RISON GROUNDWATER CONSULTING

GEOHYDROLOGICAL INVESTIGATION:

KOMATI ASH DAM EXTENSION

FINAL REPORT

FEBRUARY 2008

Adrian van Bart *(Pr. Sci. Nat.)*
Senior Hydrogeologist

Prepared by:

Rison Groundwater Consulting cc

Reg No: CK2001 0749 7623

2 Van Oordt Street
Krugersdorp, South Africa, 1739

Tel: (+2711) 954 0560
Cell: (+2782) 875 7265
Fax: (+2711) 954 3568

December 2007

EXECUTIVE SUMMARY

Rison Groundwater Consulting cc (RGC) was contracted by Synergistics Environmental to undertake a geohydrological investigation at the Komati Power Station where a new ash dam is to be constructed. The site is located approximately 35km south of Middelburg in the Mpumalanga Province. The surrounding area is used predominantly for agriculture (crop farming) and coal mining activities. From the 1:50 000 topographic sheet (2629AB and 2629BA) there are no major surface water bodies in close proximity to the site. The general area consists of gentle undulating hills and valleys. The area is well vegetated with grasses, small shrubs and trees. Annual rainfall is in the region of 700 mm per annum.

The regional geology consists of various groups within the Karoo Supergroup as well as numerous dolerite intrusions, occurring as both dykes and sills. The most relevant Karoo Supergroup unit to this study area is the Permian aged Ecca Group. Although the Ecca Group is defined by 16 formations, only one dominates the immediate study area, namely the Vryheid Formation. The Karoo rocks are not known for the development of economic aquifers but occasional high yielding boreholes may occur. Generally these rock types can be divided into two distinct aquifers, namely a shallow weathered aquifer and a deeper fractured aquifer.

The Komati Power Station falls within quaternary catchment B11B which has a surface area of approximately 482 km^2. The annual recharge is estimated to be 1% of the mean annual precipitation. This is equivalent to 3 374 000 m^3 per year.

Aquifer testing was undertaken on three existing monitoring boreholes, namely B1, B2 and B4. The tests undertaken were of short duration to estimate the local aquifer parameters, namely transmissivity (T) and hydraulic conductivity (k). An important aspect of any groundwater study is to evaluate the groundwater flow directions. In order to evaluate the groundwater flow it is necessary to understand the groundwater flow mechanisms, of which the groundwater levels in the area is a starting point.

It is known that in similar geological terrains a relationship exists between the groundwater table and the topography. This relationship, which is known as the Bayesian relationship assumes that the groundwater table mimics the topography. This relationship was confirmed by plotting topographic elevation against groundwater elevation. A strong relationship exists between topography and groundwater level as indicated by a 99.96%.

Contoured data generated from undertaking a Bayesian interpolation indicates a predominant flow in a northerly direction. Groundwater flow in the study area occurs along a topographical gradient of approximately 1:70.

Historical groundwater data from 2004/5 were made available by Synergistics. To supplement the existing data set, additional samples were taken at B1 – B6. Samples collected at Komati Power Station were analysed by DD Science which is a SANAS accredited laboratory. The inorganic groundwater quality is between Class 1 and Class 2 as it currently shows definite signs of contamination.

The chemical character of the groundwater samples was determined with the aid of the Piper diagram. The Piper diagram, introduced by Arthur Piper in 1944, is one of the most commonly used techniques to interpret groundwater chemistry data. The predominant water-type is reverse ion exchange water ($CaCl_2$) which is typical of contaminated water. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions.

The second groundwater-type is classified as a recharging water ($Ca(HCO_3)_2$) as indicated by B6. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively.

Conclusions related to the numerical groundwater flow model:

Two aquifers are present in the study area, namely a shallow perched and a deeper fractured rock aquifer. The hydrogeological boundaries for the study area is formed by the Koringspruit and an unnamed tributary, a water divide in the north and flow lines in the west and east. The study area is separated from the Olifants River catchment by the water divide.

Groundwater flows in a northerly direction towards the streams at a gradient of approximately 1:70, following the topography. A numerical groundwater flow and solute transport model was constructed and calibrated with available information. An analysis was undertaken to determine the model's sensitivity to changes in hydraulic conductivity, storativity and recharge. Results indicate that the model is sensitive to large variations in hydraulic conductivity and recharge, but not sensitive to changes in storativity.

