Bakubung TSF Impact Assessment

Project Number:

DTMP042016

Prepared for:

Gemini GIS & Environmental Services (Pty) Ltd

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1 Introduction

DTM mining has been appointed by Gemini GIS & Environmental Services (Pty) Ltd to conduct a groundwater impact assessment for the proposed Bakubung Platinum Mine (hereafter Bakubung) tailings storage facility (TSF).

Bakubung is located near Ledig, just south of the Pilanesburg National Park and Sun City in the North West Province (Figure 1). Two reefs will be mined for Platinum Group Elements - platinum, palladium, rhodium and gold, with copper and nickel as by-products. As part of the project, a TSF is proposed on the farm Mimosa 81 JQ. A site characterization was conducted by MDC Consulting Engineers. This report focuses on the impact of the proposed TSF on the groundwater environment, evaluated using a three (3D) groundwater model.

1.1 Objectives and Scope of Work

The objective of the hydrogeological study is to provide a reference point (current conditions) against which potential TSF impacts on the groundwater system can be identified and measured and include:

- A description of the groundwater flow system and the main processes that influence system behaviour;
- An assessment of potential impacts (type, degree, extent) related to various project components (potential mounding of groundwater underneath the TSF, and degradation of groundwater quality during and after mining); and
- An assessment of potential effects and mitigation options related to groundwater use, or contamination.

The scope of work in summary included:

- Conceptual and numerical groundwater model; and
- Specialist report with impact assessment and mitigation measures.

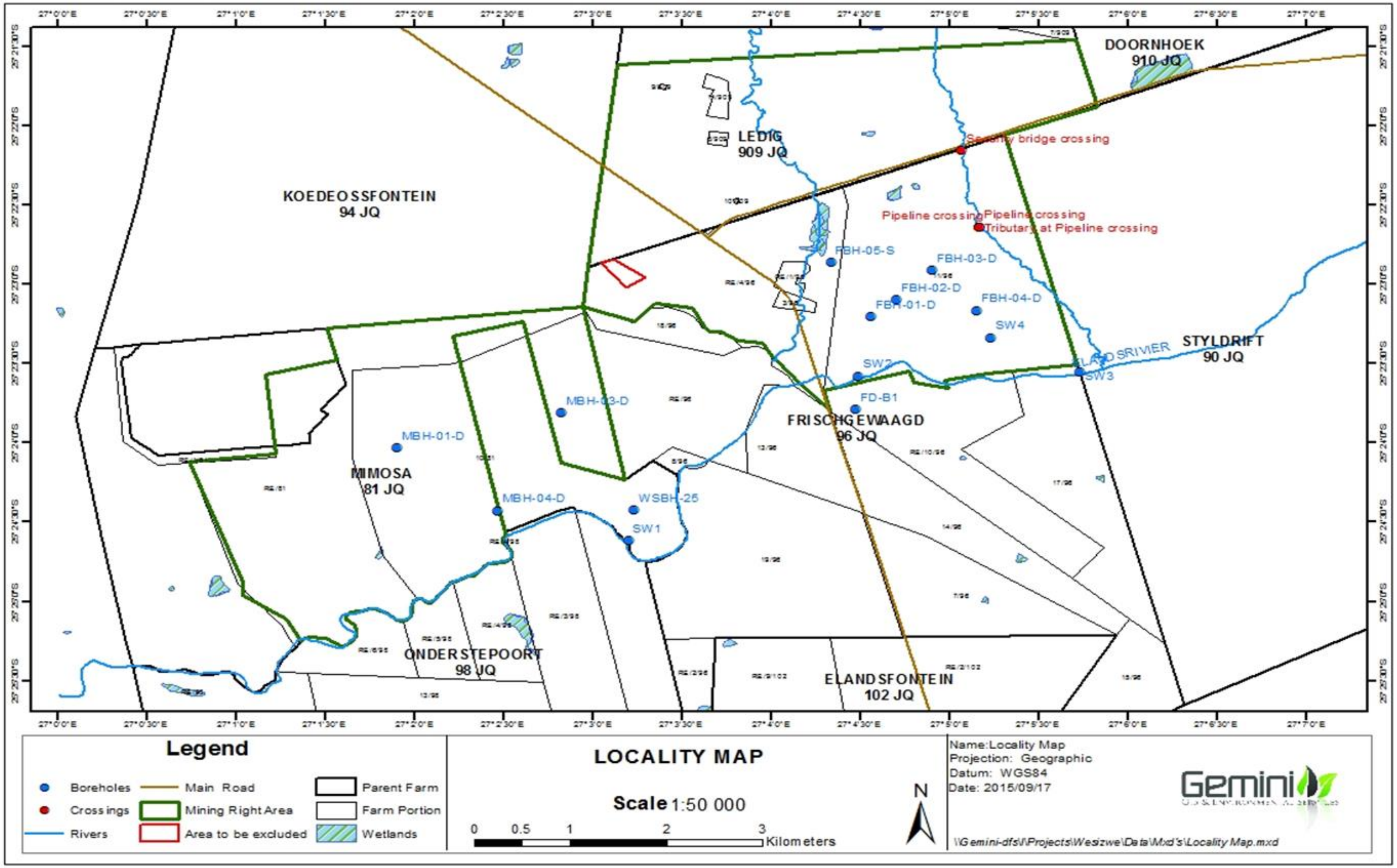

Figure 1: Locality Map

2 Site Description

2.1 Climate

The climate in the project area is seasonal, with wet summers and dry winters. The average annual rainfall is 463 mm, most of which occurs during the period from November to April (SRK, 2013). The temperatures peak during the summer months and are lower during the winter months, dropping to below 0˚C during some nights. The winds are predominantly east, east-northeast, west-southwest and west. Average wind speeds are higher during the period from September to February coinciding with the warmer periods of the year. During the period from March to August, the prevailing wind conditions are calmer with the exception of a few days when high speed winds are observed.

Relatively high levels of evaporation occur as a result of the elevated solar radiation levels. The maximum evaporation rate occurs in December with a mean rate of greater than 7 mm per day. Evaporation is greater than rainfall for all months of the year resulting in a marked moisture deficit in the region (Evans & Mnisi, 2007).

2.2 Topography and Drainage

The project area is located within the A22F quaternary catchment, and consists of a relatively flat landscape intersected by drainage lines with the mountainous Pilanesberg Volcanic complex occurring in the north of the area. The average elevation is 1060 meters above mean sea level (mamsl). Drainage lines are associated with the Elands River that runs along the southern border of the Mimosa farm. The Sandspruit runs along the eastern corner of the site.

2.3 Geology

The site is underlain by the Rustenburg Layered Suite of the Bushveld Complex in which the PGM bearing Merensky and UG2 reefs occur. Numerous faults and north-south striking dykes cut through and across the area, including the Rustenburg and Caldera Faults.

Lithological logs from boreholes drilled on Mimosa farm indicate that the local geology of the site consist of a two metre clay layer, underlain by weathered anorthosite to a maximum depth of 10 metres below ground level (mbgl). Below the weathered anorthosites are alternating layers fractured to fresh norites, gabbro-norites and anorthosites. A typical lithologic profile is given in Figure 2.

2.1 Groundwater Monitoring

As depicted in Figure 1, the groundwater monitoring database at Bakubung consist of 11 boreholes, of which six are located on the Mimosa farm. The only receptor to any potential pollution emanating from the proposed TSF will be the Elands River, as there are no private groundwater users in the vicinity of Mimosa farm. Analyses of groundwater levels are discussed in Section 3.

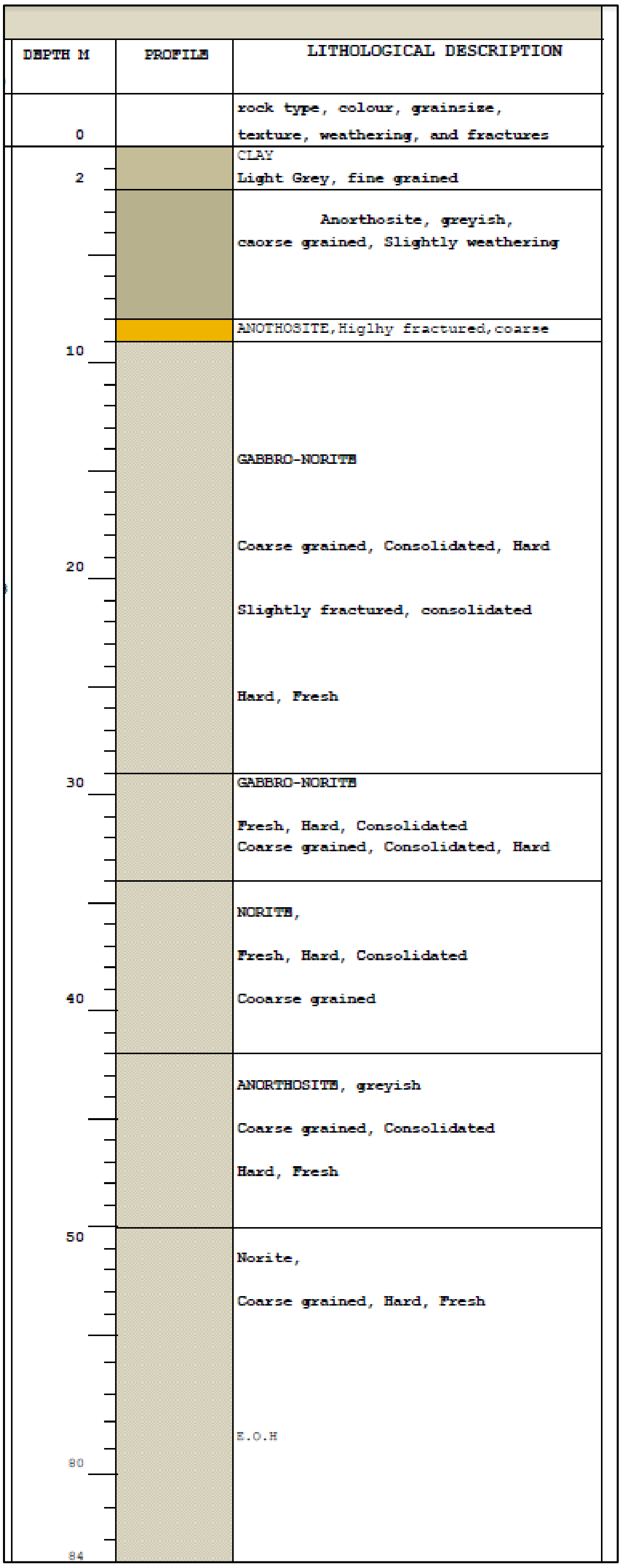

Figure 2: Typical site lithological profile

3 Conceptual Model

A conceptual model is a simplified representation of the essential features of a hydrogeological system that provides the basis for numerical simulations of groundwater flow. In this section we:

- Define the major hydro-stratigraphic units at Mimosa farm and characterize their hydraulic properties based on hydraulic testing data;
- Interpret spatial variations in groundwater levels across the site in order to identify recharge and discharge areas, to determine the directions of groundwater flow; and
- Characterize groundwater quality across the site for baseline conditions.

Information for this section is drawn from JMA (2006), SRK (2013) and MDC (2016). These reports present a more detailed description of drilling results, hydraulic testing data and groundwater quality.

3.1 Model Domain

Figure 3 shows the boundaries of the model domain. The boundaries of the model were defined by local topographic highs to the north and west. The western boundary is represented by the A22F catchment boundary. The south boundary is represented by the Elands River, and the Sandspruit represents the eastern boundary.

3.2 Aquifer Units and Properties

Two aquifer systems have been identified in the Mimosa area based on knowledge gathered from mine geology, groundwater exploration drilling data and groundwater monitoring information. Groundwater occurrence is associated with

- Shallow Weathered Zone;
- Lower Fractured to Fresh Zone.

The following is a description of the aquifer systems present at Mimosa farm. Schematic view of the aquifers is given in Figure 8.

3.2.1 Upper Weathered Aquifer

The weathered aquifer extends to a depth of 10 m below ground level (bgl). The weathered material forms due to vertical infiltration of recharging rainfall into the anorthosites/norites. The recharging water is retarded by the lower permeability of the overlying clay material. Data from drilling indicates that no water strikes were intersected in the weathered zone, and the composite groundwater levels are on average 10 m below the weathered zone. This signifies that the weathered aquifer in the vicinity of the Mimosa farm is partially saturated to unsaturated.

