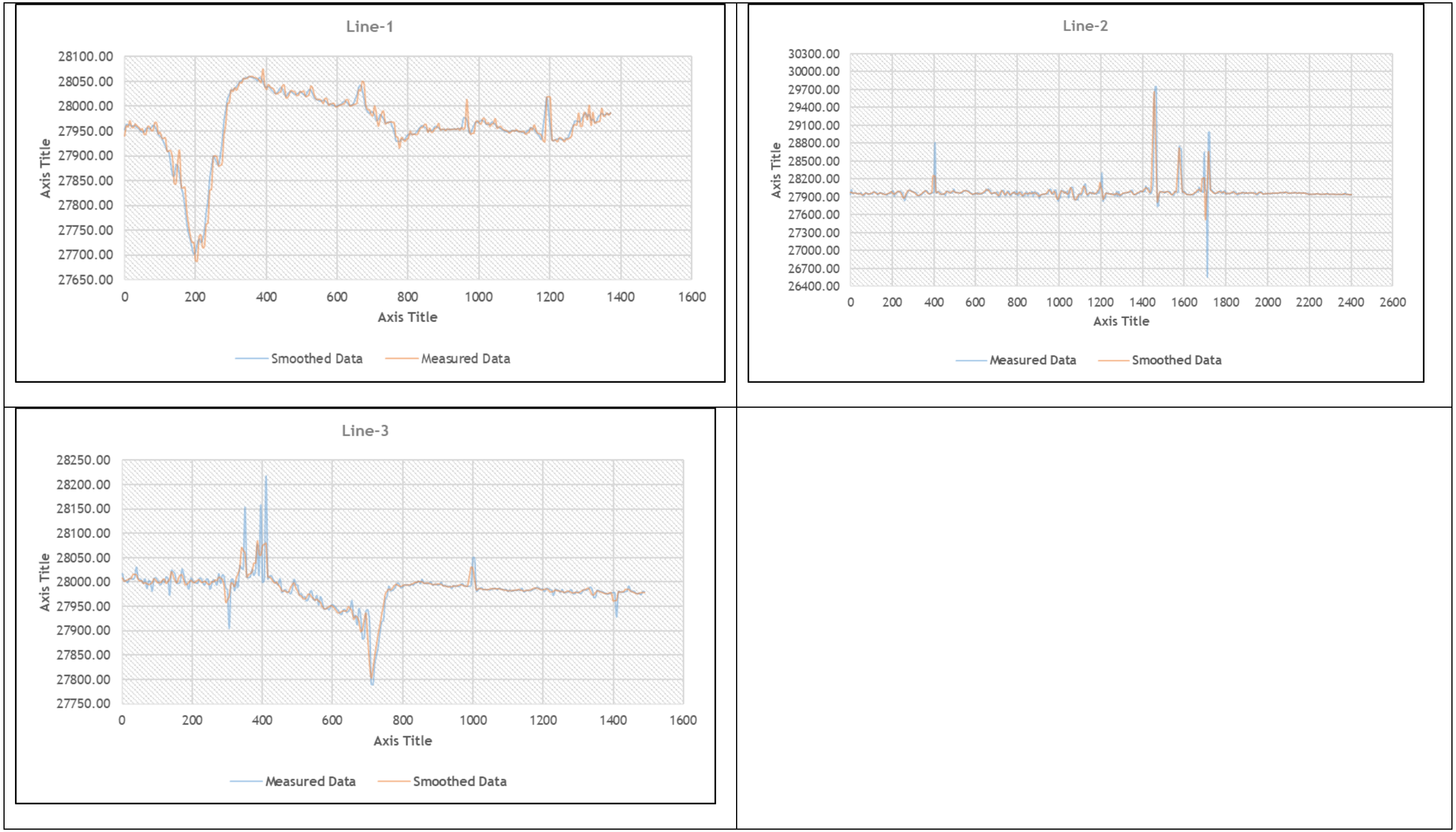


Figure 7-5: MAG Line 1, north of Mponeng TSF, from west to east, MAG Line 2, south of Mponeng TSF, from west to east and MAG Line 3, North of Mponeng TSF, from west to east

8 SOURCE TERM DATA

8.1 Geochemical Overview

Detailed geochemical sampling and modelling were conducted for the Mponeng TSF in 2002 by Pulles Howard and De Lange (PHD). Figure 8-1 shows the positions of the samples obtained. The sampling records are attached in Appendix A.

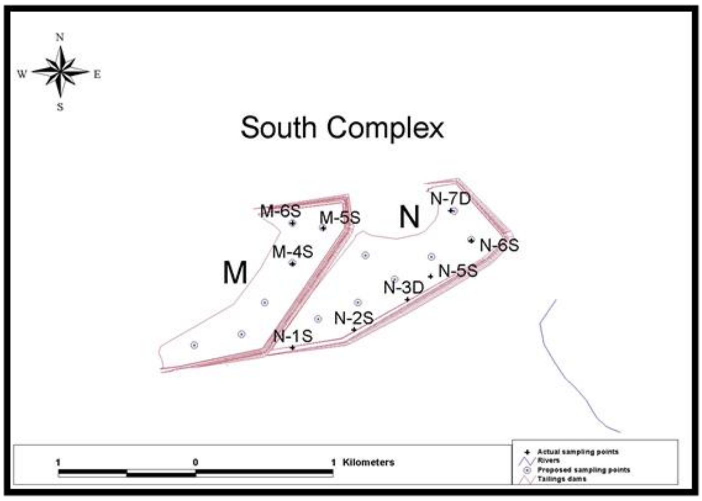


Figure 8-1: Mponeng TSF geochemical sampling positions (PHD, 2002)

Table 8-1 supplies an overview of the acid base accounting data received from the geochemical laboratory analyses. All samples can be classified as "Type 1" and potentially Acid forming (Total S(%) > 0.25% and NP:AP ratio 1:1 or less).

Table 8-1: ABA data for West Wits Mponeng TSF

Sample ID	Paste pH	Total S (%)	AP (kg/t)	NP:AP Ratio	C-NP (kg/t)	C-NNP (kg/t)	Rock Type Total S	Rock Type AP:NP
N-7D	7.24	0.652	20.38	0.48	9.75	-10.63	I	I
N-6S	7.46	0.716	22.38	0.31	7.00	-15.38	I	I
N-5S	7.77	0.764	23.88	0.31	7.50	-16.38	I	I
N-1S	7.96	0.789	24.66	0.11	2.75	-21.91	I	I
N-2S	7.85	0.656	20.50	0.37	7.50	-13.00	I	I
N-3D	7.79	0.691	21.59	0.45	9.75	-11.84	I	I
N-5S	7.77	0.764	23.88	0.31	7.50	-16.38	I	I
N-6S	7.46	0.716	22.38	0.31	7.00	-15.38	I	I
N-7D	7.24	0.652	20.38	0.48	9.75	-10.63	I	I
N-Average	7.62	0.71	22.22	0.35	7.61	-14.61	I	I
M-4D	8.15	0.564	17.63	0.45	8.00	-9.63	I	I
M-5S	8.12	0.713	22.28	0.46	10.25	-12.03	I	I
M-6S	8.02	0.833	26.03	0.38	10.00	-16.03	I	I
M-Average	8.10	0.70	21.98	0.43	9.42	-12.56	I	I

Fergusson and Moring (1991) found that the NP/AP = 1 criterion could be used to separate acid and non- acid producing mines. Total Sulphur content of 0.25 % is also regarded as a criterion to separate acid and non-acid producing mines. Based on these criteria the Mponeng residue deposits, are interpreted to be potentially acid generating facilities (Table 8-2).

Table 8-2: Summary of the ABA data as a preliminary assessment of ARD

Complex/Dam	Paste pH	Total S		NP/AP Ratio (NPR)	
		Total S	AMD?	NP/AP	AMD?
Dam N	7.24	0.71	**Yes**	0.35	**Yes**
Dam M	8.10	0.70	**Yes**	0.43	**Yes**

8.1.1 Geochemical Model

The Mponeng TSF consists of upper and lower dams, both of which are currently operational. The modelling results for the base case are summarised in Figure 8-2 and Table 8-3.

At the first, the pH increases to alkaline at about 8.5 in the first five years, and then stabilises at a circumneutral 7.2 to 7.4. TDS is relatively high, peaking at about 2500 mg/l in the first five years, and then gradually and consistently dropping to below 500 mg/l over the long term.

The significant salts predicted to be leached from this facility are Na, Ca, SO4 and HCO3, each of these showing an early peak with a gradual tapering off over time.

Table 8-3: Base case modelling results for West Wits south tailings dams

Parameter	First 5 years	10 years	20 years	20-100 years
pH	Alkaline – up to 8.2	Drop to 7.2	7.3	7.4
TDS (mg/l)	To about 2500	About 1800	1500	500
SO4--	700	900	900	150
Major cations (>500mg/l)	Na, Ca, HCO_3	Na, Ca, HCO_3	Na, Ca, HCO_3	Na, Ca, HCO_3
TDS Load (t/annum)	470	340	280	95

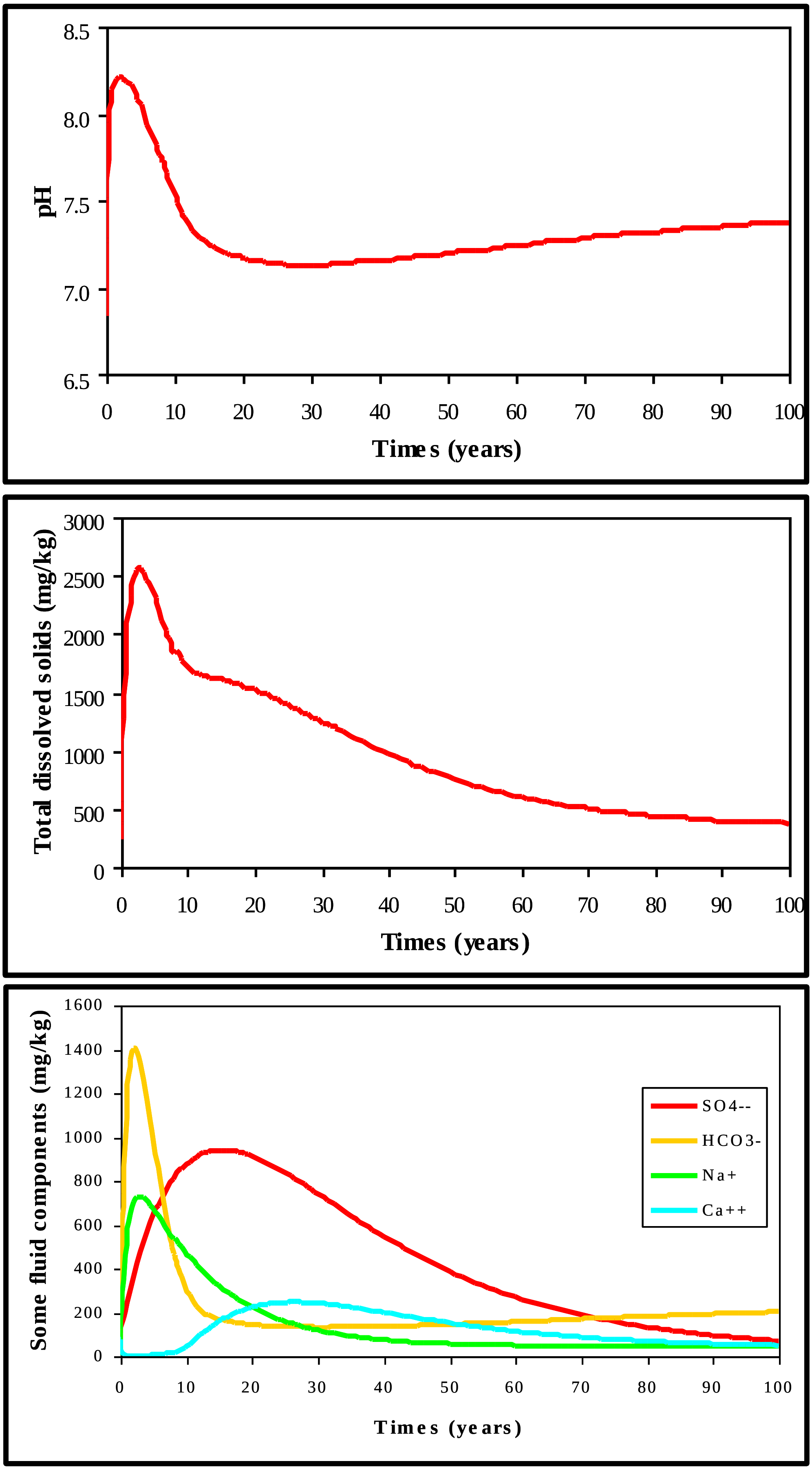


Figure 8-2: **Base case scenario for West Wits south tailings dam**

The major results from the base case geochemical modelling are summarised in Table 8-4. Although the long term water quality characteristics of each facility are different, they can be grouped in the following ways:

pH classification

P1. Facilities predicted to turn and remain strongly acid (pH<5)