The objective of the numerical model is to determine the possible impact that the ash dam extension (Dam 3) may have on the underlying aquifer as well as to determine the effectiveness of remedial measures proposed for the expansion of the ash dams at Komati Power Station.

Based on available information, simulations over a 100 year period indicate that contamination from the ash dams, the return water dam and the coal stockpiles (which were identified to be the main sources of contamination to groundwater) will move in a northerly direction towards the streams. Increased salt content in groundwater will become noticeable at the streams after some 50 – 80 years.

It is expected that if no remedial measures are implemented, that sulphate, sodium and electrical conductivity levels will exceed SABS Class 0 drinking water standards in the vicinity of the stream. It is however unlikely that groundwater at any of the existing farm homesteads would be affected.

The implementation of the proposed remedial measures will have a significant positive impact on long-term groundwater quality in the area. The measures will retard the spread of contamination, reduce the areal extent of potential pollution plumes and could possibly prevent groundwater quality from exceeding drinking water standards in the vicinity of the stream. The significance of additional salt load originating from the study area needs to be measured against water flow and quality in the streams.

It is concluded that, without the implementation of the mitigation measures proposed, the impact of Ash Dam 3 on the groundwater environment could be highly significant. Without mitigation measures, Ash Dam 3 will cause deterioration of downstream groundwater quality as well as of the river water quality with time. With the implementation of the downstream drains as mitigation measures it is likely that the impact on groundwater quality downstream of the new ash dams would be reduced, but would still occur, due to the fact that potentially contaminated groundwater would escape underneath the drains. However, simulations indicate that river water quality further downstream may not exceed in-stream water quality objectives with the drains in place. The significance rating for Ash Dam 3, with mitigation measures, is therefore considered to be moderate. It must be noted that the proposed remediation measures would also reduce the impact of the existing Ash Dams on the groundwater and surface water environments.

TABLE OF CONTENTS

List of Figures

List of Tables

ANNEXURES

SECTION 1 - INTRODUCTION

1. BACKGROUND

Rison Groundwater Consulting cc (RGC) was contracted by Synergistics Environmental Services (Pty) Ltd to undertake a geohydrological investigation at the Komati Power Station where an extension to the existing ash dams is to be constructed (Dam 3). The site is located approximately 35km south of Middelburg in the Mpumalanga Province (**Figure 1**).

There are six existing monitoring boreholes that are relevant to this investigation. Their localities are indicated on **Figure 2**.