This can be attributed to the fact that evaporation in the area is greater than rainfall for all months of the year resulting in a marked moisture deficit. Hence little or no recharge occurs. In nearby area where the weathered zone is saturated, with an average thickness of 32 m, the hydraulic conductivity (K) values obtained for the shallow boreholes representing the weathered aquifer range between 0.005 and 0.05 m/d. A representative value of 0.015 m/d is estimated (JMA, 2006).

3.2.2 Lower Fractured Aquifer

The competent anorthosite/norite/gabbro-norites are subjected to fracturing associated with tectonic movements, and layering of the rock suites. The primary porosity does not allow significant groundwater flow, except where the porosity has been increased by formation of secondary structures. Groundwater flow in the fractured aquifer is mostly associated with these secondary fracture zones, provided that they are open and have not been filled with secondary mineralization. Water strikes encountered during drilling were associated with contact zones between the interbedded rock suites. Blow yields ranged between 0.5 to 3.5 L/s. These boreholes have not been aquifer tested. The numerical model will be use to estimate the representative aquifer properties of this formation.

3.3 Groundwater Flow Patterns

The depth to groundwater level in the database dates as far back as 2010. From this database groundwater levels and flow patterns, as well as the change in groundwater levels and flow patterns over time can be determined.

3.3.1 Natural groundwater levels and flow patterns

The data, depicted in Figure 4, indicates that the current depth to groundwater level ranges between 18 and 22 m, with an average of 20 m. Plotting groundwater levels against topographical elevation yields a 98 % correlation (Figure 5). The groundwater levels are below the weathered zone, indicating that there is no saturated thickness in the weathered zone.

The resulting groundwater level elevations, Figure 6, indicate that groundwater flow patterns in mimics topography. The groundwater flows from the west in a south easterly direction towards the Elands River. The Elands River represents a groundwater divide. This typically indicates that any potential pollution from the proposed TSF will end in the Elands River.

Long term groundwater monitoring (Figure 7) indicates little or no influence of recharge on the aquifers especially in the low lying areas to west and south of the TSF footprint. The hydrograph of borehole MBH01D indicates the influence of minor recharge in eastern corner of the TSF. This may be due to its proximity to higher lying areas.

3.4 Groundwater Quality

Three (3) groundwater samples from the project area were collected and analysed. The laboratory results are given in Appendix A and summarised in Table 1. The groundwater quality, compared against the SANS 241:2015 guidelines indicate that:

- The pH of groundwater in the project area is neutral to alkaline (7.4 to 8.1);
- The TDS and EC are typical of fresh groundwater with low salinity levels;
- The low concentrations in major cations (Ca, Mg, Na and K) and major anions (Cl and SO_4) are indicative of unpolluted groundwater; and

- All heavy metals apart from Zn occur below detection limit. The elevated concentration of zinc in groundwater can be attributed to the geology.