P2. Facilities predicted to turn and remain slightly acid (pH 5-6.5)

P3. Facilities predicted to remain neutral to alkaline (pH >6.5)

P4. Facilities with initial strongly acid conditions rapidly returning to slightly acid to neutral

Salinity classification

S1. Facilities with persistent very high salinity (TDS > 3000 mg/l)

S2. Facilities with persistent medium salinity (TDS 1000 – 3000 mg/l)

S3. Facilities with persistent low salinity (TDS < 1000 mg/l)

S4. Facilities with initial medium to high salinity declining to low salinity

Table 8-4: Summary of the results from base case modelling for long term water quality prediction

Facility	pH Characteristics		Salinity Characteristics		
	Class.	Min. pH	Class.	Max TDS (mg/l)	Max salt load (t/a)
WW old north tailings complex	P1	4.9	S2	2000	400
WW new north 5A/5B tailings dams	P3	6.7	S3	1050	75
WW new north 7A/7B tailings dams	P3	7.3	S2	2000	370
WW Mponeng tailings dam	**P3**	**7.1**	**S4**	**2500**	**470**

The results in Table 8-4 are also colour coded from green (best case) to orange (intermediate case) to red (worst case). **In assessing the results, it must be stressed that the geochemical modelling was undertaken as a screening level study and the absolute values shown here should not be taken as definitive but rather as indicative.**

8.2 Seepage Modelling

8.2.1 Geotechnical Data (SLR, 2017)

Based on the profiling, core logging and laboratory testing the soils underlying the Mponeng TSF complex can be characterised as follows:

- The Colluvium had a mean gravel, sand, silt, and clay content of 61, 22, 12 and 5 % respectively and is classified as a SC according to the Unified Soils Classification System and can be described as a clayey sand with gravel. The in situ moisture content is at 10 % with a Liquid Limit of 25 % and a Plasticity Index of 10%.The permeability of the Colluvium is expected to range between 1.99×10^{-4} m/s (17.27 m/day) and 3.85×10^{-6} m/s (0.33 m/day).
- The Coarse Colluvium had a mean gravel, sand, silt and clay content of 66, 19, 10 and 5 % respectively and is classified as a GP-GC according to the Unified Soils Classification System and can be described as a poorly graded gravel with clay. The in situ moisture content is at 9 % with a liquid limit of 25% and a Plasticity Index of 10. The permeability of the coarse colluvium is expected to range between 1.99×10^{-4} m/s and 8.8×10^{-9} m/s (0.00076 m/day), depended on the fines type and content.
- The Residual Shale had a mean gravel, sand, silt and clay content of 48, 24, 20, 8% respectively and is classified as a GM according to the Unified Soils Classification System and can be described as a silty gravel with sand. The in situ moisture content is at 14% with a liquid limit of 34% and a Plasticity Index of 11%. The permeability of the Residual Shale is expected to range between 1.99 x 10^{-4} m/s and 1.5×10^{-9} m/s.
- The Shale bedrock can be described as weak rock with a UCS of between 5 and 25 MPa which is thinly bedded horizontally. The typical mi constant for a Shale is 6 and given the description of the Shale it is expected to have a Geological Strength Index (GSI) between 45 and 55.
- The overall average permeability calculated from the 2013 piezocone test results was 2.2×10^{-8} m/s. A value of 1×10^{-8} m/s was chosen for the tailings for the seepage modelling in order to simplify the assessment.

A total of 3 rotary cored boreholes (DLM01 to DLM03) at Mponeng TSF Complex were drilled by Roelf Fourie geotechnical services during 15 November to 8 December 2016.

A summary of the ground conditions encountered during the rotary core drilling geotechnical investigation indicates that the Mponeng TSF site comprised the following horizons (the geological logs and core photos are attached in Appendix B):

- Fine Colluvium: The material comprises generally dry, reddish brown to dark brown, medium dense or firm, silty sand or clayey silt.

- Residual Shale: The consistency of soils derived from the Shale were found to be stiff to very stiff, showing the typical relic jointed and bedding structure and consisted of clayey silt sand with scattered angular shale gravel, similar to what was encountered during test pitting.
- Carbonaceous Shale Bedrock: Carbonaceous Shale bedrock was exposed across the Mponeng TSF site during the drilling and is described as dark grey, moderately weathered, fine grained, thinly bedded, weak rock. The Shale bedrock was encountered at an average depth of 2.7 m (minimum and maximum depth of 0 m and 7.5 m respectively)

8.2.2 Seepage Assessment

The seepage assessments were conducted using SEEP/W (2007) version 7.20, which is a Windows based software programme from Geo-Slope. SEEP/W is a finite element software programme used for analysing groundwater seepage and excess pore-water pressure dissipation problems within porous materials such as soil and rock. Its comprehensive formulation allows the user to consider analyses ranging from simple, saturated steady-state problems to sophisticated, saturated/ unsaturated time dependent problems. For this project, the seepage models were analysed for steady-state conditions. Under steady state conditions, the flux entering and leaving an elemental volume is the same at all times. The cross section lines are also presented in Figure 8-3 and a typical cross section view from Seep/W software presented in Figure 8-4.

The purpose of the seepage modelling is to determine the location of the phreatic surface and foundation seepage range. The seepage models were calibrated using the phreatic surface results obtained from the 2013 piezocone testing and standpipe piezometer data at various cross sections.

The material parameters used in the seepage models were determined from the 2013 piezocone investigation, the 2013 tailings test work, the geotechnical investigation on the foundation materials (refer to Section 5) and experience on similar materials. The material parameters used in the seepage model analyses are shown in Table 8-5.

Table 8-5: Material Parameters (SLR, 2018)

Material	Horizontal Coefficient of Permeability k_h (m/s)	Conductivity Ratio (k_x/k_y)	Vertical Coefficient of Permeability K_v (m/s)
Average (Daywall) Tailings	1×10^{-8}	0.5	5×10^{-9}
Coarse Tailings	1×10^{-8}	0.5	5×10^{-9}
Medium Tailings	1×10^{-8}	0.1	1×10^{-9}
Fine Tailings	1×10^{-8}	0.1	1×10^{-9}
Starter Wall	1×10^{-9}	1.0	1×10^{-9}
Drain	1×10^{-6}	1.0	1×10^{-6}
Colluvium	1.4×10^{-7}	1.0	1.4×10^{-7}

Residual Shale	1×10^{-7}	1.0	1×10^{-7}
Residual Andesite	6×10^{-8}	1.0	6×10^{-8}
Shale Bedrock	1×10^{-9}	1.0	1×10^{-9}
Andesite Bedrock	1×10^{-9}	1.0	1×10^{-9}

Two basic scenarios were modelled to obtain an idea of the seepage potential of the Mponeng TSF, these were 60m (1599 mamsl) and 66m (1581 mamsl) final height for the lower and upper TSF compartments respectively and the current status heights. The results are summarised in Table 8-6 below.

Table 8-6: Summary of the Seep/W results – presented as a range in m^3/day/ha

Tailings Storage Facility	Scenario	Seepage Flux Range (m^3/day/ha)	
Mponeng Lower TSF	Scenario 1 (Elevation - 1540 mamsl) Current Height	0.010	0.305
	Scenario 2 (Elevation - 1581 mamsl) Final Height = 66m	0.046	0.967
Mponeng Upper TSF	Scenario 1 (Elevation - 1577 mamsl) Current Height	0.010	0.527
	Scenario 2 (Elevation - 1599 mamsl) Final Height = 60m	0.016	0.880

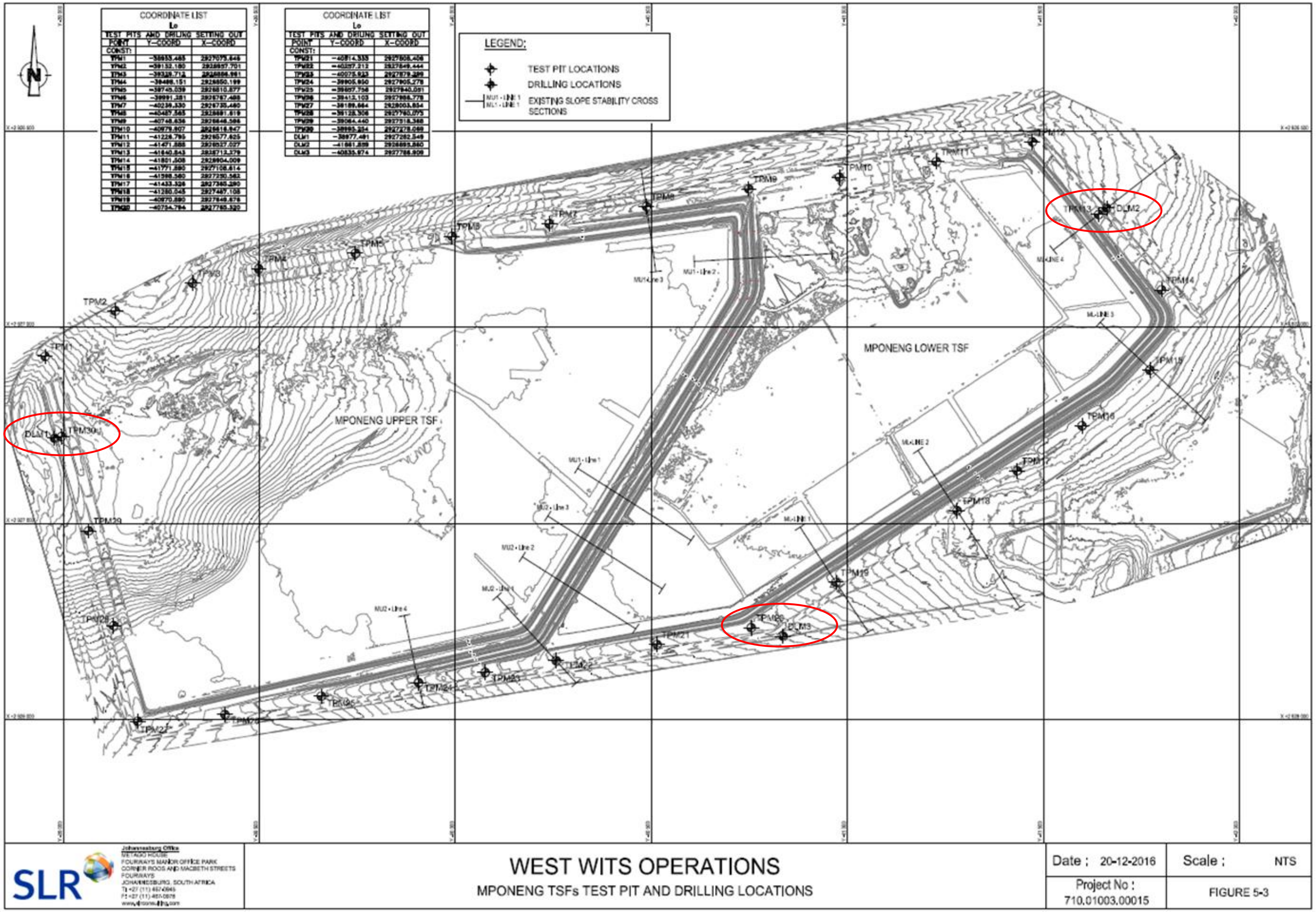
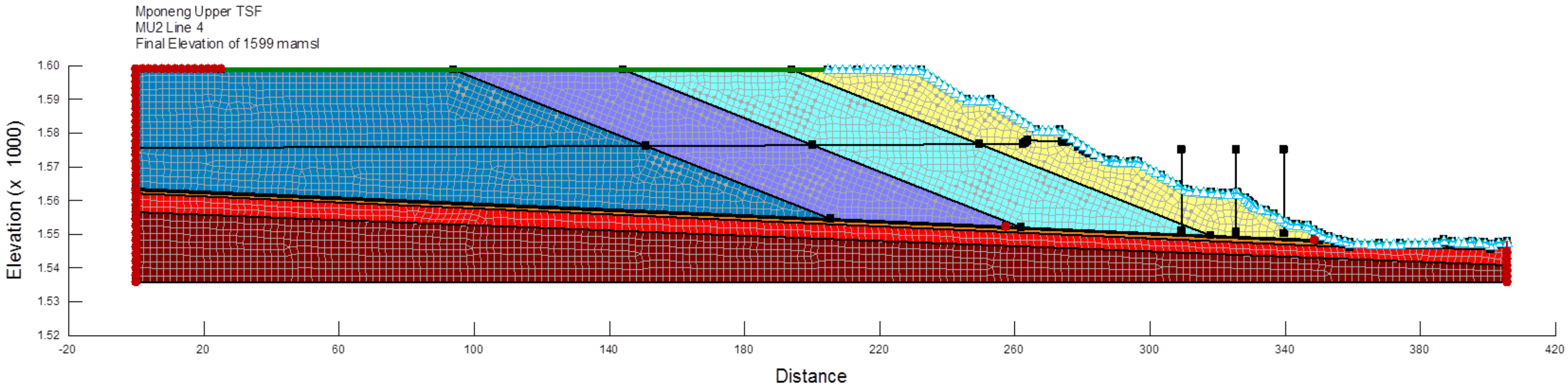