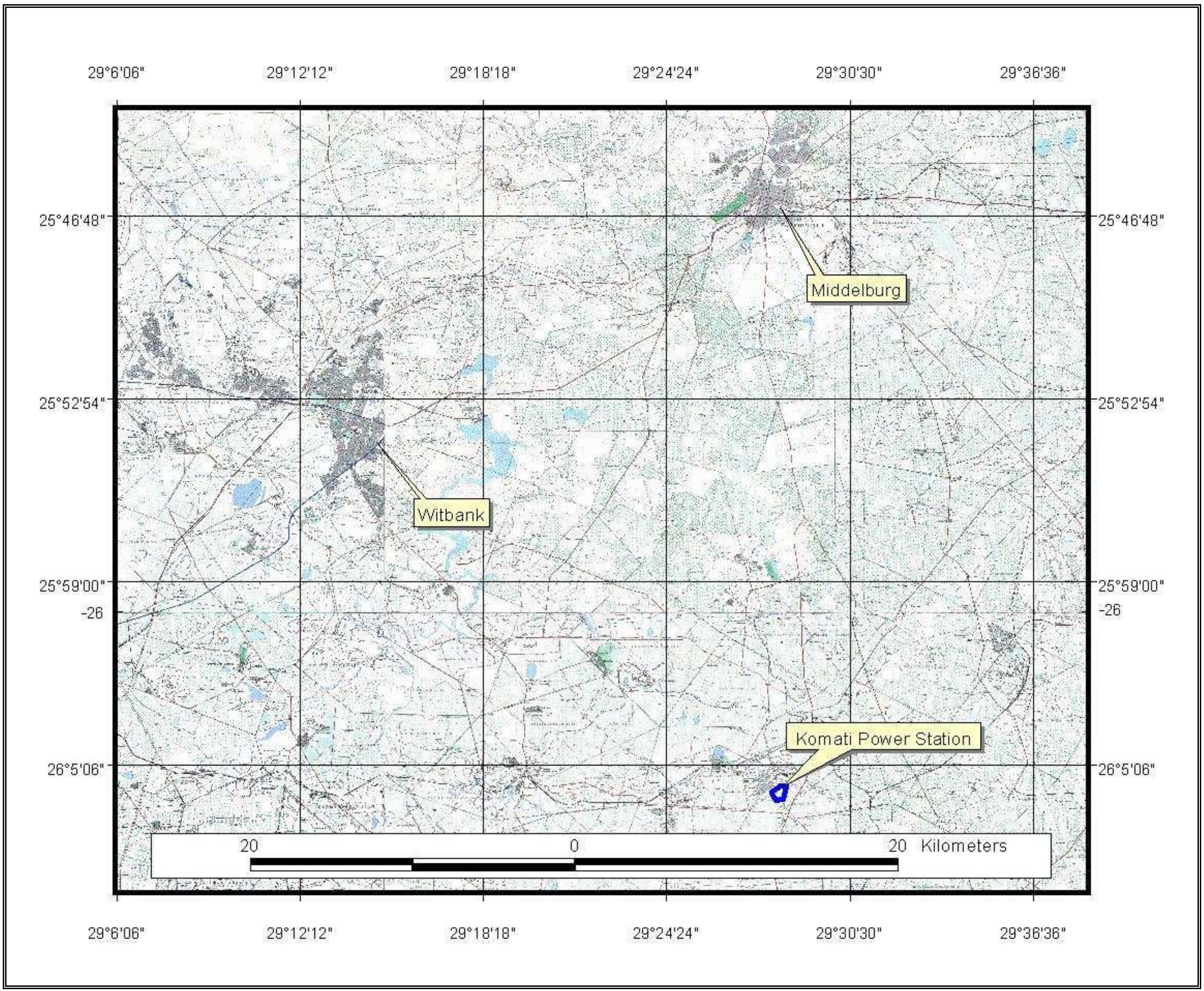


Figure 1: Locality of study area.