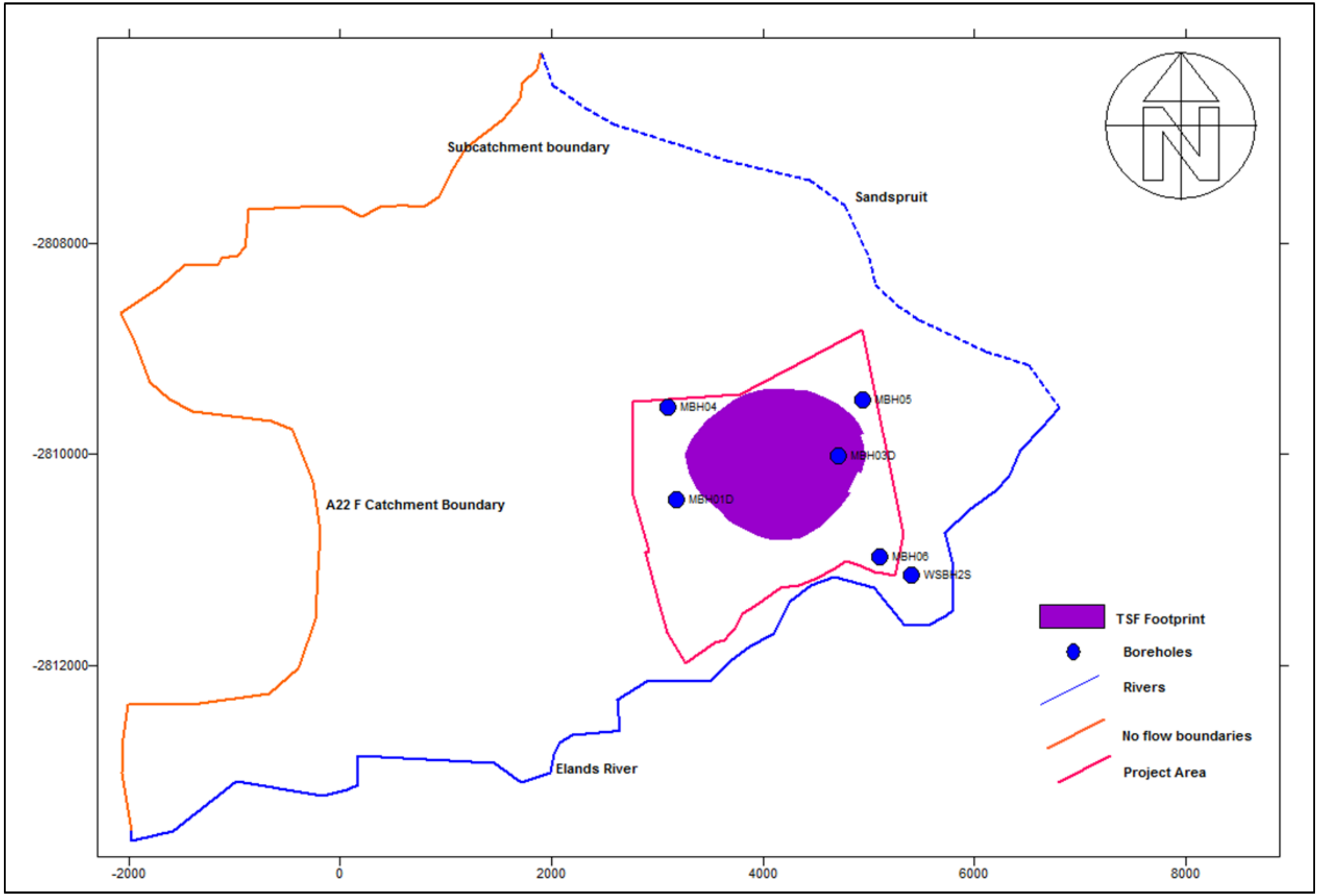

Figure 3: Model domain

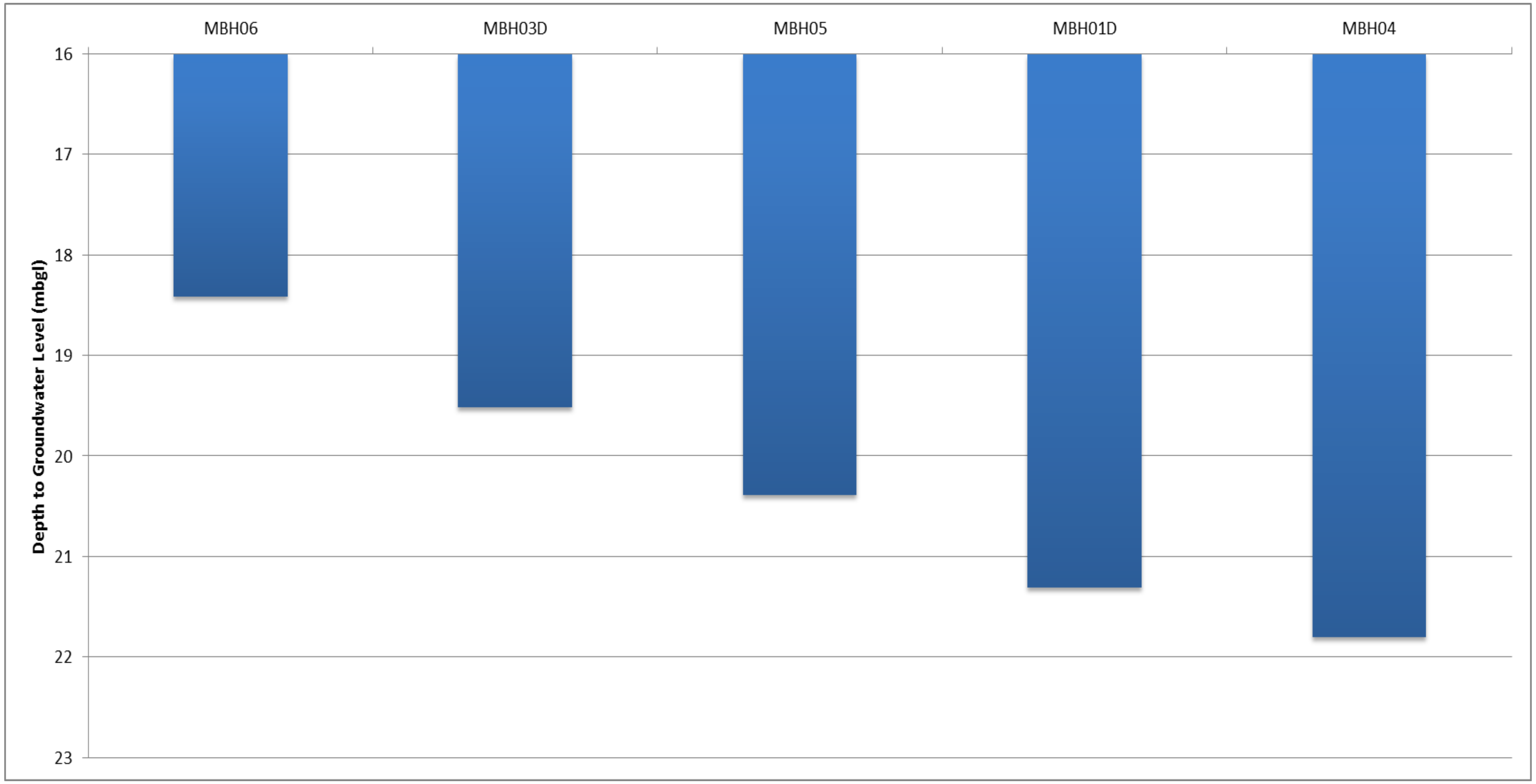

Figure 4: Depth to groundwater level

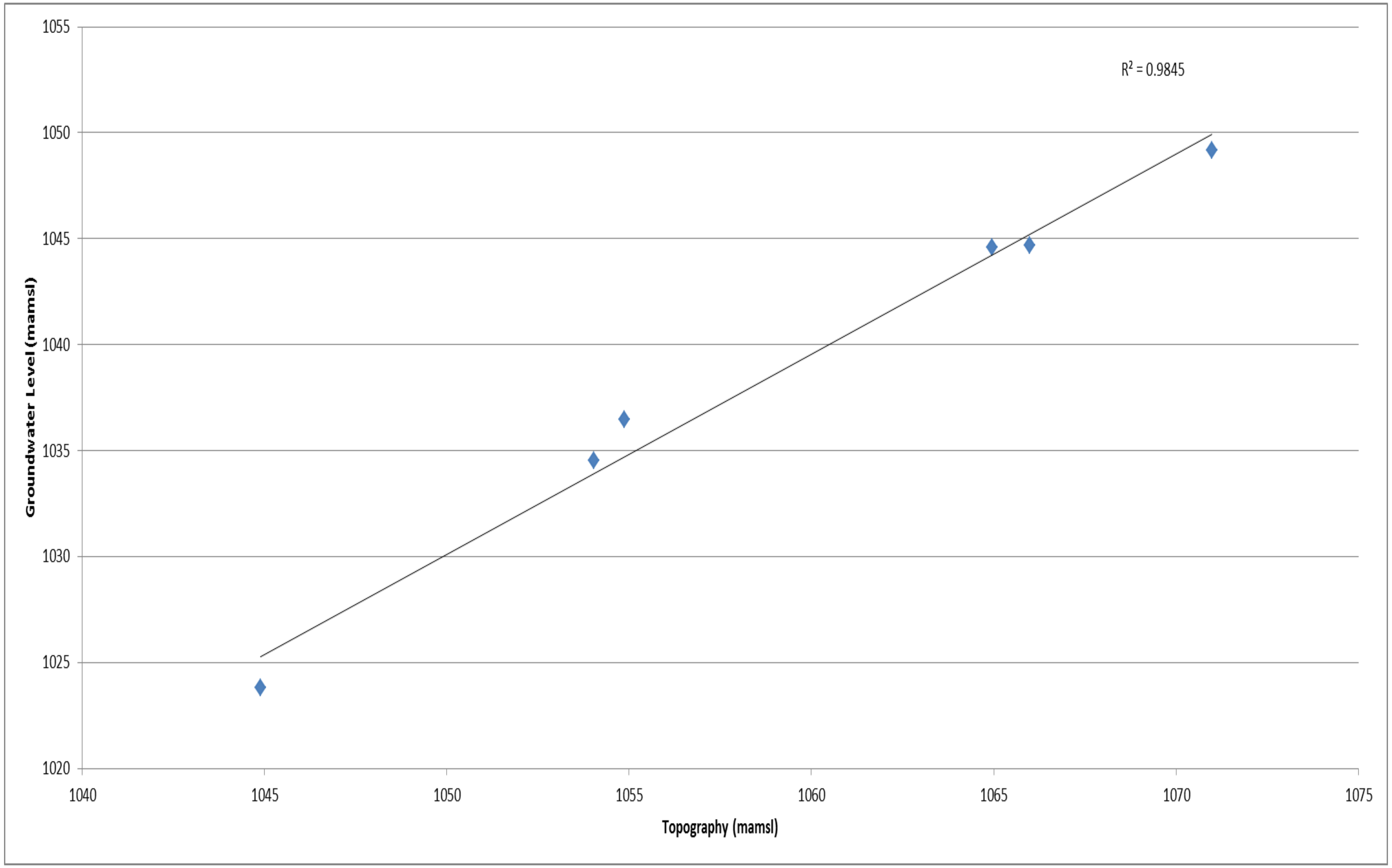

Figure 5: Groundwater level elevation versus topography

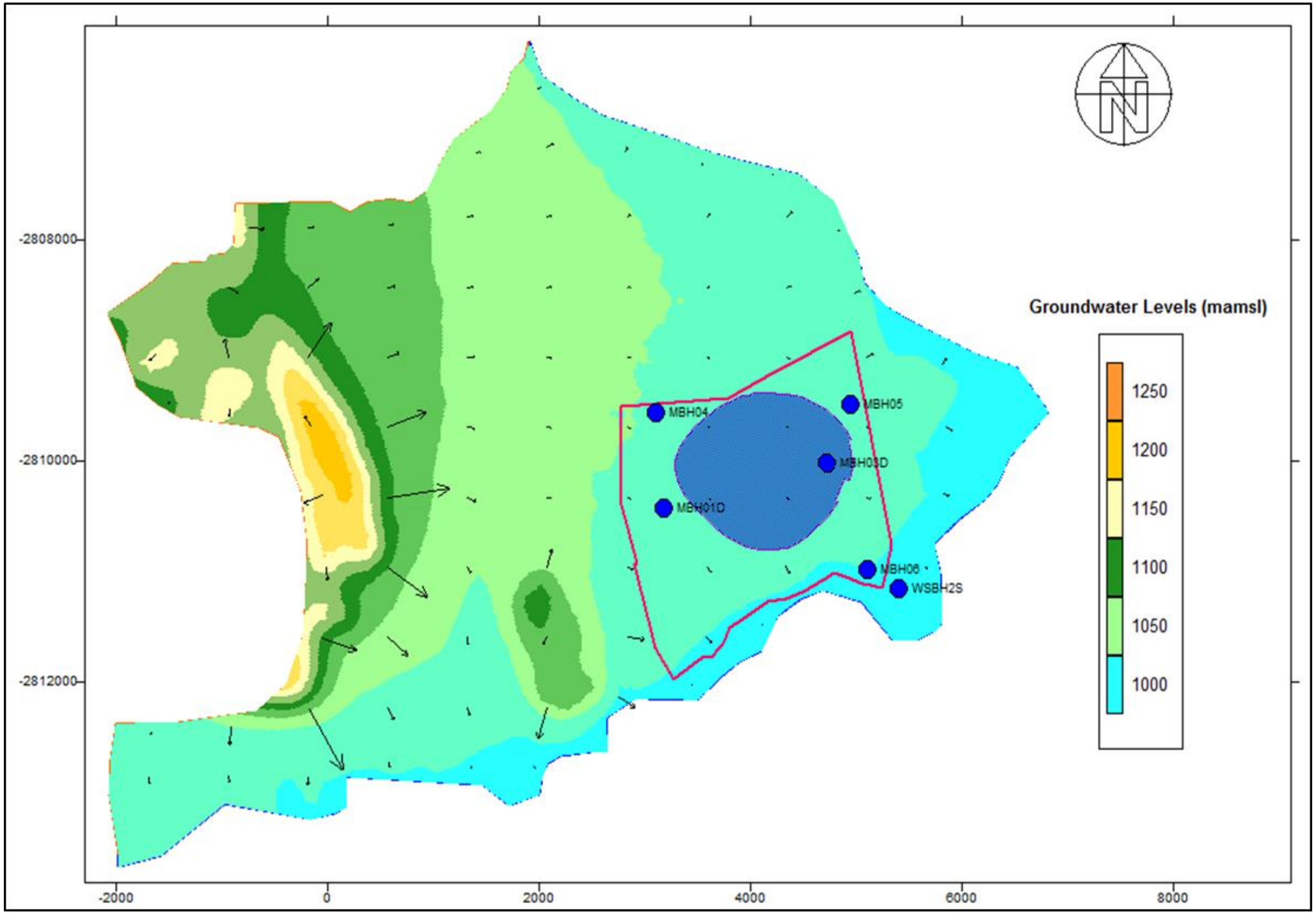

Figure 6: Natural groundwater flow contours

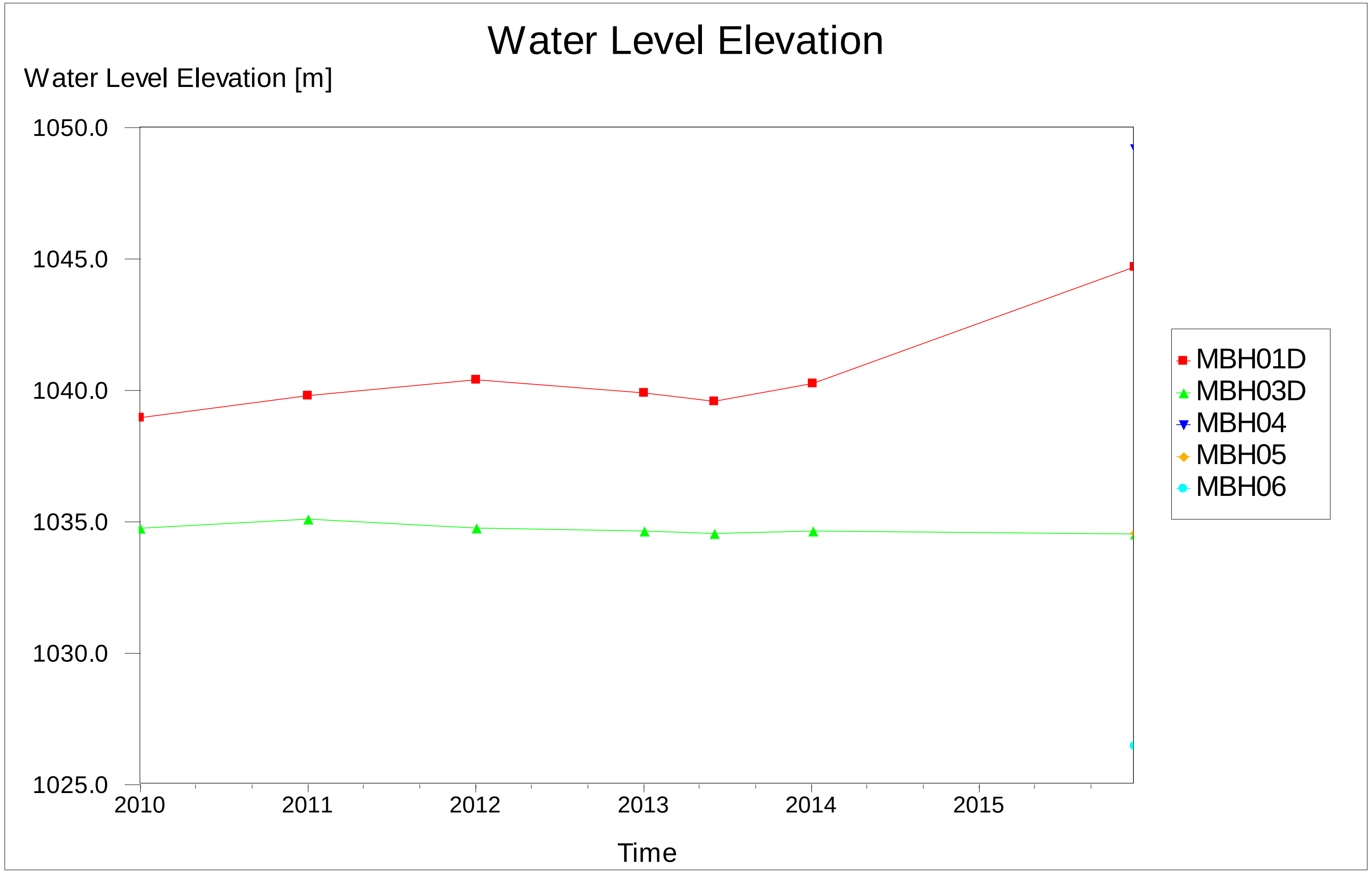

Figure 7: Groundwater levels over time

Table 1: Summary of groundwater quality results

	pH	EC	TDS	Ca	Mg	Na	K	Cl	SO4	NO3 as N	F	Al	As	Cd	Cr	Co	Cu	Fe	Pb	Mn	Ni	Zn
SANS241:2015 Limits	<5 or >9.7	≤170	≤1200	N/A	N/A	≤200	N/A	≤300	≤500	≤11	≤1.5	≤ 0.3	≤ 0.01	≤0.003	≤ 0.05	N/A	≤ 2	≤ 2	≤ 0.01	≤ 0.4	≤ 0.07	≤ 0.005
MBH04D	7.4	76.6	452	60	55	24	1.6	19	12	2	<0.2	<0.1	≤ 0.01	≤0.003	<0.025	<0.025	≤ 0.01	<0.025	≤ 0.01	<0.025	<0.025	0.04
MBH05D	8.1	65.7	452	60	49	42	1.1	11	5	8.6	<0.2	<0.1	≤ 0.01	≤0.003	<0.025	<0.025	≤ 0.01	<0.025	≤ 0.01	0.04	<0.025	0.04
MBH06	8.1	73.4	538	67	72	29	1.2	9	24	0.5	<0.2	<0.1	≤ 0.01	≤0.003	<0.025	<0.025	≤ 0.01	<0.025	≤ 0.01	<0.025	<0.025	0.05