Figure 8-3: Locations of Tests pits and Core boreholes (core locations circled with red)



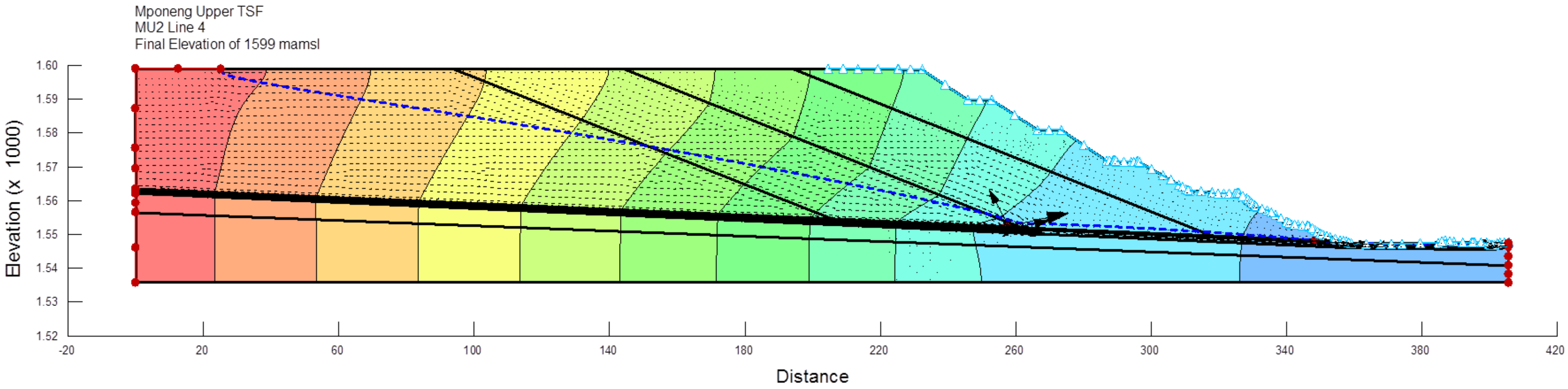


Figure 8-4: Typical cross section line with Seep/W model software

9 MPONENG NUMERICAL GROUNDWATER MODEL

9.1 Introduction

The purpose of the following section is to combine all the available hydrogeological data into a mathematical platform where the knowledge of the system is integrated to simulate typical tailings storage conditions and identify knowledge gaps and areas of uncertainty. The model provides important insight on how the Mponeng aquifer currently reacts and how it might react when future TSF expansion is implemented.

Appendix C – Numerical Groundwater Model Setup, supplies an overview of the numerical groundwater model setup as well as insights on the transient state model.

The effect of tailings seepage and groundwater flow will be simulated. The model provides an estimate of the mass transport and associated impact on the aquifer and Vaal River. Furthermore the model assists with the feasibility assessment of possible interception and intervention methodologies.

It is important to note that this preliminary numerical groundwater model would require future updates as more data becomes available. Specifically, monitoring data regarding the system behavior due to head fluctuations/increase and influences on the boundaries to improve the prediction capability of the model.

9.2 Model Limitations and Assumptions

The following assumptions were applied:

- Limited aquifer tests have been completed, aquifer properties for the different geological units were averaged for the preliminary numerical applications as per the discussion above.
- It is assumed that the aquifer is a continuous unit between the boreholes and that no compartmentalization exits within the identified aquifer zones apart from lower and higher hydraulic conductivity zones.
- It is believed that the numerical groundwater model represents conservative predictions.

9.3 Sulfate Mass Transport Simulation

After calibration of the groundwater flow model (Appendix C), the sulphate mass transport was simulated.

After the calibration of the groundwater flow model, the mass transport model was set up using the MT3DMS[1] model package. Sulphate was applied as the mass transport indicator.

The recharge concentrations are based on seepage flow (under-drain) monitoring data as per Figure 9-1 and geo-chemical data (PHD, 2002) ranged between 800 and 2200 mg/l SO4.

Table 9-1 supplies the seepage rates used in the numerical groundwater model.

[1] *A modular three-dimensional multispecies transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems*

Table 9-1: Seepage analyses rates applied in model

Tailings Storage Facility	Scenario	mm/day High	mm/annum	Model Use
Mponeng lower TSF	Scenario 1 (Elevation - 1540 mamsl) Current Height	0.0305	11.1325	15
	Scenario 2 (Elevation - 1581 mamsl) Final Height = 66m	0.0967	35.2955	50
Mponeng upper TSF	Scenario 1 (Elevation - 1577 mamsl) Current Height	0.0527	19.2355	25
	Scenario 2 (Elevation - 1599 mamsl) Final Height = 60m	0.088	32.12	40

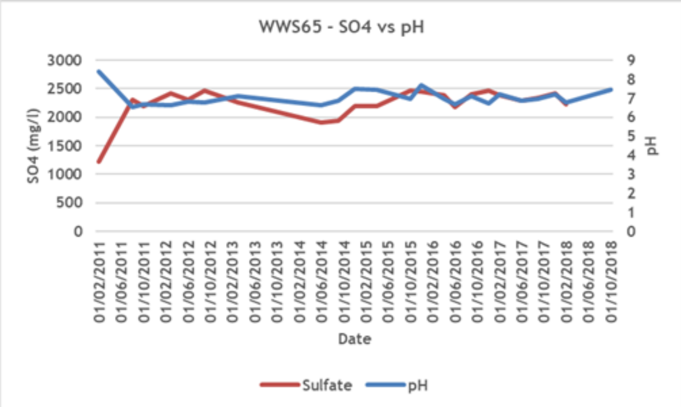


Figure 9-1: Mponeng TSF underdrains South 15 Sulphate Trend Graph

9.3.1 Mass Transport Calibration

The monitoring data was applied as observations points across the model grid and acceptable correlation between the observed and calculated concentrations were obtained (Figure 9-2).

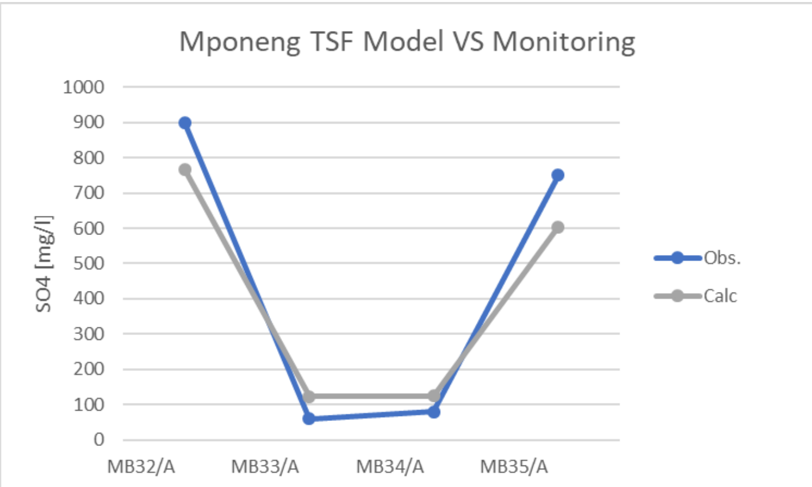


Figure 9-2: Calculated vs observed concentrations obtained for the South Model

9.4 Scenario Modelling

Recharge cells and recharge concentrations cells were applied to simulate seepage and sulphate mass transport. Recharge applied were based on the seepage calculations (SLR, 2018) and sulphate concentrations on available monitoring and geochemical data as discussed above. Two basic scenarios were simulated and supplies an overview of the current and predicted life of mine sulphate plume dimensions. Groundwater management will be discussed in the next section.

- The 1st Scenario is to use the 2017 SLR seepage model and apply an approximate foundation seepage range. This will be called "Status Quo" or current status. The current status sulphate plume, based on 2018 monitoring results, is presented in Figure 9-3. Overall sulphate concentrations appears to be fairly low and stable in most the groundwater monitoring sites except for monitoring boreholes MB32 (down-gradient of the return water dam) and MB35 (east of the south eastern corner of the lower compartment). Sulphate concentrations, overall are below 100 mg/l but above 500 mg/l in these two boreholes. It appears if geological lineaments and seepage flux from the TSF and RWD add to mass flux at these 2 boreholes.
- The 2nd scenario is where the lower compartment be raised to a height of 66m (1599 mamsl) and the upper compartment to 60m (1581 mamsl) final height. The predicted sulphate plume for the year 2060 is presented in Figure 9-4. This includes all proposed water management and upgraded return water dam facility. The assumption was applied that zero to limited seepage will occur from the return water dams because of proper lining implemented. Overall, sulphate concentrations tend to be on the low side and the sulphate plume contained to the direct vicinity of the TSF.

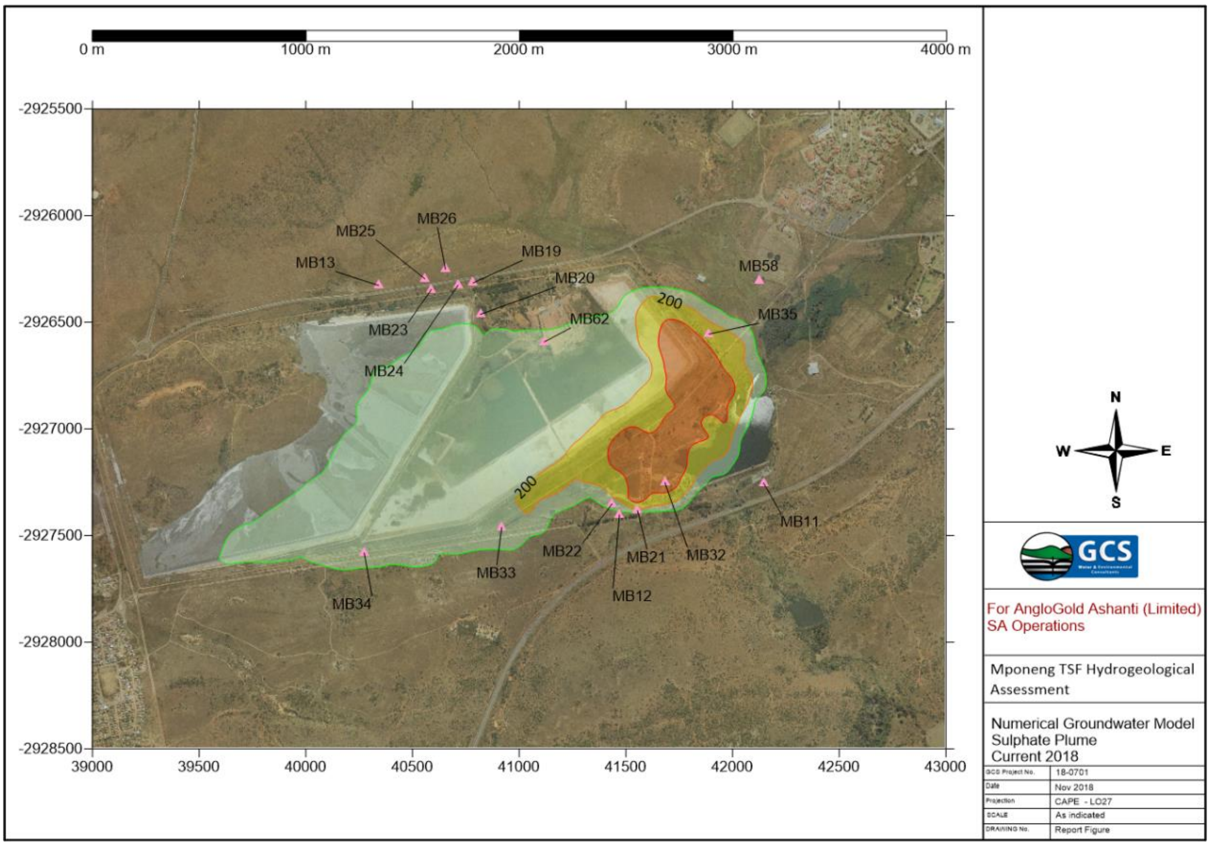


Figure 9-3: Current status of the Mponeng TSF sulphate plume (2018)