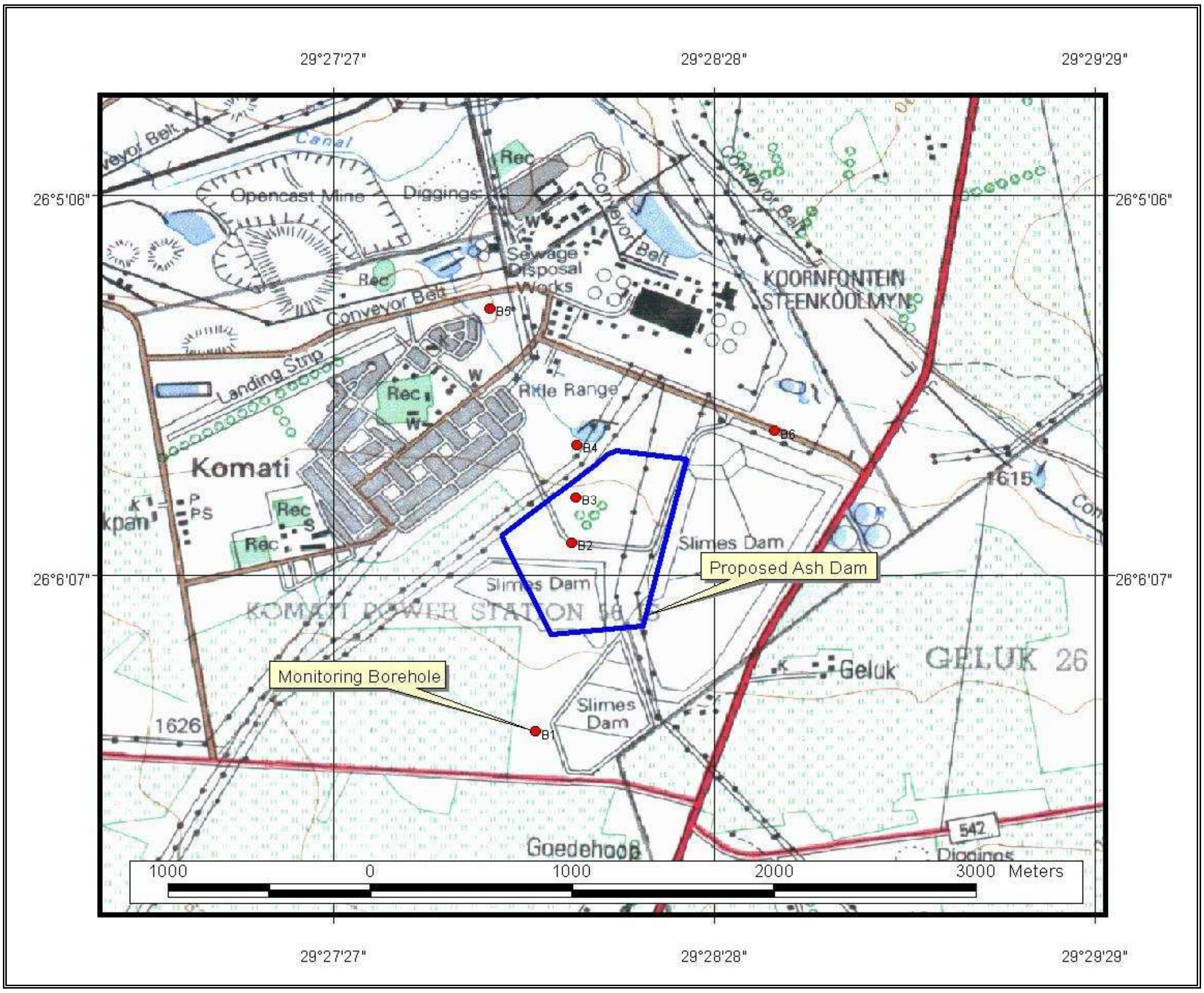


Figure 2. Locality of the proposed development and existing monitoring boreholes.

The aim of this investigation was to predict possible impacts that Dam 3 could have on the underlying aquifer and surrounds as well as to determine the effectiveness of suggested remedial options. All existing technical data made available to RGC were used to define the baseline conditions. The investigation undertaken consisted of the following:

- Evaluation of available site-specific hydrogeological data
- Determination of regional geology
- Evaluation of regional hydrogeology and groundwater quality
- Aquifer testing
- Groundwater sampling
- Numerical Groundwater Modeling

2. SITE DESCRIPTION

The surrounding area is used predominantly for agriculture (crop farming) and coal mining activities. From the 1:50 000 topographic sheet (2629AB and 2629BA) there are no major surface water bodies in close proximity to the site. The general area consists of gentle undulating hills and valleys. The area is well vegetated with grasses, small shrubs and trees. Annual rainfall is in the region of 700 mm per annum.

3. REGIONAL GEOLOGY

The regional geology consists of various groups within the Karoo Supergroup as well as numerous dolerite intrusions, occurring as both dykes and sills. The most relevant Karoo Supergroup unit to this study area is the Permian aged Ecca Group (**Figure 3**). Although the Ecca Group is defined by 16 formations, only one dominates the immediate study area, namely the Vryheid Formation.

The lower Vryheid Formation is described by Steyn and Beukes (1977) as upward coarsening shale and sandstone cycles, which represent prograding deltaic environments. This in turn is overlain by upward fining sandstone and shale cycles, which are of a fluvial origin. The coal beds, which were deposited in the backswamps of meandering river systems, cap the Lower Vryheid lithologies. The depositional environment is believed to be a dendritic channel system that resulted in the deposition of more arenaceous material in the active channels and mud and coal deposited on their floodplains. Channel closure led to the filling of channels by mud, the establishment of swamps and the deposition of coal beds within them. Similar deltaic and fluvial processes characterise the sediments overlying the coal seams, consisting mainly of alternating sequences of shale and sandstone. The more competent sandstone formations can result in localised hilly terrains.