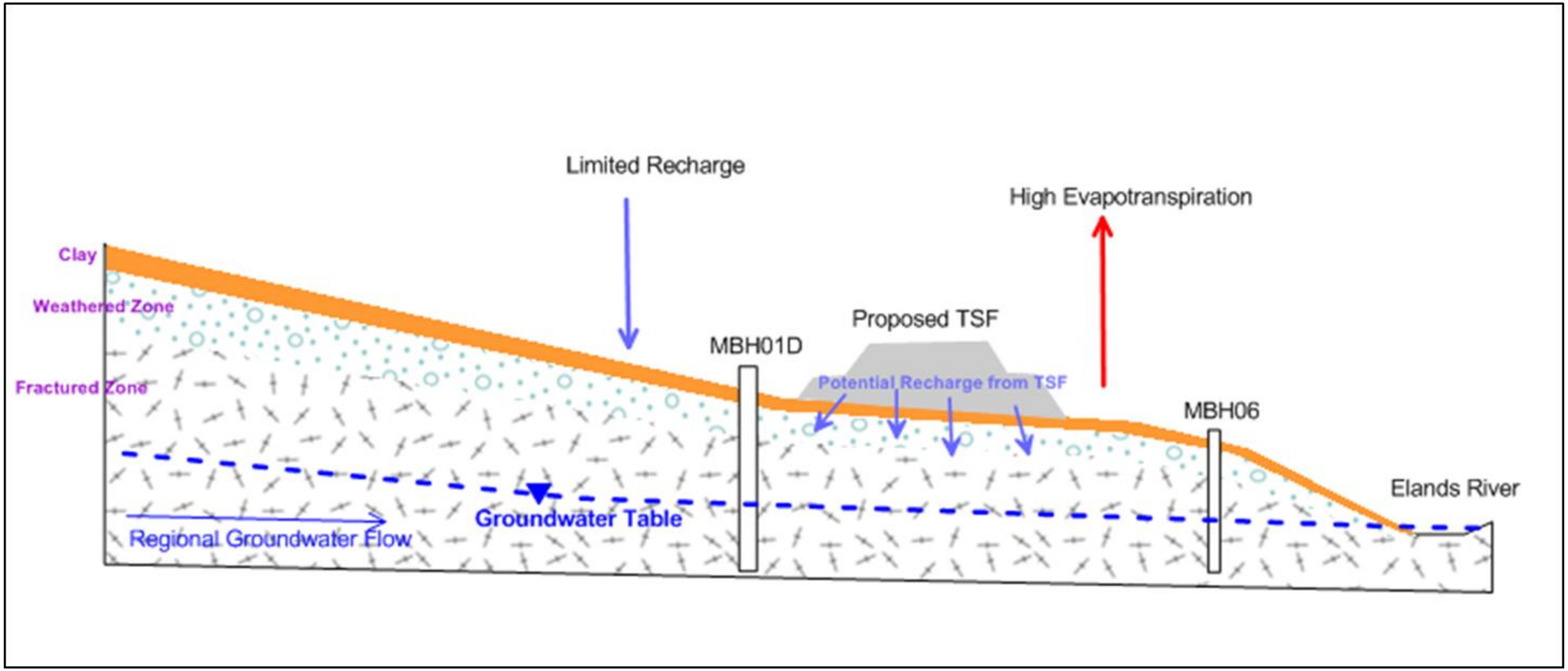

Figure 8: Conceptual model representation

4 Numerical Model

A numerical groundwater flow model was constructed to simulate the groundwater system at the proposed TSF area. This numerical model is a mathematical representation of the conceptual model presented in Section 3 and enables a quantitative analysis of local groundwater flow and contaminant plume migration. The conceptual model was represented numerically based on the following assumptions;

- The aquifer systems at the proposed TSF area can be subdivided into hydrostratigraphic units to represent naturally occurring aquifers;
- Groundwater movement in the hydrostratigraphic units follows Darcy's law and hence can be modelled using the 'equivalent porous medium' approach. i.e. the use of effective (or bulk) hydraulic properties to approximate conditions in the aquifer;
- Net recharge to the area is limited and weathered aquifer is mostly dry except in areas close to the Elands River; and
- The Sandspruit can be adequately represented by drain nodes set below ground surface to receive flows from the aquifers.

These assumptions and other aspects of the numerical representation of the conceptual model are explained in more detail in the sub-sections below. Also described is the rationale for employing a finite difference model and any model parameters set prior to beginning the calibration process.

4.1 Code Selection

Groundwater flow at the proposed TSF was simulated with a finite difference model called MODFLOW-NWT that was developed by the United States Geological Survey. MODFLOW has been rigorously evaluated and is periodically updated since it was first published in 1984 and is widely-used by governmental and non-governmental agencies worldwide to simulate saturated flow in porous media.

For the current model, the Layer Property Flow (LPF) package and the Newton solver were used to solve the flow matrix. The LPF package involves assigning hydraulic properties to individual cells based on their location within a particular layer of the model domain. The critical assumption of this approach is that every cell within a particular section of a layer is assigned the same set of hydraulic properties and that any localized heterogeneity is subsumed into the bulk permeability of a zone. There is however no limit to how finely a layer can be discretized horizontally into rectangular cells, but each layer of a finite difference grid is necessarily one cell thick.

For the current model, The Elands River was modelled using the river (RIV) package. Also used was the recharge (RCH), drain package (DRN), which are each described in subsequent sections. The process of evapotranspiration was not explicitly modelled, but is implicitly included in the model by the use of "net recharge".

4.2 Model Boundaries and Discretisation

Recall that the model domain was defined by local topographic highs to the north and west. The southern boundary is represented by the Elands River, and the Sandspruit represents the eastern boundary.

The numerical model domain was spatially discretized into a 3-dimensional grid with a grid spacing of 25 by 25 m within the site and up to 100 m by 100 m in areas beyond the site. The domain was discretized as a 2-layer model (i.e. the finite volume grid is 2 cells thick). Layer depths are summarized as follows:

- Layer 1 (weathered aquifer): 0 to 10 m; and
- Layer 2 (fractured aquifer): 10 to 70 m.

The topography of the site was used to define the top of the model domain. The bottom of each layer was specified by applying the corresponding depths stated above to the topography. A 3D view of the model domain is given in Figure 9.

4.3 Model Calibration

During steady state model calibration the principle of parsimony was followed, i.e. an attempt was made to keep the model complexity to a minimum. The model domain was therefore discretized solely on the basis of lithology and estimates of recharge, and horizontal and vertical hydraulic conductivity (Kh and Kv). The model was then calibrated by manually adjusting recharge and the aquifer properties within an acceptable range in order to fit simulated water levels to the observed groundwater levels.

The quality of the fit between simulated and observed water levels was visually evaluated based on the geodetic elevation of the simulated water level and by means of a statistical analysis.

Model calibration indicated that 0.001% of MAP can be effectively used to simulate net recharge to the low lying areas. Recharge to the elevated areas was calibrated at 0.005%. The hydraulic parameters used to simulate the current conditions are given in Table 2. Simulated calibration targets are given in Figure 10 and Figure 11. Steady state hydraulic heads are given in Figure 12 and Figure 13.

Table 2: Calibrated horizontal and vertical hydraulic conductivities

Layer	Description	Kh (m/d)	Kv (m/d)
1	Weathered	0.015	0.0015
2	Fractured	0.002	

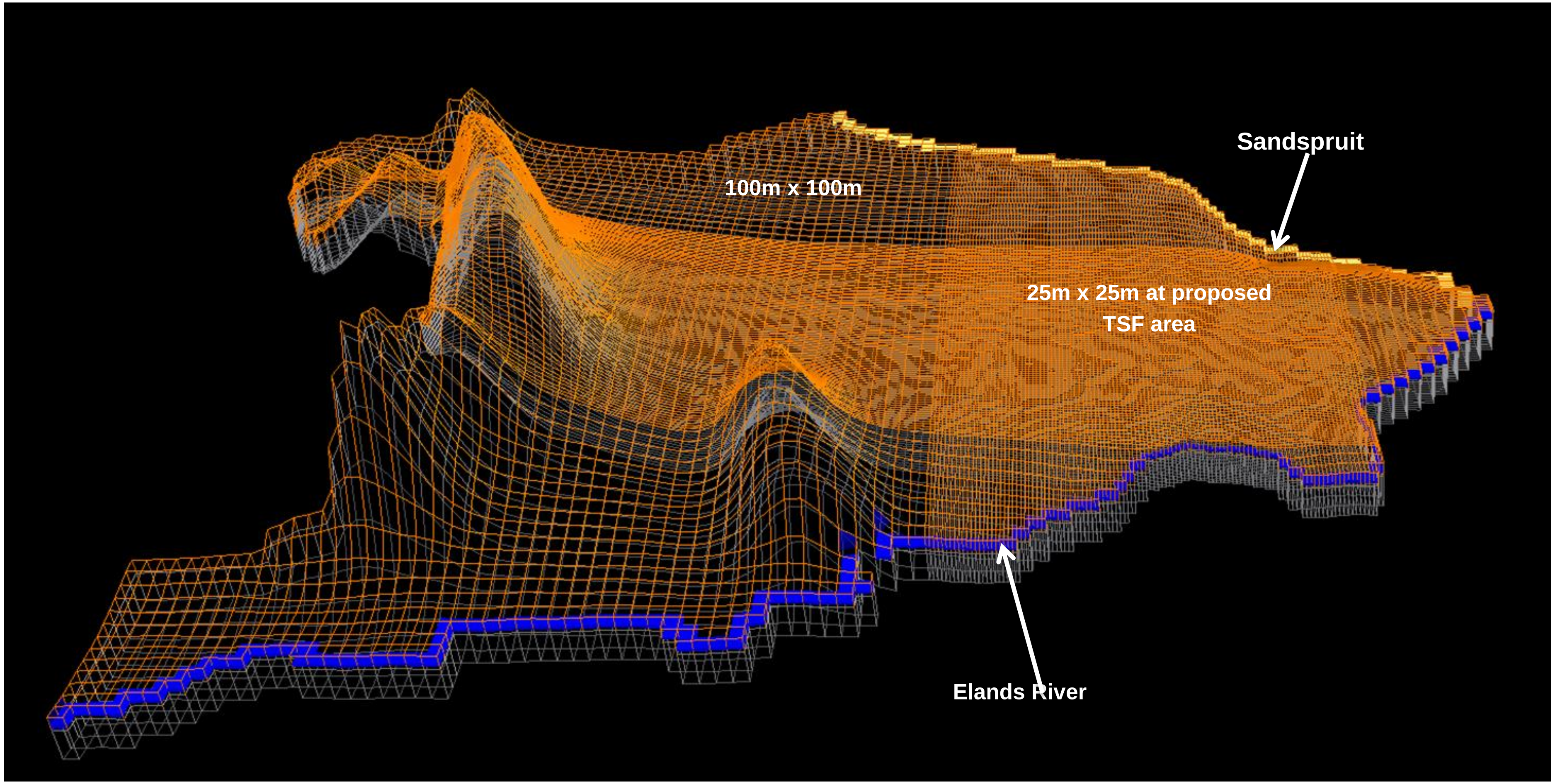

Figure 9: 3D model domain

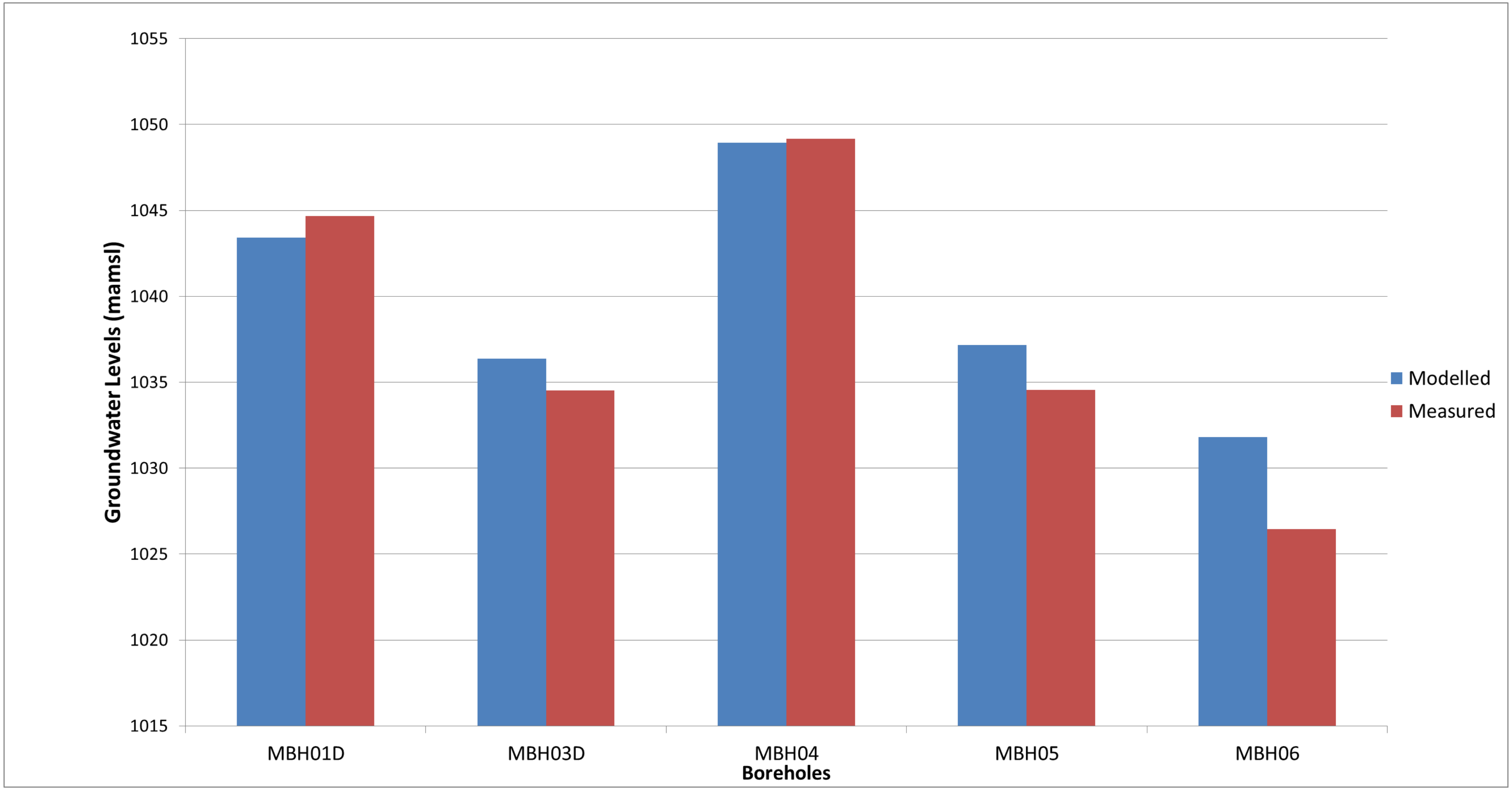

Figure 10: Modelled versus measured groundwater levels (RMSE=2.8 m, mean= 1.7 m, max 5.3 m, min= -1.3)