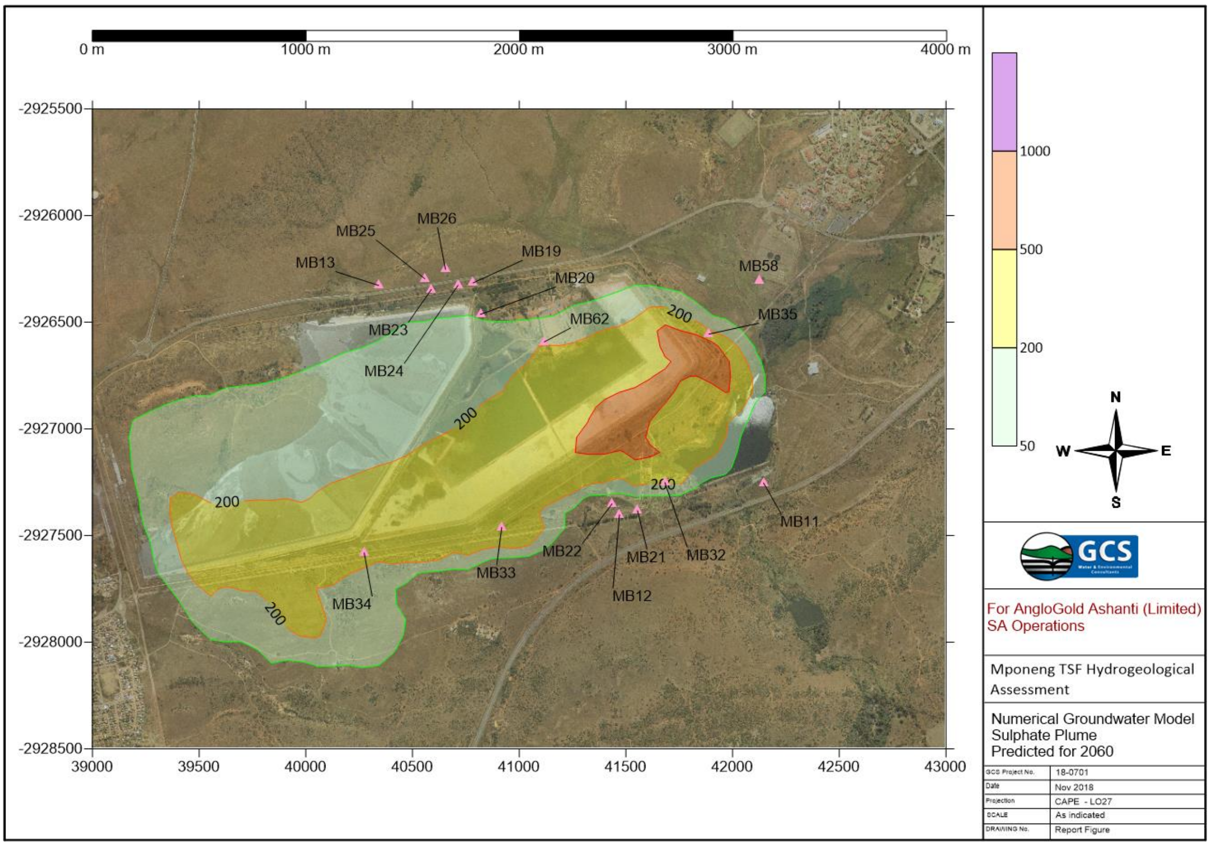


Figure 9-4: Predicted sulphate plume at 2060, three years before final life of facility is reached

10 DISCUSSION

The following risk areas have been identified through the work completed above and discussed in this report:

- Seepage from the TSF and associated drainage infrastructure appears to have a low to medium salt load effect on the Aquatic Dam. It can be seen from Figure 10-1 that sulphate concentrations at the outlet are around 200mg/l and inlet around 100mg/l, measured up-stream. This suggests that some degree of deeper seepage from the TSF/RWD occurs and appears to be a stable source of sulphate influx into the aquatic dam.

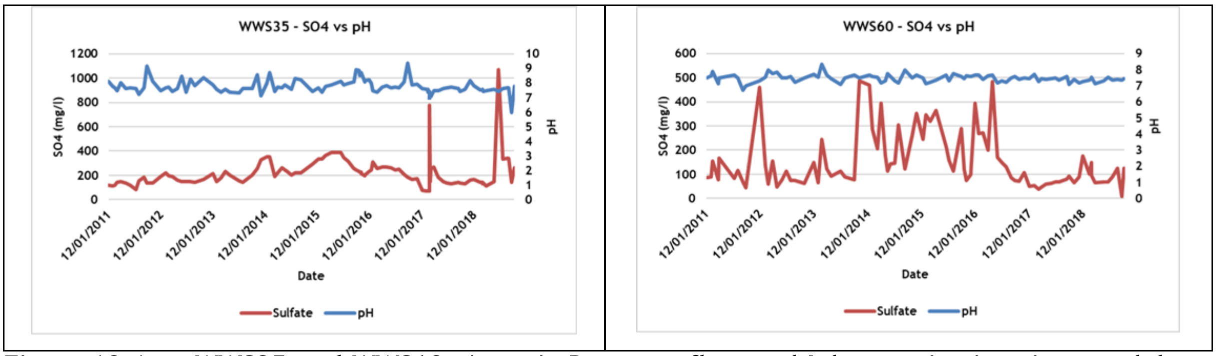


Figure 10-1: WWS35 and WWS60, Aquatic Dam overflow and Inlet monitoring sites - sulphate time graphs

- Significant groundwater seepage from the TSF and RWDs is evident in two areas, monitoring boreholes MB32 and MB35. Monitoring borehole MB33 is also starting to indicate signs of sulphate flux from the TSF (Figure 10-2). The groundwater level at these three boreholes also indicates a gentle increase as a result of seepage (Figure 10-3).

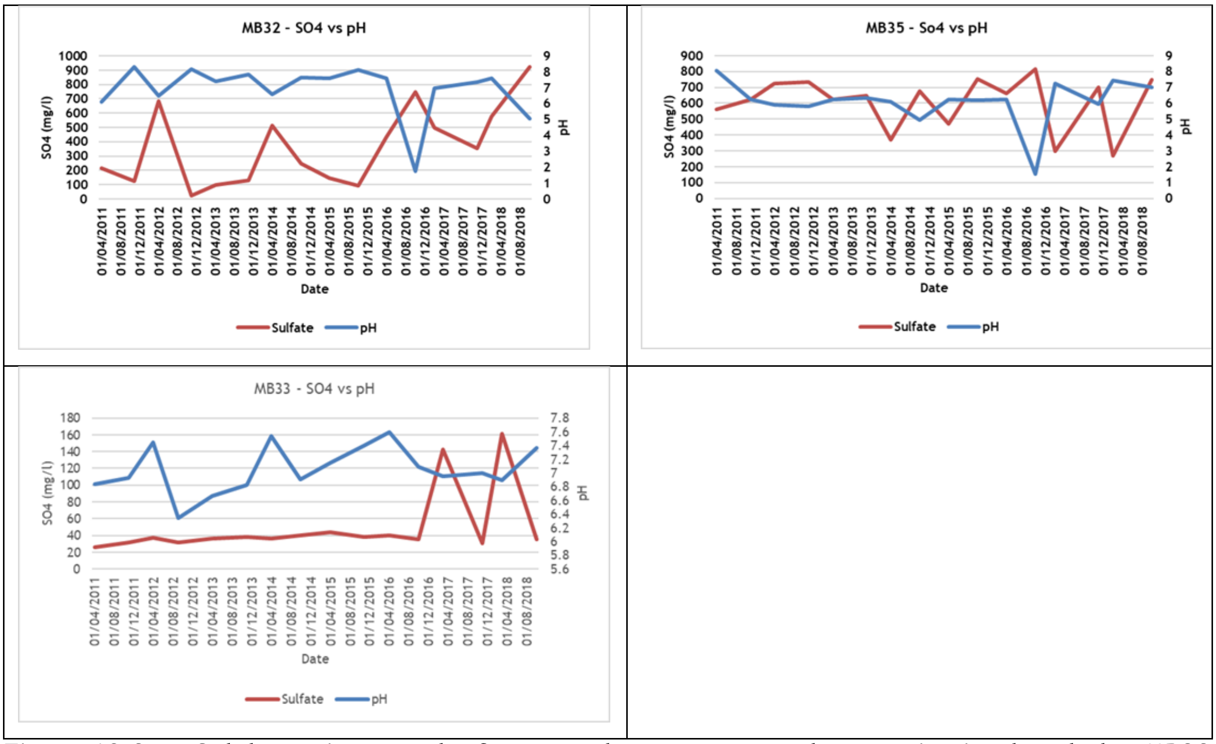


Figure 10-2: Sulphate time graphs for groundwater measured at monitoring boreholes MB32 (south at RWD), MB33 (south) and MB35 (east of TSF)

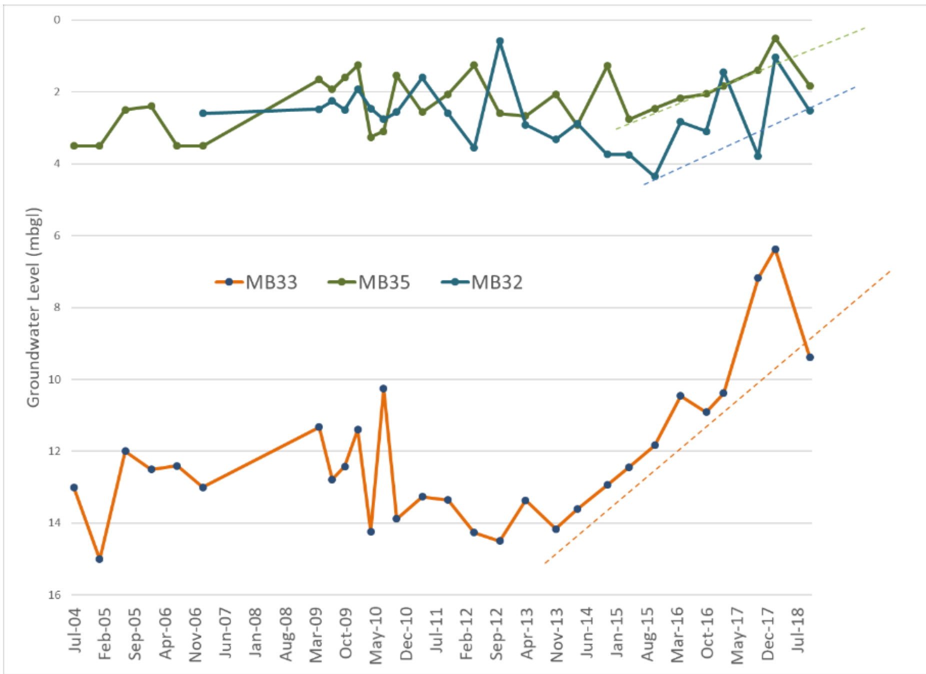


Figure 10-3: Sulphate time graphs for groundwater measured at monitoring boreholes MB32 (south at RWD), MB33 (south) and MB35 (east of TSF)

- Sulphate concentrations at the spring outflow, measured at the spring dam, appears to be under control and around 100 mg/l since 2017 after concentrations of 400 to 500 mg/l were observed in 2014 to 2016. However, with future expansions the spring needs to be "ring-fenced" to ensure that tailings seepage does not impact on the water quality.