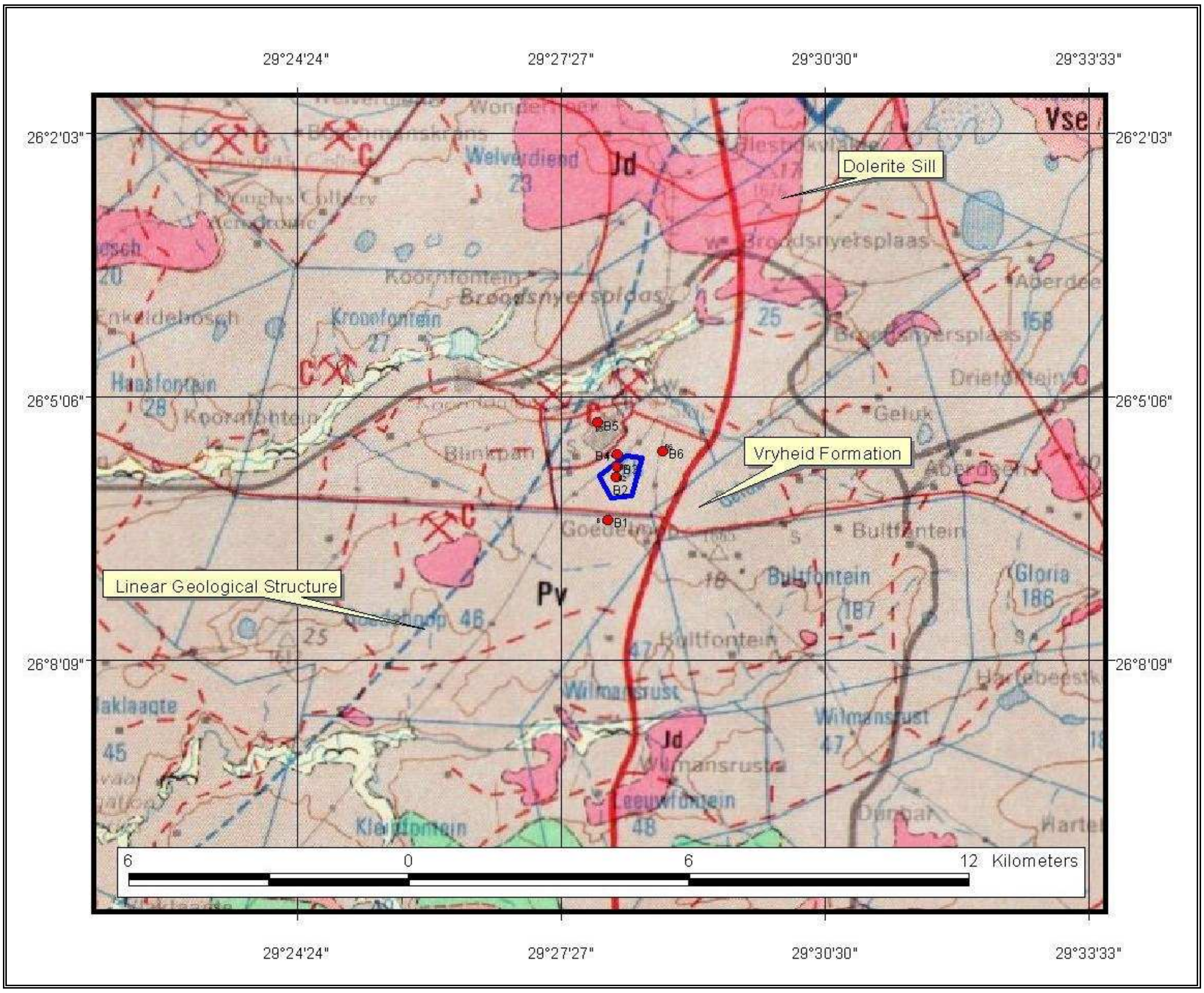


Figure 3: Regional Geology.

4. GEOHYDROLOGICAL SETTING

The Karoo rocks are not known for the development of economic aquifers but occasional high yielding boreholes may occur. Generally these rock types can be divided into two distinct aquifers, namely a shallow weathered aquifer and a deeper fractured aquifer.

Shallow Weathered Aquifer

Based on the geological borehole logs the depth of weathering in the weathered aquifer is relatively deep in places, reaching depths in excess of 66m in valleys and in swamp areas. The general weathered aquifer, however, extends to approximately 15 m below surface. This aquifer, which is recharged by rainfall, is often perched and due to the impermeable shale horizons may even be artesian in places, hence the many natural springs. The recharge to this aquifer is estimated to be in the order of 3% of the annual rainfall (Hodgson & Krantz, 1998). The numerous shale layers in these formations often restrict the downward filtration of rainwater into the aquifer. The largest accumulation of water is normally confined to the contact between the weathered and “fresh” bedrock. The borehole yields in this aquifer are generally low due to the very low aquifer parameters of the aquifer material. The groundwater quality in undisturbed areas is good due to the dynamic recharge from rainfall. This aquifer is, however, more likely to be affected by contaminant sources situated on surface, an aspect that will be discussed in more detail later in this report.