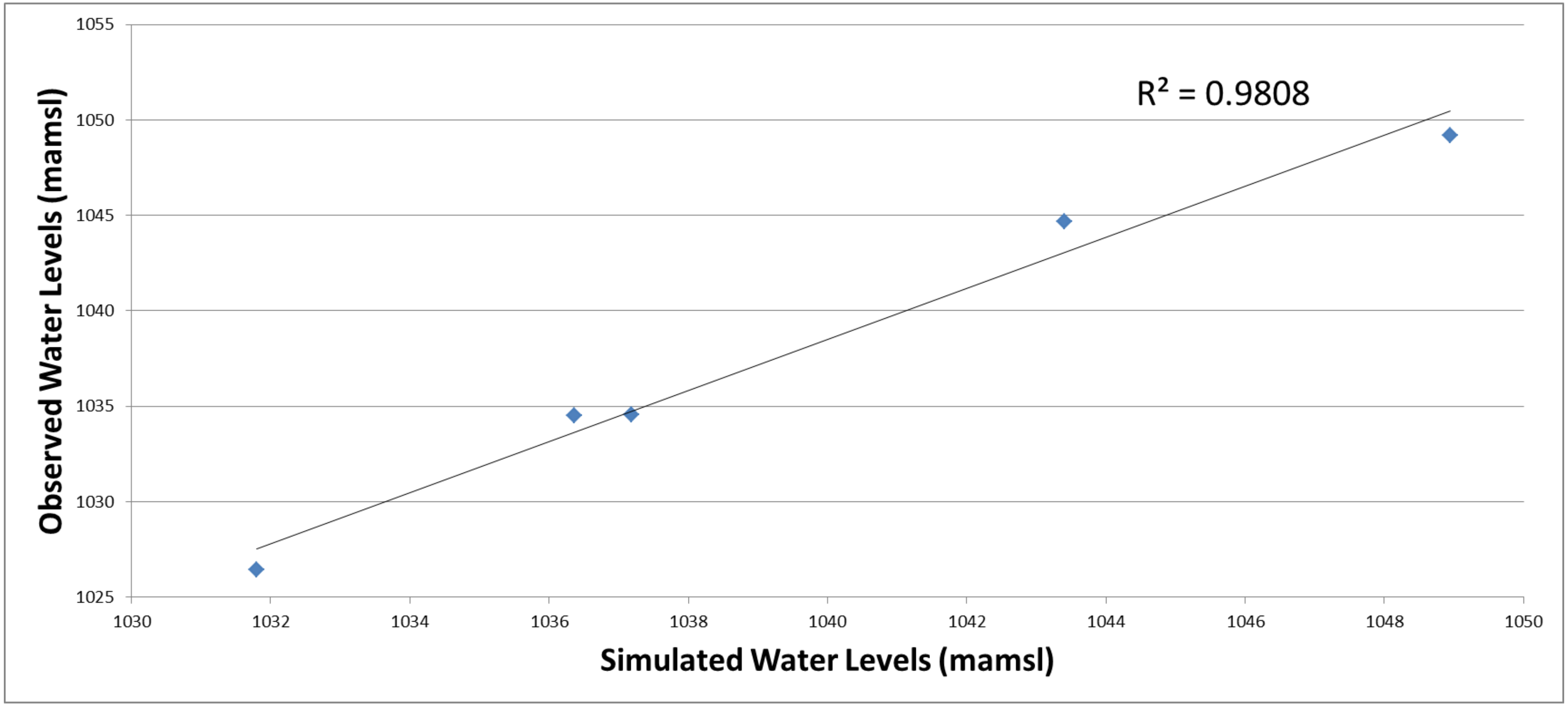

Figure 11: Correlation between observed and simulated groundwater levels

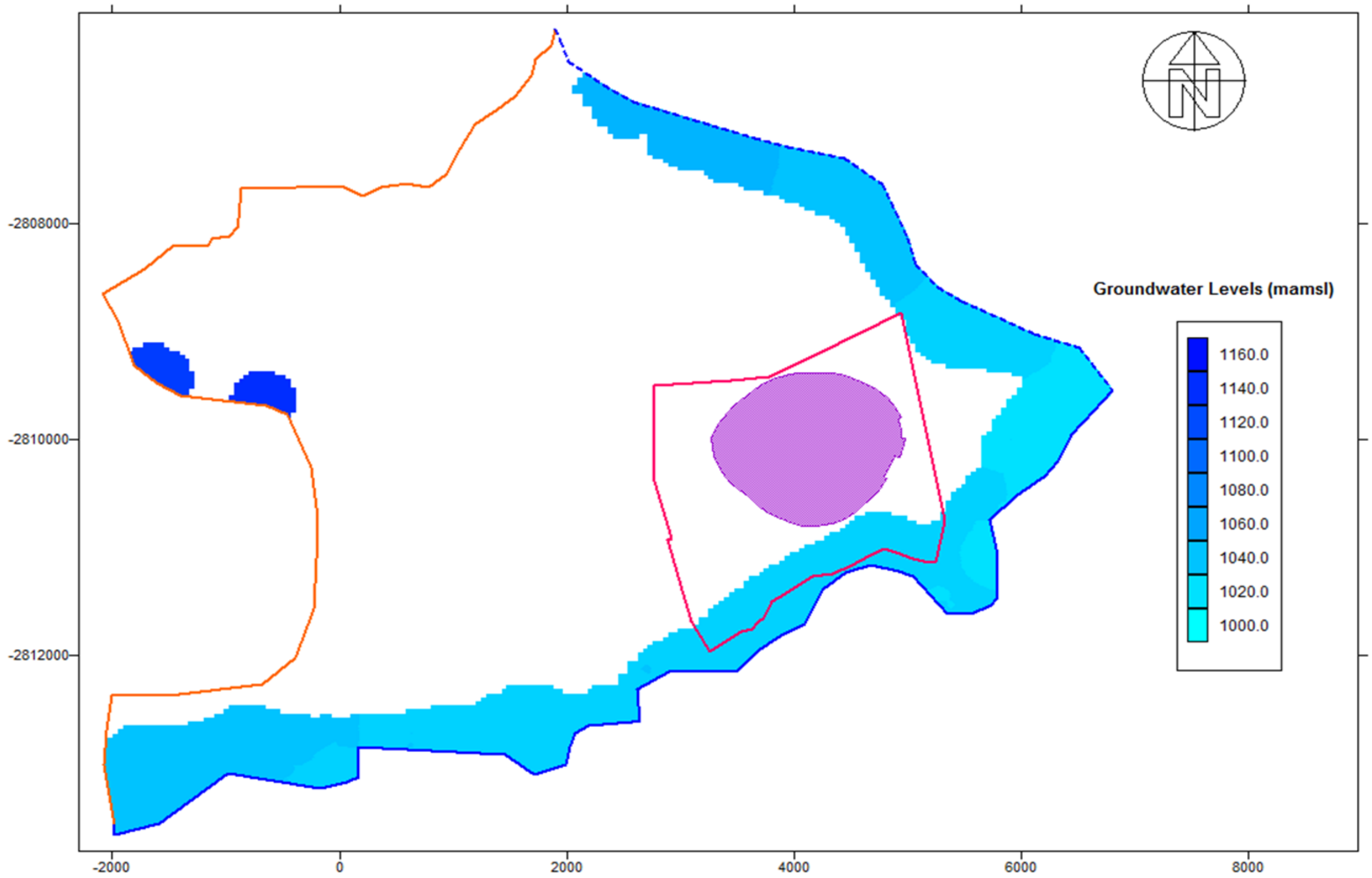

Figure 12: Simulated steady state heads in weathered aquifer depicting saturated and unsaturated areas within model domain

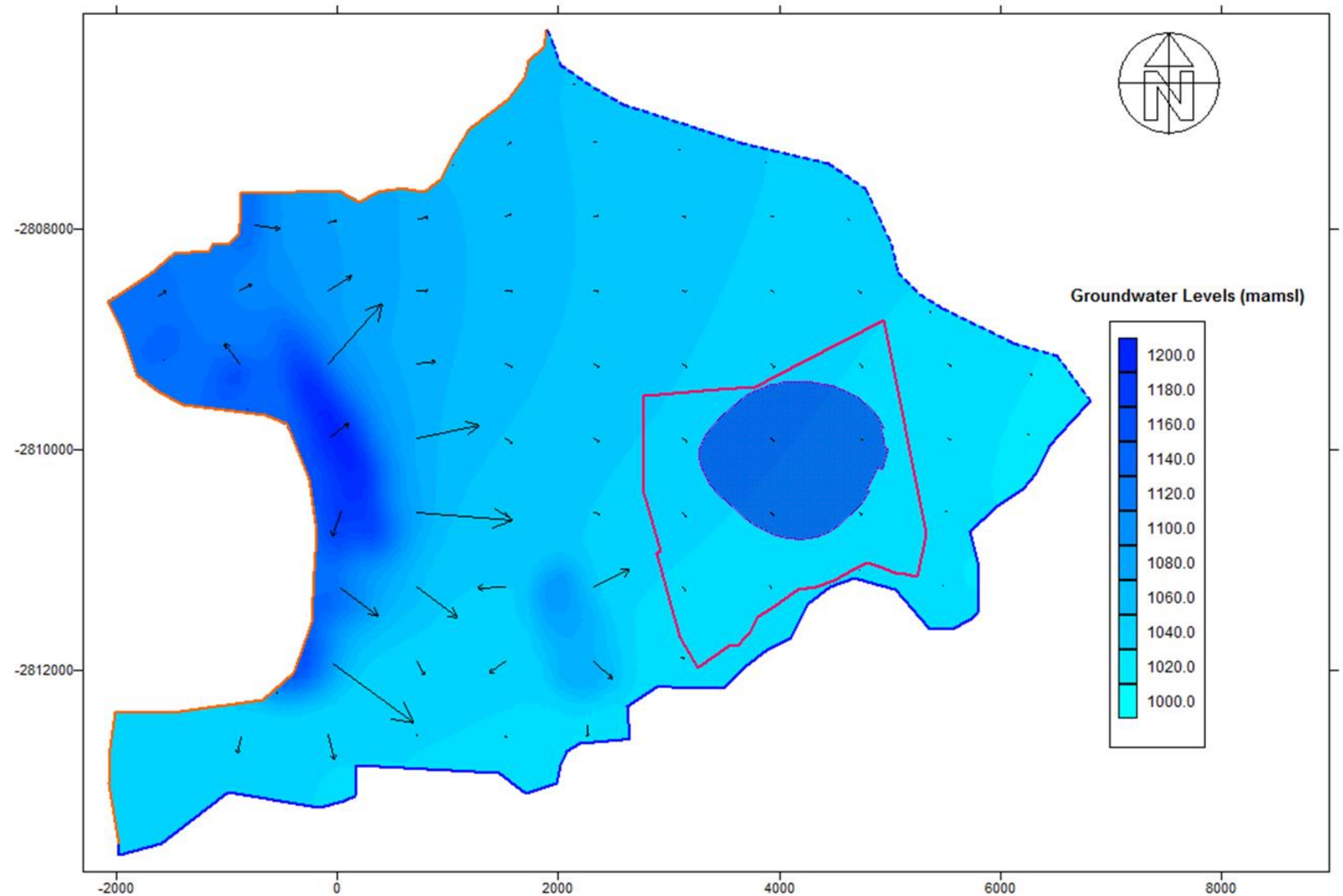

Figure 13: Simulated steady state heads in fractured aquifer

5 Impacts Assessment

The potential groundwater impacts were assessed considering the three phases of the life of TSF: the construction, operation and closure phases.