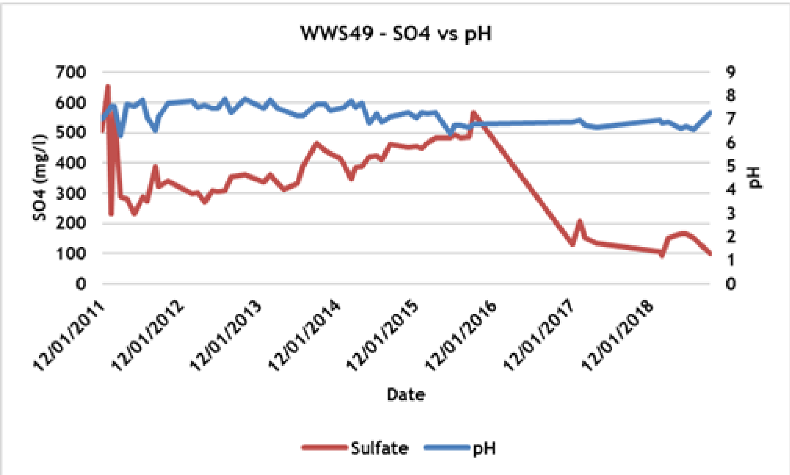


Figure 10-4: WWS49, Spring Dam outlet monitoring site - sulphate time graph

10.1 Groundwater Management Options

10.1.1 Sulphate plume and seepage

- The geophysical survey indicated shallow seepage at the south eastern corner of the TSF which corresponds with water quality data. It is recommended that the feasibility of an interception trench be investigated to intercept seepage migrating towards the Aquatic dam. This seepage will increase if the TSF lower compartment is elevated to 66m. Two areas are indicated on Figure 10-5 for shallow interception (blue lines) and two resistivity anomalies (black lines on map) may suggest deeper seepage where interception boreholes may work to manage the sulphate plume.
- The resistivity line completed to the south of the TSF also indicated an area of shallow seepage which migrates on top of the andesite formation (refer to the blue line on Figure 10-6). Three possible groundwater interception locations were also identified (refer to the black lines).
- It is recommended that shallow interception mechanisms be implemented in the areas indicated on Figure 10-5 and Figure 10-6 to drain shallow seepage towards the proposed lined RWDs and that three to five deeper interception boreholes be established to intercept deeper aquifer seepage.

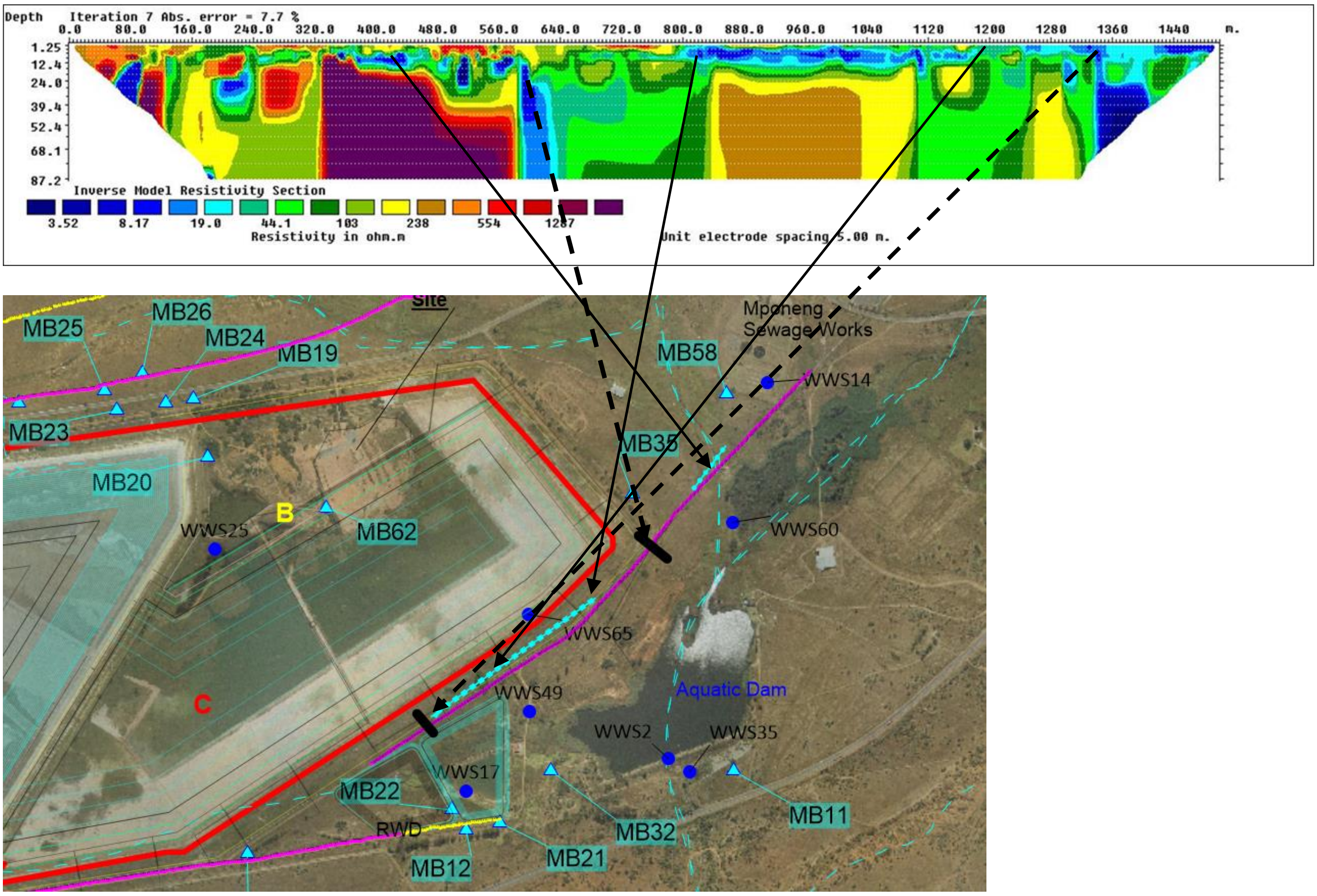


Figure 10-5: Identified seepage and probable lineaments east and south-east of TSF

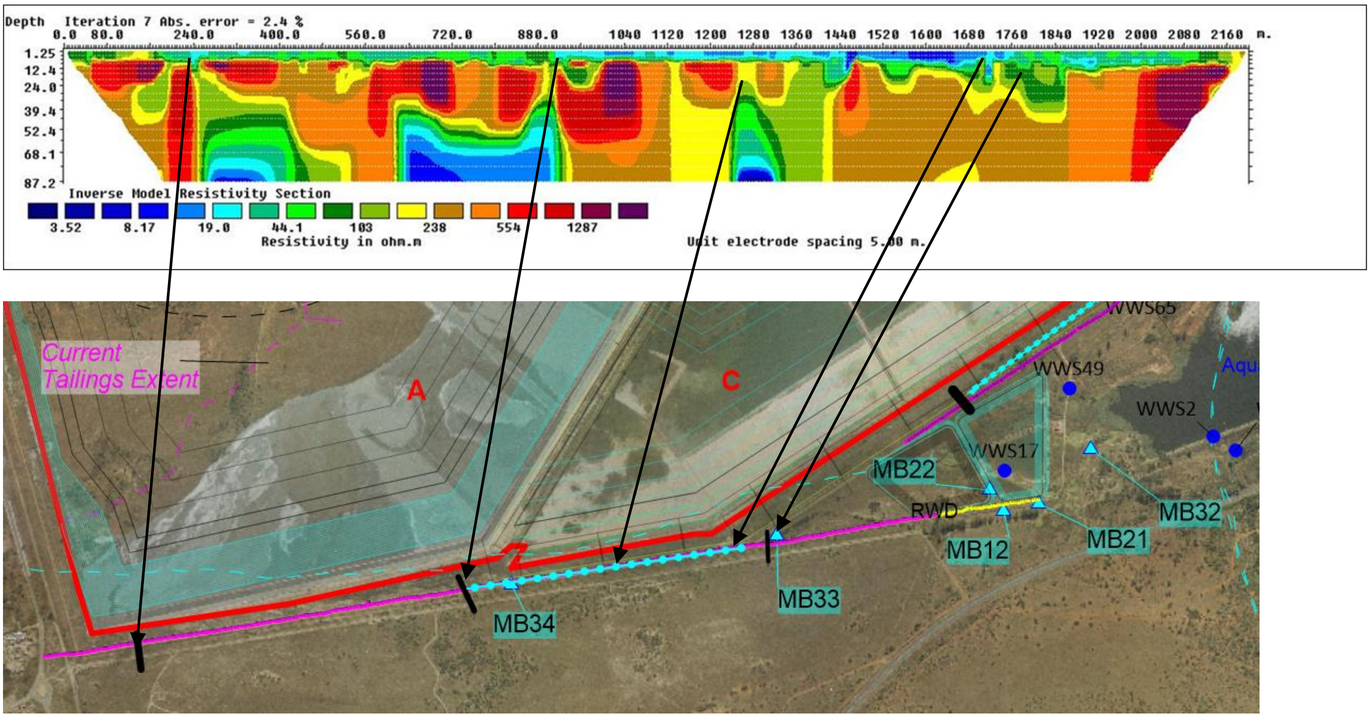


Figure 10-6: Identified seepage and probable lineaments south TSF

10.1.2 Spring and groundwater flow

The objective is to manage the water flow and water quality of the spring when the upper compartment and lower TSF compartment are developed in height over the life of mine of the TSF and after closure. The location of the spring is diffuse within the area directly north of borehole MB20 as indicated on the map below (Figure 10-8).

There are two ways to manage the spring which would involve:

- Interception of the spring at a known “connected” location and pump water around TSF into the clean flow path east of the TSF which eventually ends up in the Aquatic Dam.
- “Ring Fence” the spring area by means of cut of drains and/or walls to prevent seepage from the TSF when elevated to 60 and 66m respectively for the upper and lower compartments. The potential negative effect of the TSF will be more prominent when reaching these heights. It is therefore recommended that the cut-off drain between the upper compartment and the spring be upgraded.

The high yielding borehole MBH20 is located at the point of a mapped lineament or interpreted structure that trends west of south-west to east of north-east. Borehole MBH13, which also indicated a significant yield in this region is also situated on a mapped lineament. Boreholes MBH19, 23, 24, 25 and 26 are for practical purposes dry and only MBH19 intersected dolerite. Borehole MB20 is therefore the only logical place to intercept the spring. Two locations which can be explored are indicated on the map Figure 10-8 and the preferred option will be on the same lineament as MB20 but further to the north east.

Further argument that borehole MB20 is a preferred position to intercept the spring is because of the water quality characteristics which suggests that the groundwater originates from a deeper aquifer system with limited connection to the TSF seepage (see Figure 10-7).

Any interception of the spring by means of a borehole must be operationally managed in such a way to prevent excessive drawdown and potential cross contamination from the TSF. Groundwater flow must be controlled to achieve an equilibrium between groundwater recharge and discharge. This can be achieved by level sensors installed into the pump/interception borehole(s).