Deeper Fractured Aquifer

The primary porosity of the Ecca Group rocks does not allow significant groundwater flow, except where the porosity has been increased by subsequent secondary structures. Groundwater flow in the fractured aquifer is often associated with the abundant dolerite dykes and sills in the area. The intrusion of dykes and sills caused the surrounding rock to fracture and although not all these fractures are necessarily water bearing, it has created additional conduits. The presence of dykes are fairly easy to identify in the field as well as the edges, with which the bulk of the fractures are associated, but individual fractures are more difficult to identify and require sophisticated geophysical techniques to identify them.

Although occasional high yielding boreholes may be intersected, this aquifer also does not constitute an economic aquifer able to sustain excessive pumping and irrigation. The groundwater quality in the fractured aquifer is generally of a poorer quality than the weathered aquifer due to the concentration of salts and slower rate of recharge. This may be attributed to a less dynamic system and a larger residence time of rainfall recharge within the aquifer. According to Hodgson and Krantz (1998) the coal seams often show the highest hydraulic conductivity.

Recharge

The Komati Power Station falls within quaternary catchment B11B which has a surface area of approximately 482 km^2 (Figure 4). The annual recharge is estimated to be 1% of the mean annual precipitation. This is equivalent to 3 347 000 m^3 per year.

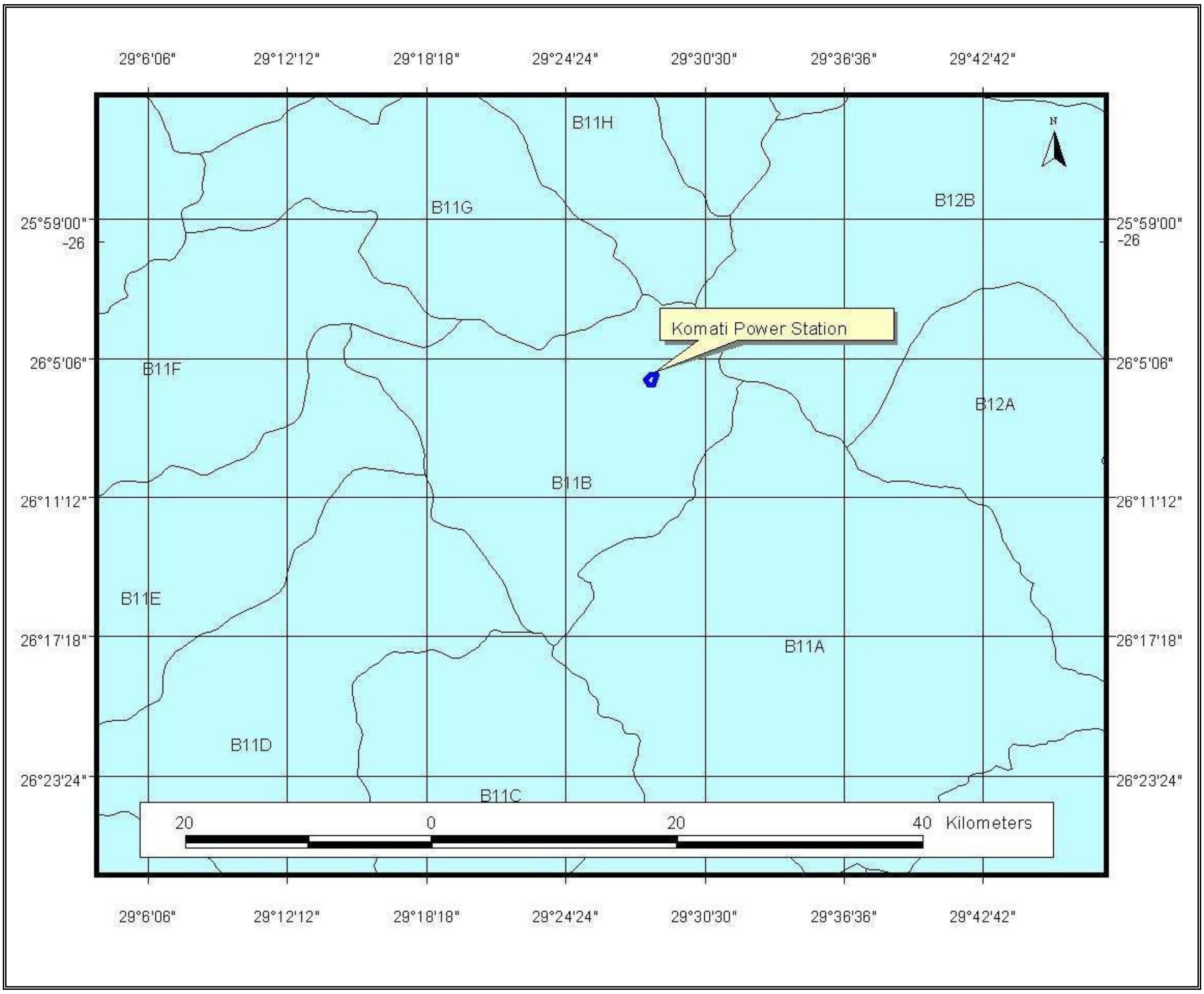


Figure 4. Quaternary catchments.

SECTION 2 - INVESTIGATION ACTIVITIES

1. AQUIFER TESTS

Aquifer testing was undertaken on three existing monitoring boreholes, namely B1, B2 and B4. The tests undertaken were of short duration to estimate the local aquifer parameters, namely transmissivity (T) and hydraulic conductivity (k). Aquifer parameters can be used to calculate flow rates through the aquifer. Each test undertaken on comprised of a maximum of 1 hour constant rate test followed by a recovery test. Recovery was measured after the CR test for a period of 1 hour or until 90% recovery was achieved. All field data are presented in Annexure A.

1.1. CONSTANT RATE TESTS