5.1 Impact Assessment Methodology

The proposed method for the assessment of environmental issues is set out in Table 3. This assessment methodology enables the assessment of environmental issues including: cumulative impacts, the severity of impacts (including the nature of impacts and the degree to which impacts may cause irreplaceable loss of resources), the extent of the impacts, the duration and reversibility of impacts, the probability of the impact occurring, and the degree to which the impacts can be mitigated.

Table 3: Criteria for assessing impacts

Note: Part A provides the definition for determining impact consequence (combining severity, spatial scale and duration) and impact significance (the overall rating of the impact). Impact consequence and significance are determined from Part B and C. The interpretation of the impact significance is given in Part D.

PART A: DEFINITION AND CRITERIA*		
Definition of SIGNIFICANCE		**Significance = consequence x probability**
Definition of CONSEQUENCE		**Consequence is a function of severity, spatial extent and duration**
Criteria for ranking of the SEVERITY of environmental impacts	**H**	Substantial deterioration (death, illness or injury). Recommended level will often be violated. Vigorous community action.
	M	Moderate/ measurable deterioration (discomfort). Recommended level will occasionally be violated. Widespread complaints.
	L	Minor deterioration (nuisance or minor deterioration). Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	L+	Minor improvement. Change not measurable/ will remain in the current range. Recommended level will never be violated. Sporadic complaints.
	M+	Moderate improvement. Will be within or better than the recommended level. No observed reaction.
	H+	Substantial improvement. Will be within or better than the recommended level. Favourable publicity.
Criteria for ranking the DURATION of impacts	**L**	Quickly reversible. Less than the project life. Short term
	M	Reversible over time. Life of the project. Medium term
	H	Permanent. Beyond closure. Long term.
Criteria for ranking the SPATIAL SCALE of impacts	**L**	Localised - Within the site boundary.
	M	Fairly widespread – Beyond the site boundary. Local
	H	Widespread – Far beyond site boundary. Regional/ national

PART B: DETERMINING CONSEQUENCE

SEVERITY = L

DURATION	Long term	**H**	**Medium**	**Medium**	**Medium**
	Medium term	**M**	**Low**	**Low**	**Medium**
	Short term	**L**	**Low**	**Low**	**Medium**

SEVERITY = M

DURATION	Long term	**H**	**Medium**	**High**	**High**
	Medium term	**M**	**Medium**	**Medium**	**High**
	Short term	**L**	**Low**	**Medium**	**Medium**

SEVERITY = H					
DURATION	Long term	**H**	**High**	**High**	**High**
	Medium term	**M**	**Medium**	**Medium**	**High**
	Short term	**L**	**Medium**	**Medium**	**High**
			L	**M**	**H**
			Localised Within site boundary Site	Fairly widespread Beyond site boundary Local	Widespread Far beyond site boundary Regional/ national
			SPATIAL SCALE		

PART C: DETERMINING SIGNIFICANCE					
PROBABILITY (of exposure to impacts)	Definite/ Continuous	**H**	**Medium**	**Medium**	**High**
	Possible/ frequent	**M**	**Medium**	**Medium**	**High**
	Unlikely/ seldom	**L**	**Low**	**Low**	**Medium**
			L	**M**	**H**
			CONSEQUENCE		

PART D: INTERPRETATION OF SIGNIFICANCE	
Significance	**Decision guideline**
High	It would influence the decision regardless of any possible mitigation.
Medium	It should have an influence on the decision unless it is mitigated.
Low	It will not have an influence on the decision.

***H = high, M= medium and L= low and + denotes a positive impact.**

5.2 Construction phase impact on groundwater availability and quality

5.2.1 Severity/Nature

In the unmitigated scenario, activities during construction phase may add contaminants to groundwater resource below and around the footprint. Groundwater levels underneath the proposed TSF are on average 20 mbgl. The related unmitigated severity is low.

In the mitigated scenario:

- Excess water that accumulates during the construction phase will be dealt with as part of the construction phase water balance;
- All unwanted water accumulating in the excavations will be used or discharged into pollution control dams; and
- Clean runoff will be diverted around the total TSF complex.

5.2.2 Duration

In the unmitigated and unmitigated scenarios, any impact on groundwater resources will only occur for a short term.

5.2.3 Spatial Scale/Extent

In the mitigated and unmitigated scenarios, the spatial scale is not likely to extend beyond the proposed project area.

5.2.4 Consequence

The consequence of the mitigated and unmitigated scenario is low

5.2.5 Probability

The probability of the impact occurring relies on a causal chain that comprises three main elements:

- Does contamination reach groundwater resources?
- Will people and livestock utilise this contaminated groundwater?
- Is the contamination level harmful?

The first element is that contamination potential contamination during construction phase will not reach the groundwater table as it may only occur in a short term and natural groundwater levels are on average 20 m below ground level.

On the second element, there is no reliance on groundwater resources in the area for domestic use or livestock. The third element is void as no contaminant will reach the groundwater table during construction phase.

As a combination, when considering the nature and location of the proposed TSF, to groundwater users, the mitigated and unmitigated probabilities are low.

5.2.6 Significance

The significance of the mitigated and unmitigated scenarios is low.

Table 4: Summary of the rated construction phase impacts on groundwater resources

Management	Severity/ nature	Duration	Spatial scale/extent	Consequence	Probability of Occurrence	Significance
Unmitigated	L	L	L	L	L	L
Mitigated	L	L	L	L	L	L

5.3 Operational phase impact of groundwater mounding underneath the TSF

5.3.1 Severity/Nature

Results from the numerical model indicate that saturated areas in the weathered aquifer are limited to areas a few metres from the Elands River and the Sandspruit.

In the unmitigated scenario, water will be pumped to the TSF in the form of slurry during operational phase. Water emanating from TSF will seep and recharge the aquifers beneath. Localised recharge to the water table from the TSF may result to the formation of a groundwater mound.

The formation of the groundwater mound was simulated in steady state by applying a net recharge to the TSF footprint to increase the hydraulic head beneath the foot print to surface levels.

It is predicted that the dry weathered aquifer underneath the TSF will become fully saturated in the long run. This will reverse groundwater gradients in the immediate vicinity of the TSF and increase groundwater levels.

Modelling simulations indicate that groundwater levels underneath the proposed TSF foot print may increase by between 19 and 23 m. The groundwater level in MBH06 is predicted to increase by 5 m, 14 m for MBH4D, 17 m for MBH01, and 15 m for MBH05 (Figure 14). The increase in groundwater levels may increase baseflow to the Elands River. Due to the low hydraulic conductivity, steady state baseflow from the groundwater system to the Elands River was estimated at 8 m^3/d. Artificial recharge from the TSF is predicted to increase baseflow to 14.8 m^3/d.

Previous studies to determine the acid mine drainage and hazardous heavy metal leachate potential on both the Merensky and the UG2 tailings has indicated that such tailings have a negligible potential to generate acid or to mobilise metals. Although acid production and metal mobilisation do not occur, the sulphide content may be sufficient to produce some soluble sulphates under oxidising conditions. This may increase the sulphate concentration in water that comes into contact with the tailings if there is not sufficient buffering capacity. With artificial recharge predicted to occur, any potential contaminant emanating from the TSF will potentially migrate downstream.

A mass transport simulation was carried out to predict the direction and receptor area of the potential plume. A recharge source term was used at 100 % of the contaminant concentration. There was no geochemistry study done. Mass transport was simulated with MT3DMS which does not show inorganic geochemical reaction of contaminants. So 100 % was used to indicate the likely hood of potential contaminants that may seep from the TSF. For example if 1 mg/L of aluminium is at the source (the TSF), 10% (0.1 mg/L) may end up in the aquifer underneath.

As given in Figure 15, up to 45 % of the initial source concentration is predicted to reach the weathered aquifer underneath the TSF footprint. The plume is predicted to move in south-south east direction from the southern elongated boundary of the TSF footprint, towards the

Elands River. The Elands River is not predicted to be impacted by potential contamination from the TSF. The related unmitigated severity is medium.

In the mitigated scenario, the TSF will be clay lined. It is unlikely that water emanating from the TSF will seep downward to the weathered aquifer beneath the facility. The will result to limited or no increase in groundwater levels beneath the TSF. The severity can be reduced to low with the following mitigation strategies:

- All excess water must be managed as part of operational phase water balance. Return water from the TSF must be used as much as possible;
- All water coming to the TSF must be treated as polluted. Where water is not returned to the plant area, disposal must take place in the correct polluted water facility;
- As the TSF will be lined, seepage of potential contaminants to the groundwater system will be significantly reduced
- The sustainability of the lining must be continuously checked through continuous monitoring of groundwater quality and levels for any type of impact; and
- If required, a groundwater abstraction scheme should be implemented around the TSF to capture polluted ground water, and to prevent the migration of polluted water away from the site.

5.3.2 Duration

In the unmitigated scenario, groundwater mounding will occur for periods longer than the life of the project. With mitigation, pollution can be prevented and/or managed as such the impacts can be reversed or mitigated within the life of the TSF.

5.3.3 Spatial Scale/Extent

In the unmitigated scenario the spatial scale is likely to extend beyond the proposed TSF footprint once seepage reaches the water table. With mitigation any seepage will be significantly reduced and diluted by flowing groundwater underneath the TSF, thus contained within the TSF footprint.

5.3.4 Consequence

In the unmitigated scenario the consequence is high and in the mitigated scenario it is low.

5.3.5 Probability

The probability of the impact occurring relies on a causal chain that comprises three main elements:

- Does contamination reach groundwater resources?
- Will people and livestock utilise this contaminated groundwater? and
- Is the contamination level harmful?

In the unmitigated scenario, potential contamination during operational phase will reach the groundwater table due to continuous seepage as slurry is added to the TSF.

On the second element, there is no reliance on groundwater resources in the area for domestic use or livestock. The Elands River is not predicted to be impacted by potential contamination from the TSF. On the third element, it is likely that only some contaminants will be at a level which is harmful to humans and livestock. However, no groundwater users are located within the predicted extent.

As a combination, when considering the nature and location of the proposed TSF, to groundwater users, the unmitigated probability is medium, reducing to low with mitigation.

5.3.6 Significance

In the unmitigated scenario, the significance of this potential impact is high. In the mitigated scenario the significance is reduced to low based on reduction of severity, duration, extent and probability.