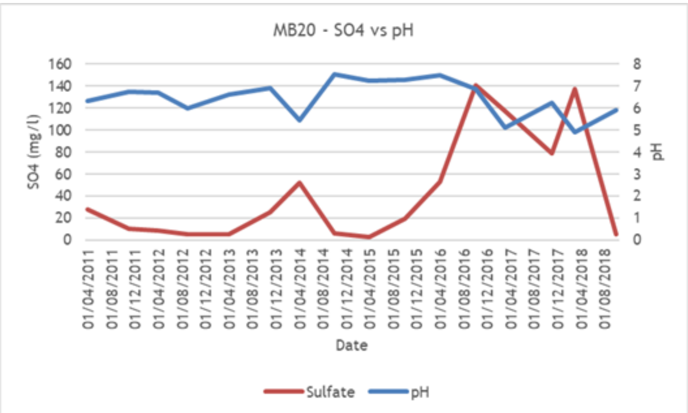


Figure 10-7: Sulphate Time Graph of borehole MB20

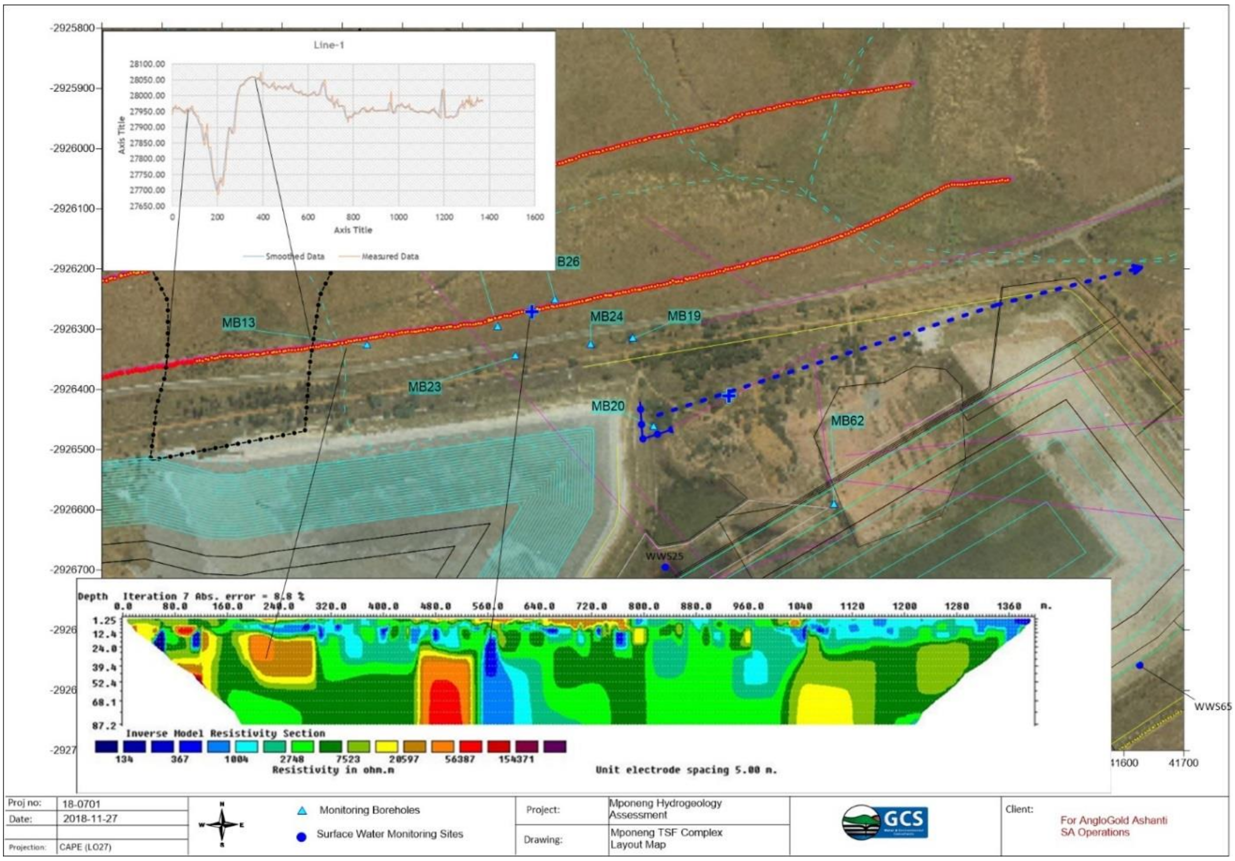


Figure 10-8: Map of Spring Area, geological lineaments and observations from geophysical survey

10.2 Numerical simulation of groundwater management options

By implementing the groundwater management options prescribed above, the sulphate plume will be limited to the direct vicinity of the Mponeng TSF with the expansion to 60 and 66m as discussed in this report. The predicted sulphate plume for the year 2060 when the TSF is in its closure phase is presented in Figure 10-9 below.

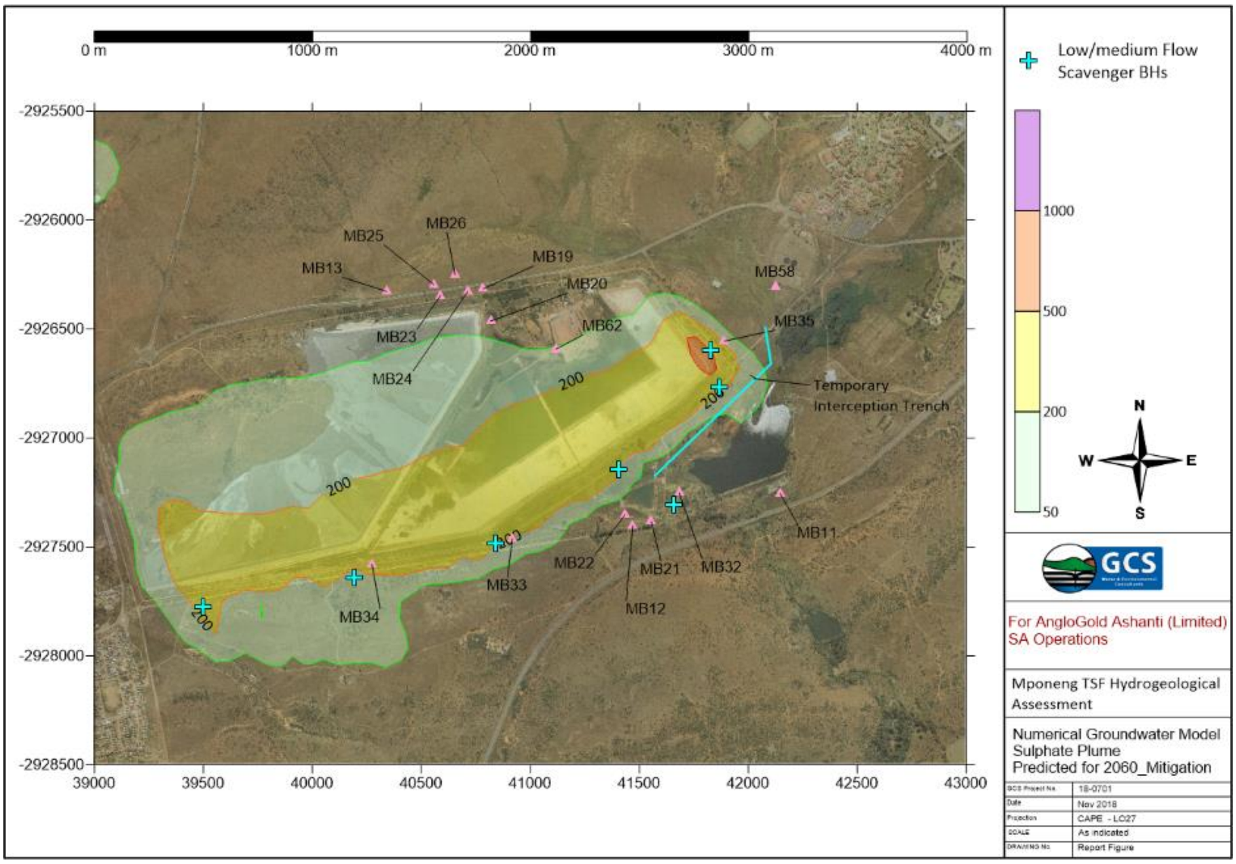


Figure 10-9: Sulphate plume prediction at 2060 with identified management options

11 CONCLUDING REMARKS

The following concluding remarks can be made:

- The objectives of the hydrogeological assessment was to determine:
    - Potential groundwater seepage as a result of increasing the height of the upper compartment to 60m and the lower compartment to 66m;
    - To comment on the hydrogeological impact and management options; and
    - To look into ways to manage the spring in terms of water quality and flow.
- The completed geophysical field survey indicated that:
    - The location of the dolerite dyke which was indicated to the north of the Mponeng TSF running from north to south from the Gatsrand Area (Westrand Hills) is confirmed and in line with the available air magnetic data (Aquisim Consulting, 2001). The dyke position indicated on older geological maps used internally in Anglogold Ashanti is not correct.
    - Seepage areas were identified south and south east of the TSF.
- It was previously thought that the spring is controlled by the dolerite dyke, however the occurrence of the dolerite dyke and sills in the area appears to have limited hydrogeological influence on the spring flow. The spring appears to originate from deeper aquifer flow and connected via geological lineaments in the area.
- Seepage analyses indicated that current seepage rates are in the order of 0.3 m^3/day/ha or 12mm/annum for the lower compartment and 0.5 m^3/day/ha or 20mm/annum for the upper compartment. This will increase to 35 and 32 mm/annum respectively with the proposed increase in heights. This can be regarded as fairly low for gold tailings and can be attributed to the foundation geology (shales and andesites) and characteristics of the tailings material.
- Monitoring data indicates that typical sulphate concentrations for the tailings seepage is in the order of 2200mg/l. The 2002 geochemical data indicated sulphate concentrations to be lower. Neutral pH values were indicated for all the monitoring points. This implies that limited acid mine drainage currently occurred at the Mponeng TSF and that limited metal mobilization is in progress.
- Only two monitoring boreholes indicated higher sulphate seepage, above 500 mg/l. Most of the sites indicate sulphate concentrations to be less than 100mg/l.
- The numerical groundwater model was successfully calibrated with the observed monitoring data and it is predicted that a sulphate plume between 200 and 600 mg/l will develop to the south and south east of the TSF with the proposed increase in height. The sulphate plume will be limited to the Mponeng TSF area and return water dam area.

- However, the main impact of the sulphate plume will be evident in the Aquatic Dam, which indicated sulphate concentrations currently to be around 200 mg/l, generally 100mg/l higher than upstream sample sites. The sulphate concentration and salt load will increase to about 300 mg/l if the seepage is not controlled.
- The control mechanisms proposed will be:
  - Upgrade of the return water dams with suitable lining systems in place;
  - Upgrade of the southern toe seepage drains and solution trenches;
  - Management of the pond size on top of the TSF compartments;
  - Installation of shallow seepage drains at the identified shallow seepage areas;
  - Installation of interception boreholes to intercept deeper aquifer flow (in the order of 20 to 30m below surface;
  - Control over the release of any contaminated water by up-stream areas like the Mponeng mine and gold plant areas.
- The probability of the spring getting contaminated, if the upper and lower compartments are raised to the proposed levels, is higher. It is therefore recommended that the cut-off drain between the upper compartment and the spring be upgraded and that the spring is "ring-fenced" with drains and impermeable flow barriers. The spring water must be diverted in an easterly direction towards the clean natural flow path which drains into the aquatic dam. Furthermore, it is recommended that a trail study be initiated where the spring is intercepted by borehole MB20 and a potential 2nd borehole about 20 to 50m to the north-east. A 3rd borehole option can be considered further to the north but needs to be confirmed with additional infill geophysical survey.

12 APPENDIX A: OVERVIEW OF MPONENG TSF GEOCHEMICAL SAMPLES

Field Data					Laboratory Analyses											
Complex	Dam	Sample No	Field colour description	Depth (m)	Colour	Paste pH	Composite for ABA	Composite for detailed analysis	XRD	XRF	M	SA	AI	WI	PSD	CL
South Complex	Lower	N-7DA	grey with brownish staff		Light brown	7.5	N-7D	N-COMP	1	0	1	1	1	1	1	
		N-7DB	light grey to yellowish color		Light brown	7.7										
		N-7DC	grey clay		Light brown	8.2										
		N-7DD	very miost grey clay		Medium brown	8.4										
		N-7DE	grey		Medium brown	8.2										
		N-7DF		3	Dark greenish yellow	8.0										
		N-7DG		3.5	Greenish yellow	7.6										
		N-7DH		4	Dark greenish yellow	8.1										
		N-6SA	grey	0.5	Dark greenish yellow	8.6	N-6S									
		N-6SB	grey	1	Dark greenish yellow	8.7										
		N-6SC	grey and very moist	1.5	Greenish yellow	8.4										
		N-6SD	grey	2	Greenish yellow	8.2										
		N-6SE	moist dark grey	2.5	Dark greenish yellow	8.5										
		N-5S A	grey with light yellowish inclusion	0.5	Medium brown	8.6	N-5S									
		N-5S B	silty grey	1	ND	ND										
		N-5S C	grey	1.5	Medium brown	8.3										
		N-5S D	grey	2	Medium brown	8.2										
		N-5S E	very moist grey	2.5	Medium brown	8.9										
		N-3DA	grey	0.5	Medium brown	8.7	N-3D									
		N-3DB	grey	1	C28-5	8.5										
		N-3DC	grey	1.5	Brown	8.8										
		N-3DD	grey	2	Medium brown	8.4										
		N-3DE	grey	2.5	Brown	8.1										
		N-2SA	stiff grey clay	0.5	Brown	8.7	N-2S									
		N-2SB	grey clay	1	Medium brown	8.9										
		N-2SC	grey and moist	1.5	Brown	8.3										
		N-2SD	grey	2	E17-7	8.6										
		N-2SE	grey	2.5	Brown	8.8										
Field Data					Laboratory Analyses											