Table 5: Summary of the rated operational phase impacts on groundwater resources

Management	Severity/ nature	Duration	Spatial scale/extent	Consequence	Probability of Occurrence	Significance
Unmitigated	M	M	M	H	M	H
Mitigated	L	M	M	L	L	L

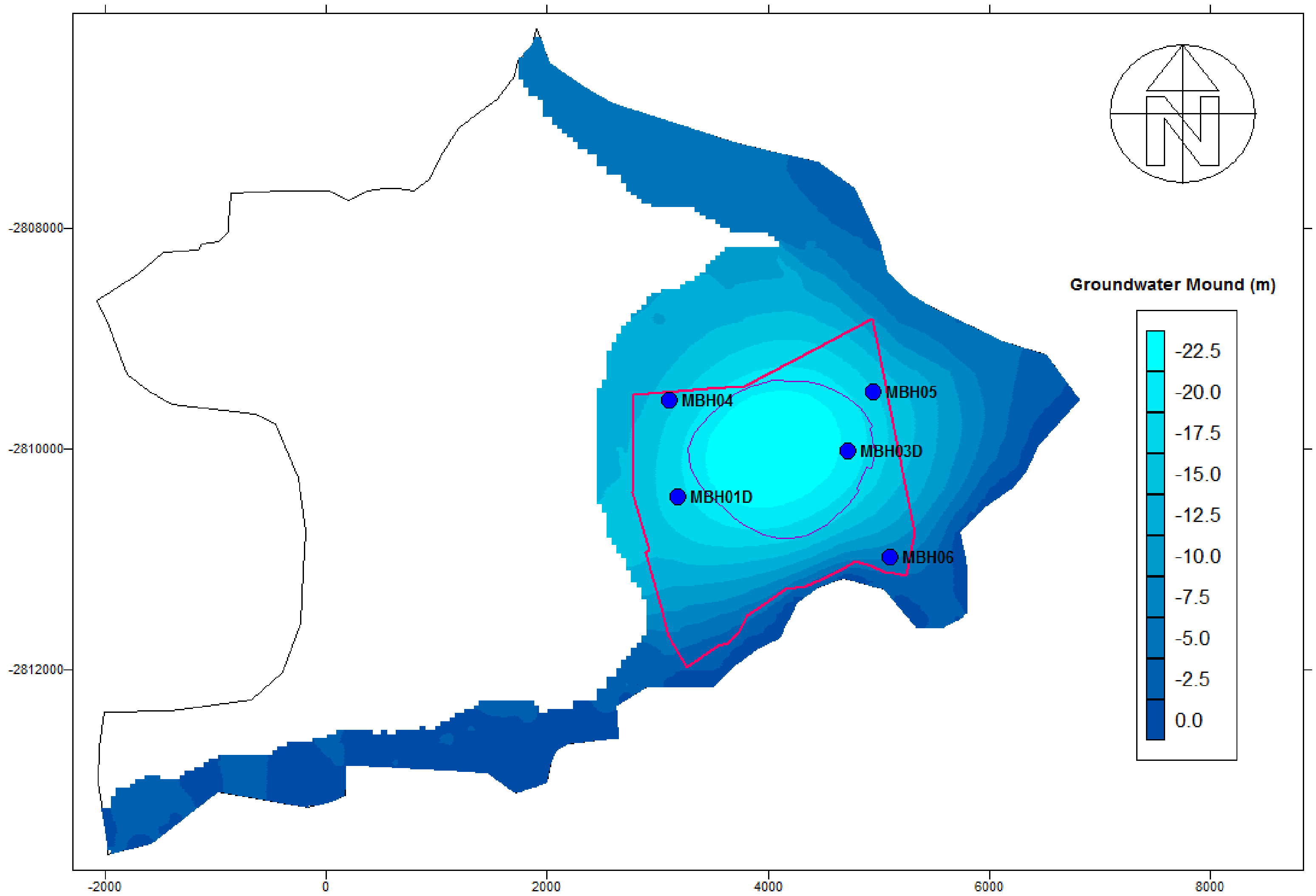

Figure 14: Predicted steady rise in groundwater levels due to TSF operations

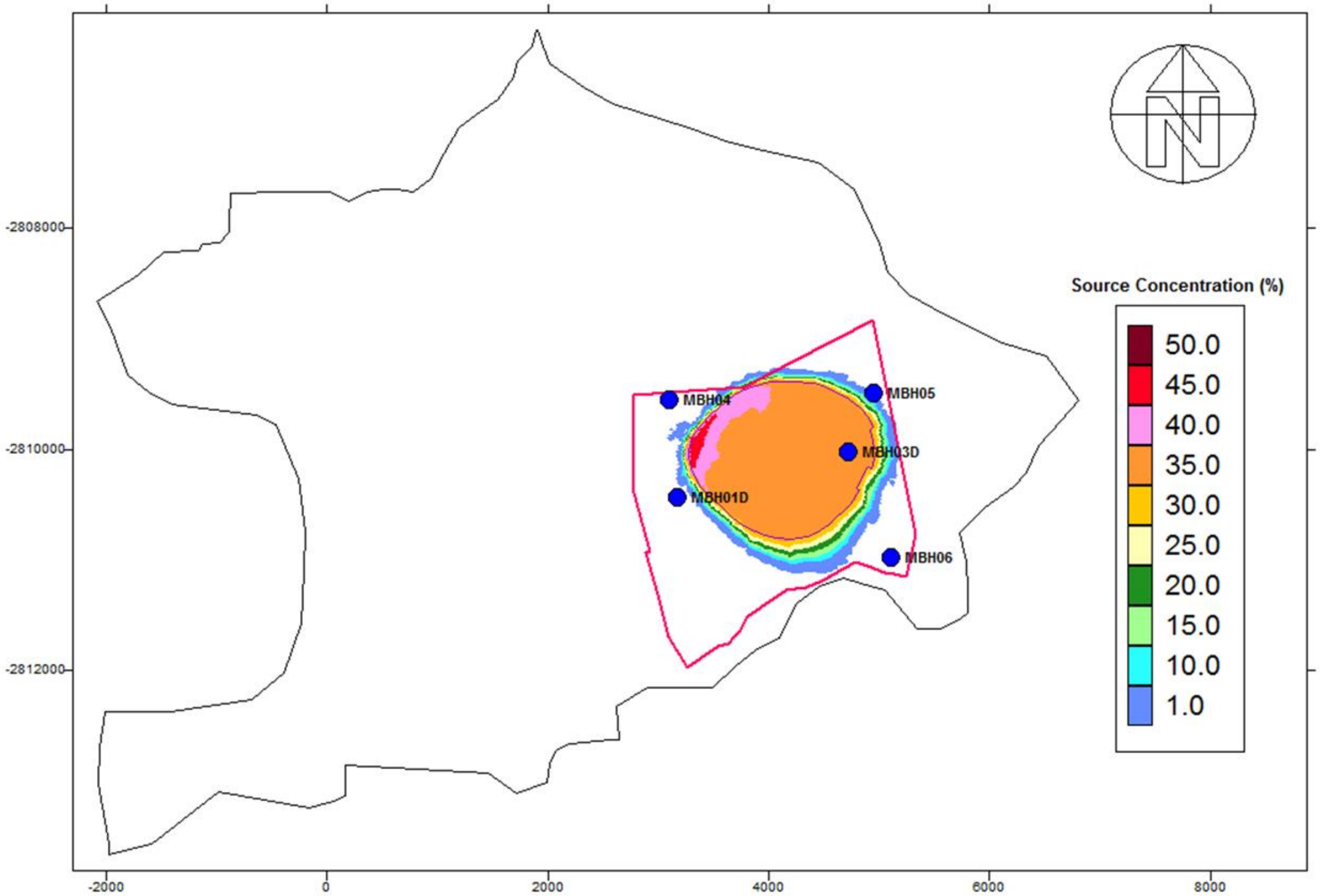

Figure 15: 100 years predicted pollution plume in weathered aquifer

5.4 Decommission, Closure and Post Closure

5.4.1 Severity/ Nature

During decommission phase, TSF activities will stop. No additional water will be pumped to the facility in the form of slurry. In the unmitigated scenario, recharge to the aquifers is expected to decrease due to no hydraulic head build up. There is also no risk of Acid Rock Drainage. The related unmitigated severity is medium.

In the mitigated scenario, a vegetation cover will be used to rehab the TSF. With the lining still in place, this will further reduce infiltration of rainfall to the TSF, minimising seepage in the post closure environment. The severity can therefore be reduced to low.

5.4.2 Duration

In the unmitigated scenario, the potential contamination of groundwater resources will be permanent. With mitigation, pollution can be prevented and /or managed in permanent mitigation.

5.4.3 Spatial Scale/Extent

In the unmitigated scenario the spatial scale is likely to extend beyond the proposed TSF footprint. With mitigation any seepage will be significantly reduced and diluted by flowing groundwater underneath the TSF, thus contained within the TSF footprint.

5.4.4 Consequence

In the unmitigated scenario the consequence is high and in the mitigated scenario it is low.

5.4.5 Probability

The probability of the impact occurring relies on a causal chain that comprises three main elements:

- Does contamination reach groundwater resources?
- Will people and livestock utilise this contaminated groundwater? and
- Is the contamination level harmful?

In the unmitigated scenario, potential contamination during post closure will add to operational phase contaminants. However this will reduce over time with absence of slurry.

On the second element, there is no reliance on groundwater resources in the area for domestic use or livestock. The Elands River is not predicted to be impacted by potential contamination from the TSF. On the third element, it is likely that only some contaminants will be at a level which is harmful to humans and livestock. However, no groundwater users are located within the predicted extent.

As a combination, when considering the nature and location of the proposed TSF, to groundwater users, the unmitigated probability is medium, reducing to low with mitigation.

5.4.6 Significance

In the unmitigated scenario, the significance of this potential impact is high. In the mitigated scenario the significance is reduced to low based on reduction of severity, duration, extent and probability.

Table 6: Summary of the rated post closure phase impacts on groundwater resources

Management	Severity/ nature	Duration	Spatial scale/extent	Consequence	Probability of Occurrence	Significance
Unmitigated	M	M	M	H	M	H
Mitigated	L	M	M	L	L	L

6 Mitigation and Monitoring Plan

6.1.1 Construction Phase

6.1.1.1 Objectives

To prevent contamination of groundwater at the TSF foot print.

6.1.1.2 Action

The mitigation strategies that will be implemented during construction phase will be as follows:

- Excess water that accumulates during the construction phase will be dealt with as part of the construction phase water balance;
- All unwanted water accumulating in the excavations will be used or discharged into pollution control dams; and
- Clean runoff will be diverted around the total TSF complex.

6.1.2 Operational Phase

6.1.2.1 Objectives

The objective of the groundwater management will be to prevent large scale mounding of groundwater and to monitor groundwater pollution around the TSF;

6.1.2.2 Action

- All excess water must be managed as part of operational phase water balance. Return water from the TSF must be used as much as possible;
- All water coming to the TSF must be treated as polluted. Where water is not returned to the plant area, disposal must take place in the correct polluted water facility;
- As the TSF will be lined, seepage of potential contaminants to the groundwater system will be significantly reduced
- The sustainability of the lining must be continuously checked through continuous monitoring of groundwater quality and levels for any type of impact;

- If required, a groundwater abstraction scheme should be implemented around the TSF to capture polluted ground water, and to prevent the migration of polluted water away from the site.

6.1.3 Decommissioning Phase

During the decommissioning phase, final rehabilitation of the TSF will take place. All measures put in place during the operational phase will be extended through the decommissioning phase to closure. The long term groundwater closure objective is to prevent any migration of polluted water from the TSF.

6.1.3.1 Action

Monitoring of groundwater levels and groundwater qualities should continue after post closure. If a groundwater abstraction scheme is required around the TSF, this process must be scoped and discussed with all the authorities. The abstraction and disposal of polluted water must be licensed.

6.2 Monitoring Program

Groundwater monitoring has to continue during all phases of the TSF operation to identify the impact on the groundwater resources over time, so effective measures can be taken at an early stage before serious damage to the environment occurs.

6.2.1 Proposed Monitoring Boreholes

The main objectives in positioning the monitoring boreholes are to:

- Monitor the movement of polluted groundwater migrating away from the TSF,;
- Monitor the mounding of the water table and the radius of influence; and
- Monitor post closure groundwater levels and qualities.

Four sets of monitoring boreholes are recommended around the TSF based on the numerical modelling results. Each set is recommended to contain:

- A borehole drilled to a maximum depth of 15 mbgl to monitor the water level and quality in the weathered aquifer; and
- A deep borehole drilled between 30 and 60 m to monitor groundwater conditions in the fractured aquifer.

There are currently five boreholes on site which are properly constructed for groundwater monitoring. Four out of the five are recommended for long term monitoring. Borehole MBH03D will be destroyed as part of TSF construction. Borehole MBH01D, MBH04 and MBH05 will serve as deep monitoring boreholes. Shallow boreholes are therefore recommended to supplement the deep boreholes. A new set of boreholes (MBH07S and MBH07D) is proposed to monitor the plume front towards the Elands River, as given in Table 7.

In total 9 monitoring points are recommended for the proposed groundwater monitoring program as depicted in Figure 16.

Table 7: Proposed monitoring boreholes

BHID	X-Coordinate	Y-Coordinate	Purpose
MBH01D and S	3184	-2810436	West of TSF
MBH04 D and S	3104	-2809560	North western corner of TSF
MBH05 D and S	4951	-2809492	North eastern corner of TSF
MBH07 D and S	4449	-2810839	South of TSF
MBH06	5106	-2810980	Elands River

6.2.2 Groundwater Level

Groundwater levels must be recorded on a monthly basis using an electrical contact tape or pressure transducer, to detect any changes or trends in groundwater flow direction.

6.2.3 Groundwater Sampling

Groundwater is a slow-moving medium and drastic changes in the groundwater composition are not normally encountered within days. Due to the proximity of the Elands River the proposed TSF, monitoring should be conducted quarterly, including two years post closure and based on the results it can be adjusted accordingly. Monitoring should continue until a sustainable situation is reached.