Complex	Dam	Sample No	Field colour description	Depth (m)	Colour	Paste pH	Composite for ABA	Composite for detailed analysis	XRD	XRF	M	SA	AI	WI	PSD	CL
South Complex	Lower	N-1SA	grey	0.5	Dark grey	8.5	N-1S	N-COMP	1	0	1	1	1	1	1	
		N-1SB	stiff grey color	1	Dark grey	8.7										
		N-1SC	grey	1.5	Dark greenish yellow	8.4										
		N-1SD	grey	2	Charcoal	8.2										
		N-1SE	grey with light yellowish inclusions	2.5	Brown	8.2										
	Upper	M-4DA	silty grey	0.5	Dark grey	7.7	M-4D	M-COMP	1	0	1	0	1	1	1	
		M-4DB	silty grey	1	Dark grey	7.8										
		M-4DC	grey	1.5	Dark grey	7.2										
		M-4DD	moist and grey in color	2	Dark grey	8.6										
		M-4DE	very moist grey	2.5	Charcoal	8.6										
		M-5SA	grey with yellow inclusions	0.5	Dark grey	8.0	M-5S									
		M-5SB	grey	1	Dark grey	7.9										
		M-5SC	moist grey	1.5	Dark grey	8.5										
		M-5SD	dark grey and stiff	2	Dark grey	8.3										
		M-5SE	grey and moist	2.5	Charcoal	8.5										
		M-6SA	silty grey	0.5	Dark grey	8.0	M-6S									
		M-6SB	grey	1	Dark grey	8.6										
		M-6SC	silty grey	1.5	Dark grey	8.3										
		M-6SD	moist grey	2	Charcoal	8.2										
		M-6SE	moist grey	2.5	Dark grey	8.6										
		M-6SF		3	Dark greenish yellow	8.4										
		M-6SG		3.5	Dark greenish yellow	8.7										
		M-6SH		4	Greenish yellow	8.8										

M = Microscopy; SA = Surface area; AI = Aquaregia + ICP-MS; WI = Water extract + ICP-MS; PSD = Particle size distribution; CL = column leach

13 APPENDIX B – CORE BOREHOLE LOG PHOTOS

BOREHOLE NO: DML02

BOX 1 OF 3

BOREHOLE NO: DML02

BOX 2 OF 3

BOREHOLE NO: DML02

BOX 3 OF 3

SLR global environmental solutions				
CLIENT: ANGLOGOLD ASHANTI		PROJECT: **AGA West Wits Geotechnical Investigation**		
DRAWN: JM	DATE: March 2017	TITLE: **AGA West Wits TSFs Stability**		
CHECKED:	DATE:			
SCALE: Not To Scale	A4	PROJECT No: **710.01003.00006**	FIGURE No.: **2**	

BOREHOLE NO: DML03

BOX 1 OF 3

BOREHOLE NO: DML03

BOX 2 OF 3

BOREHOLE NO: DML03

BOX 3 OF 3

SLR global environmental solutions	CLIENT: ANGLOGOLD ASHANTI		PROJECT: **AGA West Wits Geotechnical Investigation**	
	DRAWN: JM	DATE: March 2017	TITLE: **AGA West Wits TSFs Stability**	
	CHECKED:	DATE:		
	SCALE: Not To Scale	A4	PROJECT No: 710.01003.00006	FIGURE No.: 3

HOLE NO: DLM01				SHEET: 1
PROJECT:	DLM01	SITE:	Mponeng TSF	SLR global environmental solutions
PROJECT NO:	710.010003.00015	NORTHING:	-38977.491	
CLIENT:	AngloGold Ashanti	EASTING:	2927282.549	
CONTRACTOR:	Rolef Fourie Geotechnical Services	EXCAVATED BY:	Drill rig	
LOGGED :	Joel Masufi	FINAL DEPTH (M):	18	

DEPTH	GEOLOGIC DESCRIPTION OF SOIL AND ROCK	WEATHERING INDEX	STRENGTH INDEX
0 – 0.5	Dark grey, slightly weathered, very fine grained, thinly bedded, medium strong rock, carbonaceous Shale.	SW	MS
0.5 – 1		SW	MS
1 – 1.5		SW	MS
1.5 – 3		SW	MS
3 – 4.5	Dark grey to reddish brown, moderately weathered, very fine grained, thinly bedded, weak rock, carbonaceous Shale.	MW	WK
4.5 – 6		MW	WK
6 – 7.5		MW	WK
7.5 – 9		MW	WK
9 – 10.5		MW	WK
10.5 – 12		MW	WK
12 – 13.5		MW	WK
13.5 – 15		MW	WK
15 – 16.5		MW	WK
16.5 – 18		MW	WK

Legend: Andesite; Shale; clayey SILT; silty sandy GRAVEL; Drill Mud; carbonaceous Shale; sandy SILT

Page: 1 of 1

HOLE NO: DLM02 **SHEET: 1**

PROJECT:	DLM02	SITE:	Mponeng TSF
PROJECT NO:	710.010003.00015	NORTHING:	-41661.859
CLIENT:	AngloGold Ashanti	EASTING:	2926695.86
CONTRACTOR:	Rolef Fourie Geotechnical Services	EXCAVATED BY:	Drill rig
LOGGED :	Joel Masufi	FINAL DEPTH (M):	12.6

SLR global environmental solutions

DEPTH	GEOLOGIC DESCRIPTION OF SOIL AND ROCK	WEATHERING INDEX	STRENGTH INDEX
0 – 0.75	Moist, reddish brown to yellowish brown, firm, intact with ferricrete nodules presents, clayey SILT. Residual Shale.	RS	F
0.75 – 1.5		RS	F
1.5 – 1.65		RS	F
1.65 – 3		RS	F
3 – 4.5	Dark grey, slightly weathered, very fine grained, medium strong rock, carbonaceous Shale.	SW	MS
4.5 – 6		SW	MS
6 – 7.5		SW	MS
7.5 – 9		SW	MS
9 – 10.5		SW	MS
10.5 – 12.6		SW	MS

Legend: Andesite; Shale; clayey SILT; silty sandy GRAVEL; Drill Mud; carbonaceous Shale; sandy SILT

Page: 1 of 1

HOLE NO: DLM03 SHEET: 1

PROJECT:	DLM03	SITE:	Mponeng TSF
PROJECT NO:	710.010003.00015	NORTHING:	-40835.974
CLIENT:	AngloGold Ashanti	EASTING:	2927786.909
CONTRACTOR:	Rolef Fourie Geotechnical Services	EXCAVATED BY:	Drill rig
LOGGED :	Joel Masufi	FINAL DEPTH (M):	11.73

SLR global environmental solutions

DEPTH	GEOLOGIC DESCRIPTION OF SOIL AND ROCK	WEATHERING INDEX	STRENGTH INDEX
0 – 0.5	Dry, dark brown, firm, intact, clayey SILT. Residual Shale.	RS	F
0.5 – 1		RS	F
1 – 1.5		RS	F
1.5 – 3		RS	F
3 – 3.5	Dark grey, highly weathered, very fine grained, weak rock, carbonaceous Shale.	HW	WK
3.5 – 4.7		SW	WK
4.7 – 6		SW	WK
6 – 7		SW	WK
7 – 7.7	Dark grey, slightly weathered, very fine grained, medium strong rock, carbonaceous Shale.	SW	MS
7.7 – 9		SW	MS
9 – 10.5		SW	MS
10.5 – 11.73		SW	MS

Legend: Andesite; Shale; clayey SILT; silty sandy GRAVEL; Drill Mud; carbonaceous Shale; sandy SILT

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14 APPENDIX C – NUMERICAL GROUNDWATER MODEL SETUP

14.1 Model Construction

The numerical model for the project was constructed using the classic version of Visual Modflow, Pro, Build 4.6.0.169 (2018), a pre- and post- processing package for the modelling code MODFLOW. MODFLOW is a modular three dimensional groundwater flow model developed by the United States Geological Survey (Harbaugh et al., 2000). MODFLOW uses 3D finite difference discretisation and flow codes to solve the governing equations of groundwater flow.

The construction of the numerical model was based on the conceptual model and basic understanding of the area.

Groundwater flow is simulated based on a 3D cell-centered grid and may be described by the following partial differential equation:

$$\frac{\partial}{\partial x}(K_{xx}\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_{yy}\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_{zz}\frac{\partial h}{\partial z})\pm W=S_s\frac{\partial h}{\partial t} \quad (1)$$

where:

- K_{xx}, K_{yy}, and K_{zz} are values of hydraulic conductivity along the *x*, *y*, and *z* coordinate axes, which are assumed to be parallel to the major axes of hydraulic conductivity (L/T);
- *h* is the potentiometric head (L);
- *W* is a volumetric flux per unit volume representing sources and/or sinks of water, with $W < 0.0$ for flow out of the ground-water system, and $W>0.0$ for flow in (T^{-1});
- S_s is the specific storage of the porous material (L^{-1}); and
- *t* is time (T).

Equation 1, when combined with boundary and initial conditions, describes transient three-dimensional ground-water flow in a heterogeneous and anisotropic medium, provided that the principal axes of hydraulic conductivity are aligned with the coordinate directions (Harbaugh et al. 2000).

14.2 Model Grid

The finite difference model grid consists of 96 170 cells which consist out of 118 rows, 163 columns and 5 layers (**Figure 14-2**)

Definition of the grid and the geometry of the layers was carried out using the VISUAL MODFLOW graphic user interface. Smaller cell sizes (25m x 25m) are specified in potential sensitive TSF seepage areas where a more accurate solution of the groundwater flow equation is required.

14.3 Flow Boundaries and Aquifer Parameters

It can be seen form **Figure 14-2** that the borders of the numerical model were chosen at what were considered to be natural flow boundaries:

- General head boundaries along the edges of the model grid;
- Stream and drain cells were applied for the network if non-perennial and the main Elandsfontein Spruit.
- No flow boundaries were applied to the sub-catchment boundaries.

The groundwater model domain covers an area of 8 x 5.5 km, where approximately 45% was allocated as no-flow cells.

Three percent recharge of the MAR was applied which is approximately 18 mm per annum.

Due to the complexity of the geological conditions different aquifer parameter values were assigned to different lithologies and geological structures. The initial parameters of the different lithologies were obtained from aquifer test data, or cited from various existing literature and geology maps. The initial parameter values were adjusted during the calibration process within realistic ranges in order to match the water level calculated by the numerical model to that measured in the field. The various parameters input into the model are shown in **Error! Reference source not found.**.

Table 14-1: Summary of hydraulic conductivity - values in m/day

	Timeball Hill Shale	Diabase	Timeball Hill Shale and Quartzite	Fracture flow	Rooihoogte shale and chert
Max	0.4163	0.0501	0.1190	10.00	2.00
Min	0.0047	0.0095	0.1190	0.5	0.30
Average	0.0964	0.0273	0.1194	2.53	1.15
Stdev	0.1224	0.0208			

- WW South Area 7 out of the 19 boreholes was tested.

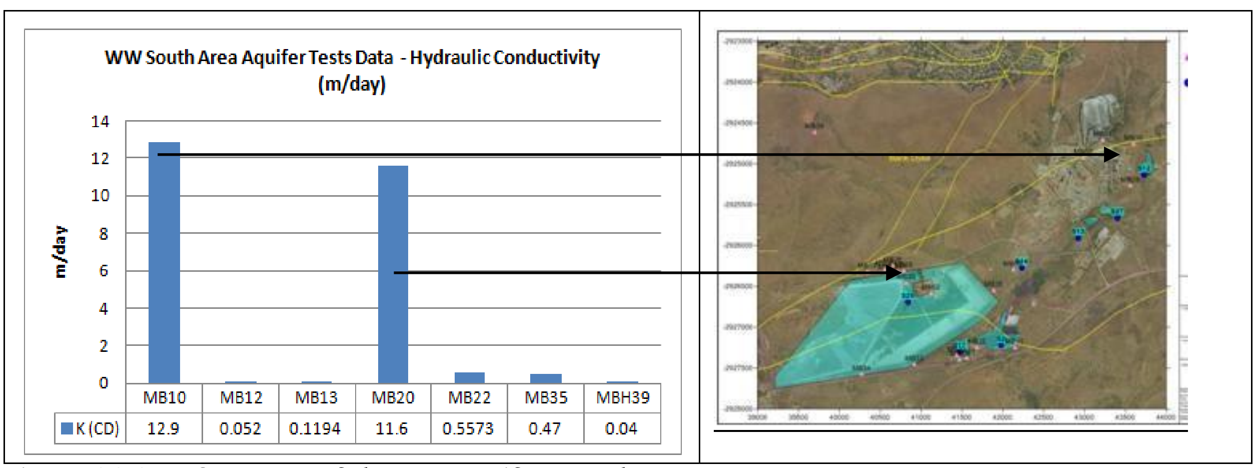

Figure 14-1: Summary of the WW aquifer test data

14.4 Calibration

The models were run in transient state mode to allow for different recharge scenarios for the available TSFs, subsequent to model grid development. The available monitoring borehole data was applied for calibration purposes. The flow model was calibrated accordingly and a satisfied relation between the observed (borehole monitoring data) and calculated (flow simulation through model) were obtained:

It can be seen from the figures below that a fairly good correlation between real field data and simulated values were obtained. This allows for a good basis to enable mass transport modelling.