When sampling the following procedures are proposed:

- One (1) litre plastic bottles with a cap are required for the sampling exercises – provided by the water laboratory;
- Glass bottles are required if organic constituents are to be tested; and
- Sample bottles should be marked clearly with the borehole name, date of sampling, sampling depth and the sampler's name and submitted to a reputable laboratory.

6.3 Parameters to be monitored

Analyses of the following constituents are recommended for first few years until demonstrated that some elements have not changed. The number and selection of parameters should be reviewed on an annual basis to optimise the monitoring programme:

- EC, pH, TDS;
- Macro Analysis i.e. Ca, Mg, Na, K, SO_4, NO_3, F, Cl; and
- Heavy metals As, Al, Co, Cr, Zn, Cd, Cu, Fe, Ni, V, Mn;

6.3.1 Data Storage

In any project, good hydrogeological decisions require good information developed from raw data. The production of good, relevant and timely information is the key to achieve qualified long-term and short-term plans. For the minimisation of groundwater contamination it is necessary to utilize all relevant groundwater data.

The generation and collection of this data is very expensive as it requires intensive hydrogeological investigations and therefore has to be managed in a centralised database if funds are to be used in the most efficient way.

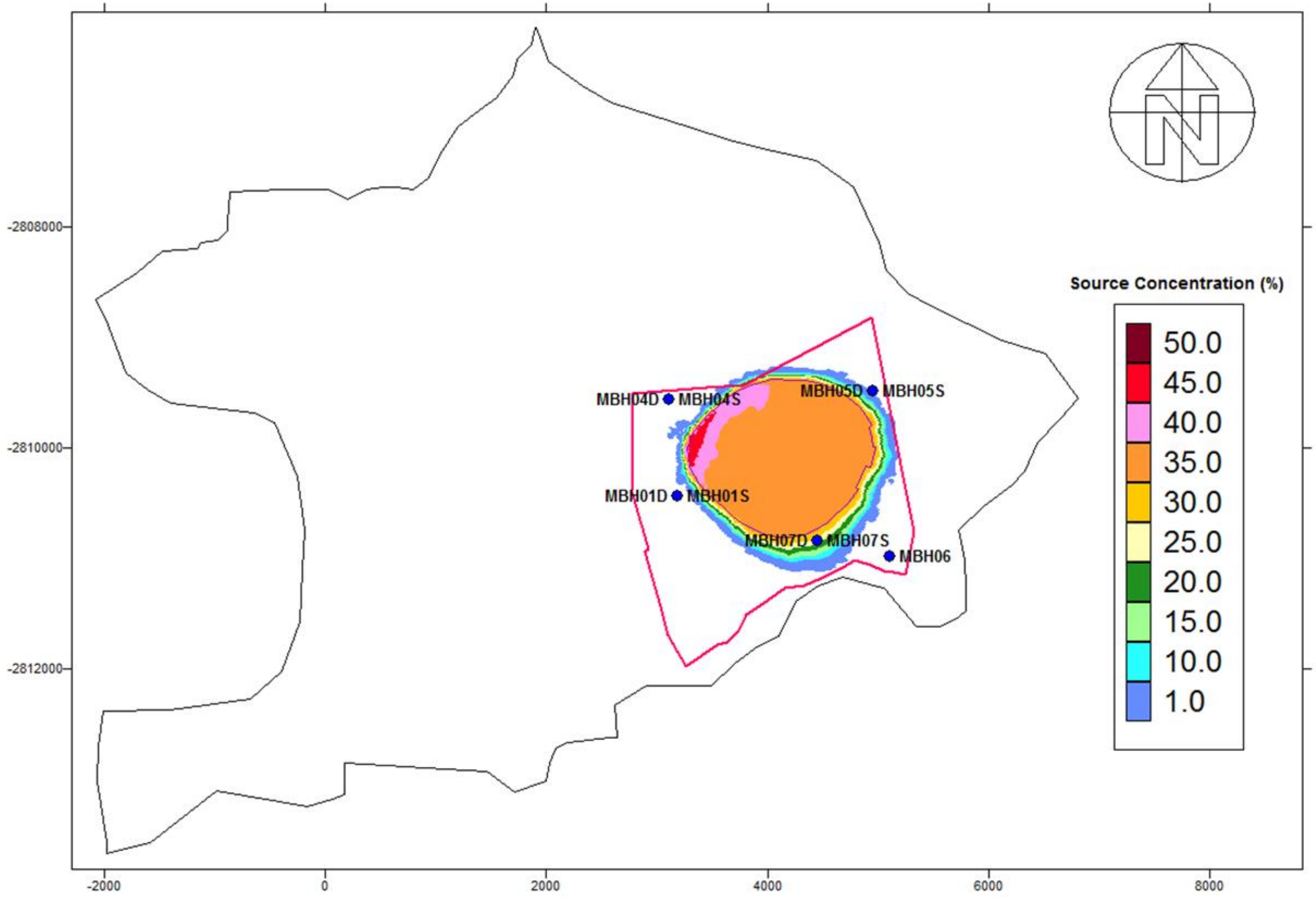

Figure 16: Position of proposed monitoring boreholes

Appendix A: Laboratory Certificates

WATERLAB (Pty) Ltd

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SANAS Accredited Testing Laboratory
No. T0391

CERTIFICATE OF ANALYSES
GENERAL WATER QUALITY PARAMETERS

Date received: 2016 - 01 - 22 **Date completed:** 2016 - 02 – 10

Project number: 1000 **Report number: 57079** **Order number: -**

Client name: Gemini GIS and Environmental **Contact person: Mr. T. Thidza**

Address: P.O Box 383 Strubensvalley 1735 **e-mail: tankisop@gges.co.za**
e-mail : elouw@slrconsulting.co.za

Telephone: **Facsimile:** **Mobile: -**

Analyses in mg/ℓ (Unless specified otherwise)	Risk	Method Identification	Sample Identification:			SANS 241:2015 (Standard Limits for Potable Water)
			MBH04D	**MBH05D**	**MBH06D**	
Sample Number			26433	26434	26435	
pH – Value at 25°C *	**Operational**	WLAB001	7.4	8.1	8.1	**≥ 5 to ≤ 9.7**
Electrical Conductivity in mS/m at 25°C *	**Aesthetic**	WLAB002	76.6	65.7	73.4	**≤ 170**
Total Dissolved Solids at 180°C *	**Aesthetic**	WLAB027	452	452	538	**≤ 1 200**
Colour in PtCo Units *	**Aesthetic**	WLAB006	6	6	**17↓**	**≤ 15**
Turbidity in N.T.U*	**Operational** **Aesthetic**	WLAB005	**14↓**	**11↓**	3.0	**≤ 1** **≤ 5**
Free Residual Chlorine as Cl_2 *	**Chronic health**	WLAB036	<0.1	<0.1	<0.1	**≤ 5**
Monochloramine*	**Chronic health**	WLAB036	<0.1	<0.1	<0.1	**≤ 3**
Chloride as Cl	**Aesthetic**	WLAB046	19	11	9	**≤ 300**
Sulphate as SO_4	**Acute health** **Aesthetic**	WLAB046	12	5	24	**≤ 500** **≤ 250**
Fluoride as F *	**Chronic health**	WLAB014	<0.2	<0.2	<0.2	**≤ 1.5**
Nitrate as N	**Acute health**	WLAB046	2.0	8.6	0.5	**≤ 11**
Nitrite as N	**Acute health**	WLAB046	<0.05	<0.05	<0.05	**≤ 0.9**
Combined Nitrate plus Nitrite *	**Acute health**	WLAB046	0.2	0.8	0.1	**≤ 1**
Free Cyanide as CN (in µg/l) *	**Acute health**	WLAB056	<10	<10	<10	**≤ 200**
Free & Saline Ammonia as N	**Aesthetic**	WLAB046	0.1	0.1	<0.1	**≤ 1.5**
Sodium as Na	**Aesthetic**	WLAB015	24	42	29	**≤ 200**
Potassium as K	---	WLAB015	1.6	1.1	1.2	**---**
Calcium as Ca	---	WLAB015	60	60	67	**---**
Magnesium as Mg	---	WLAB015	55	49	72	**---**
Aluminium as Al (in µg/l)	**Operational**	WLAB015	<100	<100	<100	**≤ 300**
Aluminium as Al (in µg/l) (Dissolved)	**Operational**	WLAB015	<100	<100	<100	**≤ 300**
Antimony as Sb (in µg/l) *	**Chronic health**	WLAB015	<20	<20	<20	**≤ 20**
Arsenic as As (in µg/l) *	**Chronic health**	WLAB015	<10	<10	<10	**≤ 10**

Analyses continued on next page

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e-mail : elouw@slrconsulting.co.za

Telephone: **Facsimile:** **Mobile: -**

Analyses in mg/ℓ (Unless specified otherwise)	Risk	Method Identification	Sample Identification:			SANS 241:2015 (Standard Limits for Potable Water)
			MBH04D	MBH05D	MBH06D	
Sample Number			26433	26434	26435	
Cadmium as Cd (in µg/l)	Chronic health	WLAB015	<3	<3	<3	≤ 3
Total Chromium as Cr (in µg/l)	Chronic health	WLAB015	<25	<25	<25	≤ 50
Cobalt as Co (in µg/l)	---	WLAB015	<25	<25	<25	---
Copper as Cu (in µg/l)	Chronic health	WLAB015	<10	<10	<10	≤ 2 000
Iron as Fe (in µg/l)	Chronic health Aesthetic	WLAB015	<25	<25	<25	≤ 2 000 ≤ 300
Iron as Fe (in µg/l) (Dissolved)	Chronic health Aesthetic	WLAB015	<25	30	<25	≤ 2 000 ≤ 300
Lead as Pb (in µg/l)	Chronic health	WLAB015	<10	<10	<10	≤ 10
Manganese as Mn (in µg/l)	Chronic health Aesthetic	WLAB015	<25	36	<25	≤ 400 ≤ 100
Manganese as Mn (in µg/l) (Dissolved)	Chronic health Aesthetic	WLAB015	<25	30	<25	≤ 400 ≤ 100
Mercury as Hg (in µg/l) *	Chronic health	WLAB047	<1	<1	<1	≤ 6
Nickel as Ni (in µg/l)	Chronic health	WLAB015	<25	<25	<25	≤ 70
Selenium as Se (in µg/l) *	Chronic health	WLAB015	<10	<10	<10	≤ 40
Uranium as U (in µg/l) *	Chronic health	WLAB015	<10	<10	10	≤ 30
Vanadium as V (in µg/l) *	---	WLAB015	<25	<25	<25	---
Zinc as Zn	Aesthetic	WLAB015	0.044	0.044	0.052	≤ 5
% Balancing *	---	---	99.6	97.3	94.9	---

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

A. van de Wetering

Technical Signatory

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Telephone:	**Facsimile:**	**Mobile: -**

Information regarding accredited analyses

Analysis	Method Identification	Reporting limit	Average Uncertainty
Sulphate	WLAB046	2 mg/L	14%
Free & Saline Ammonia	WLAB046	0.1 mg/L	14%
Nitrate	WLAB046	0.1 mg/L	6.2%
Nitrite	WLAB046	0.05 mg/L	10%
Ortho Phosphate	WLAB046	0.1 mg/L	26%
Chloride	WLAB046	2 mg/L	10%
Sodium	WLAB015	1 mg/L	1.5%
Potassium	WLAB015	0.5 mg/L	3.0%
Calcium	WLAB015	1 mg/L	2.5%
Magnesium	WLAB015	1 mg/L	2.1%
Aluminium	WLAB015	0.100 mg/L	2.3%
Cadmium	WLAB015	0.003 mg/L	2.3%
Cobalt	WLAB015	0.025 mg/L	2.1%
Chromium	WLAB015	0.025 mg/L	2.0%
Copper	WLAB015	0.010 mg/L	1.7%
Iron	WLAB015	0.025 mg/L	1.5%
Manganese	WLAB015	0.025 mg/L	2.9%
Nickel	WLAB015	0.025 mg/L	1.6%
Lead	WLAB015	0.010 mg/L	2.2%
Zinc	WLAB015	0.025 mg/L	1.9%
Total Coliform Bacteria	WLAB021	0 CFU/100 mL	41%
E. coli	WLAB021	0 CFU/100 mL	61%

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