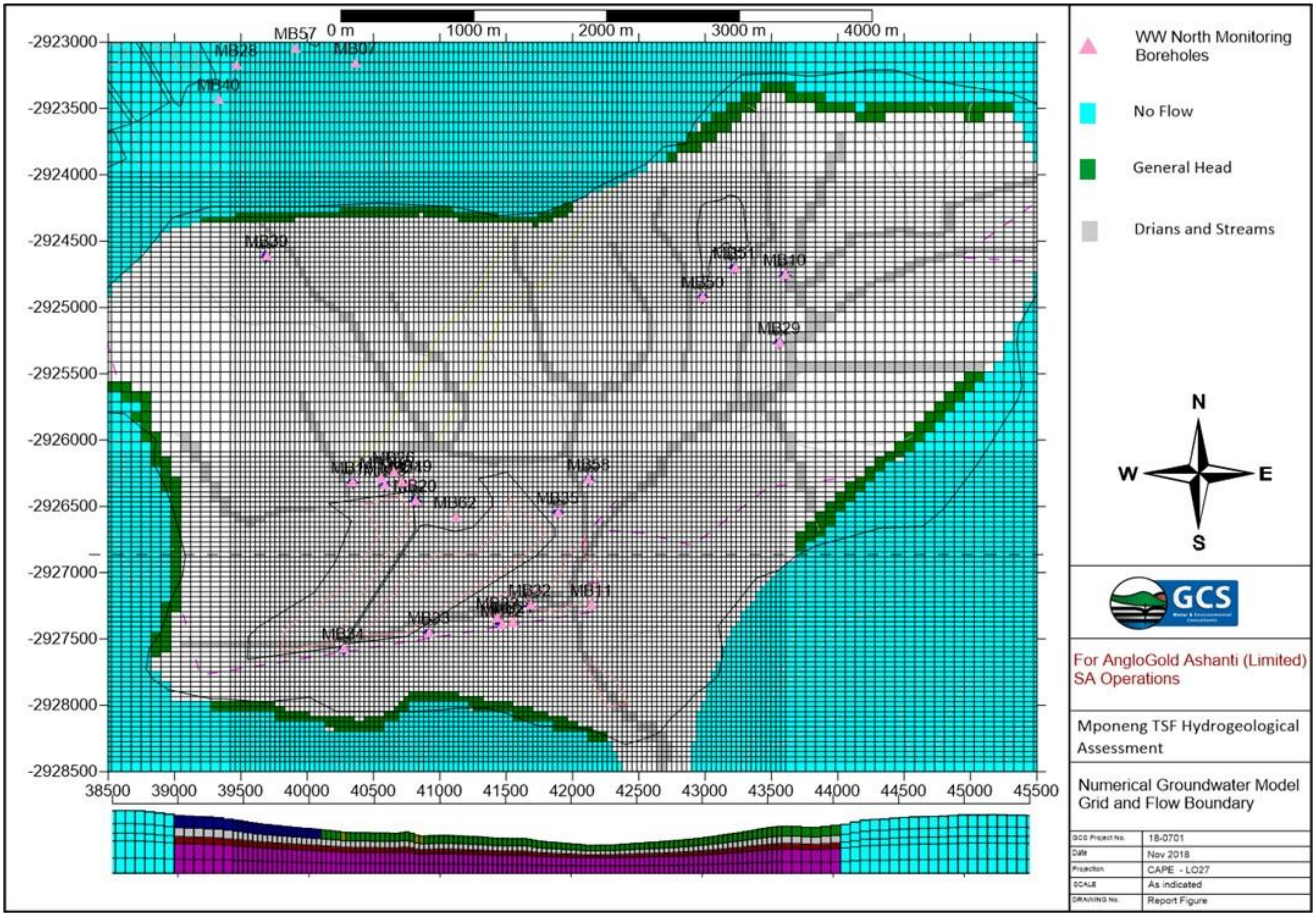

Figure 14-2: Model grid and boundaries applied for the Mponeng TSF and sub-catchment

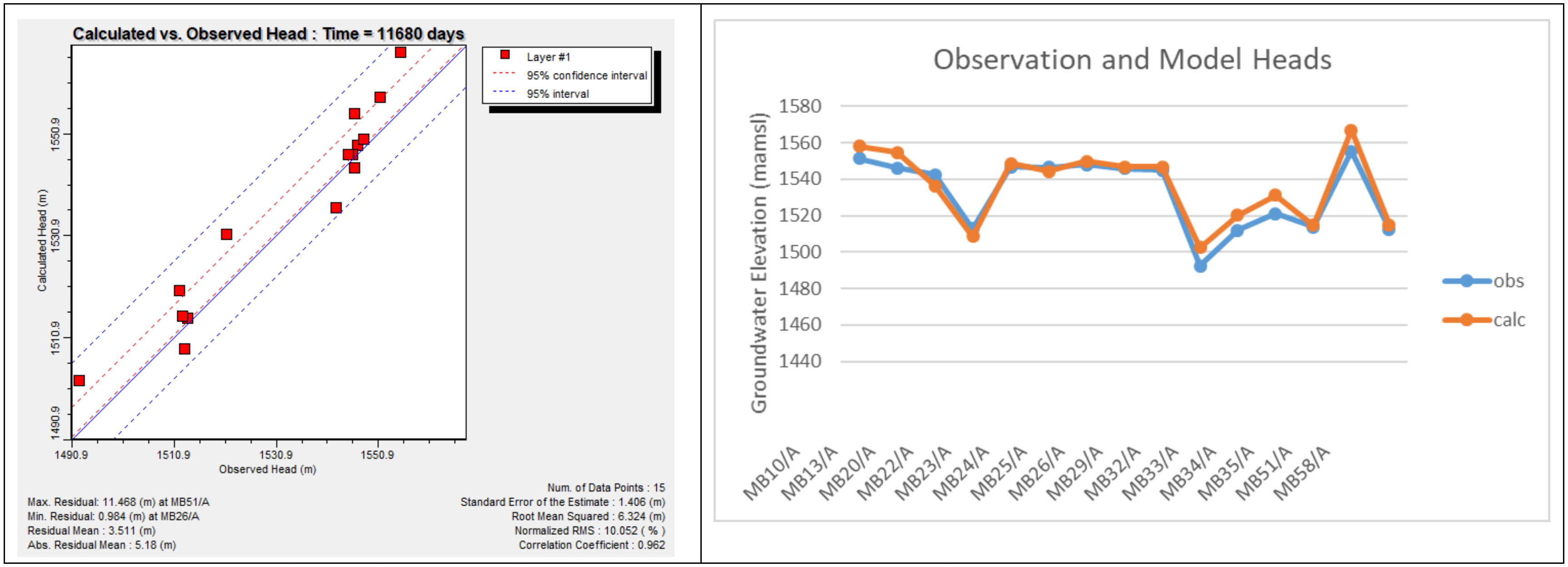

Figure 14-3: Numerical groundwater model steady state calibration output correlation

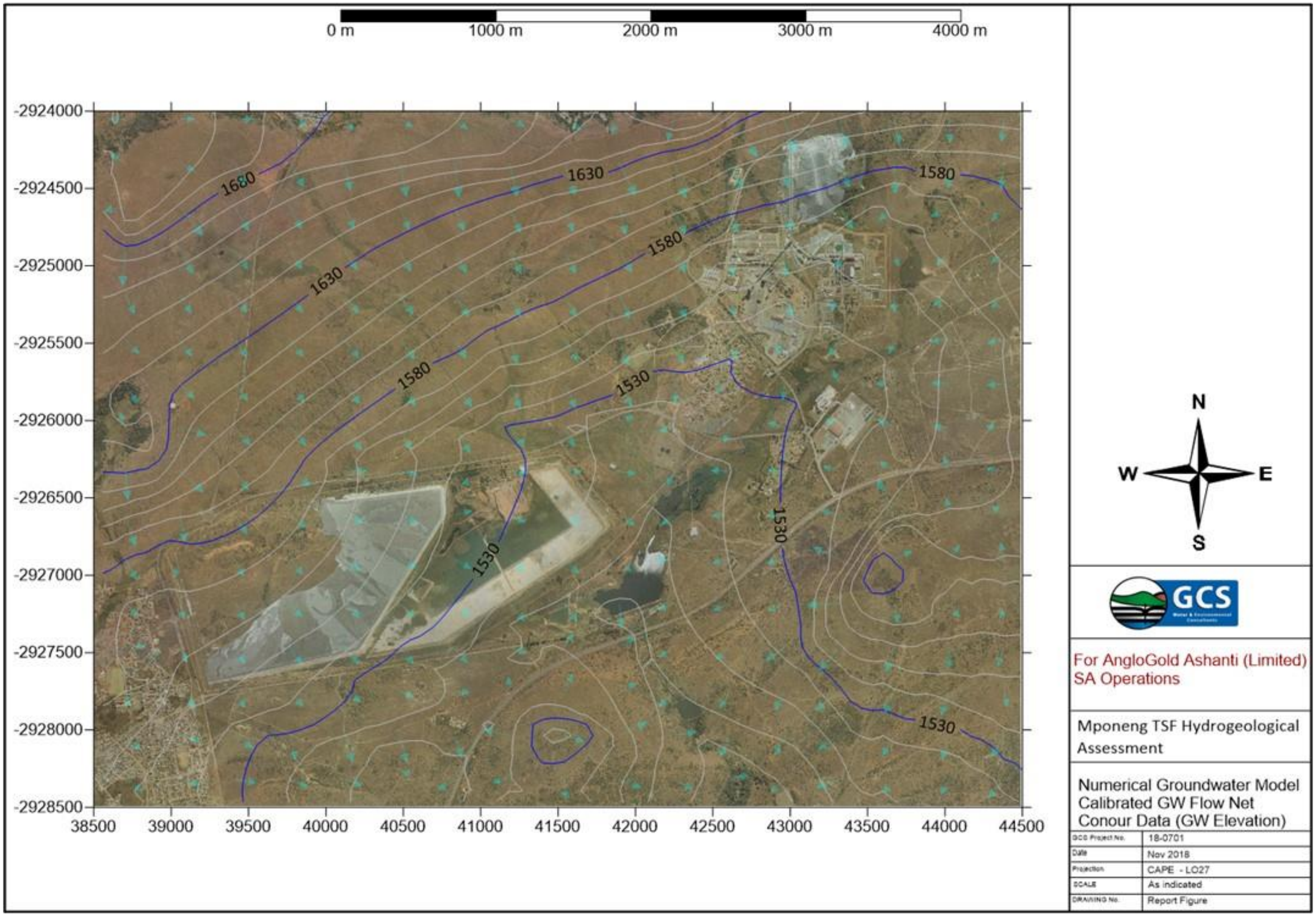

Figure 14-4: Calibrated heads and flow vectors for the Transient State and current time period (2018)

14.5 Sensitivity analysis

After a model has been calibrated and used to draw conclusions about a physical hydrogeologic system (for example, estimating the capture zone of a proposed extraction well), a sensitivity analysis can be performed to identify which model inputs have the most impact on the degree of calibration and on the conclusions of the modelling analysis.

A sensitivity analysis was carried out on the calibrated current mining steady state model using zones to assess the influence on groundwater level and flow dimensions by running the model in the PEST (Parameter Estimation Simulation) and sensitivity mode.

- That change in K values have generally a significant impact on flow and mass transport.
- Change in recharge has a high influence on model output.

14.6 Model Uncertainty

The model uncertainty level can be regarded as medium as more work should be conducted to have better resolution in terms of:

- Aquifer hydraulic conductivity – some of the newer boreholes should be tested. Simple slug test can be applied as an interim solution and longer term constant rate pump tests later to refine values.
- For vertical discretization, down-hole logging to determine TDS anomalies vertically may assist to understand vertical seepage depths. Conductivity measurements must be conducted as a normal aquifer characterization application.
- Aquifer recharge must be confirmed by means of field tests and the chloride method can be used.