Data from the constant rate tests was used to estimate the hydraulic characteristics of the aquifer. Data were analysed using the Cooper Jacob method to provide estimates of aquifer transmissivity as summarised below in **Table 1**. No observation data were available for estimating aquifer storativity.

Table 1. Pump test summary and aquifer parameters.

	B1	B2	B4
Transmissivity (m^2/day) (Cooper Jacob)	0.40	0.30	0.60
Transmissivity (m^2/day) (Recovery)	2.90	0.40	1.00
Average Transmissivity (m^2/day)	1.65	0.35	0.80
Approx. BH Depth (mbs)	40.00	40.00	40.00
Static Water Level (mamsl)	1648.51	1630.27	1620.52
Hydraulic Conductivity (m/day)	0.08	0.02	0.04

B1 was pumped at a rate of 0.8 L/s over a period of 8 hours. In this time a total drawdown of 34.18 m was achieved. After the constant rate test 15 % recovery was achieved within 60 minutes.

B2 was pumped at a rate of 0.2 L/s over a period of 50 minutes. The constant rate test was terminated at 50 minutes because the water level began recovering. In this time a total drawdown of 8.23 m was achieved. After the constant rate test 94 % recovery was achieved within a 50 minute period.

B4 was pumped at a rate of 0.2 L/s over a period of 30 minutes. In this time a total drawdown of 9.41 m was achieved. Cascading water into the borehole column made water level measurements impossible hence the shorter duration constant rate test. After the constant rate test 96 % recovery was achieved within 25 minutes.

2. REGIONAL GROUNDWATER ELEVATION AND FLOW DIRECTIONS

An important aspect of any groundwater study is to evaluate the groundwater flow directions. In order to evaluate the groundwater flow it is necessary to understand the groundwater flow mechanisms, of which the groundwater levels in the area is a starting point. Measurements were taken at six existing monitoring boreholes, details of which are provided in **Table 2**.

Table 2. Details of existing groundwater monitoring boreholes.

ID	X	Y	Z	Measured SWL	Collar Height	Corrected SWL	BH Diameter	Casing	Type
				mamsl	magl	mamsl	mm		
B1	29.46651	-26.10890	1650	1648.74	0.23	1648.51	165	Steel	Monitoring
B2	29.46812	-26.10050	1631	1630.35	0.08	1630.27	165	Steel	Monitoring
B3	29.46827	-26.09848	1627	1626.07	0.20	1625.87	165	Steel	Monitoring
B4	29.46833	-26.09613	1622	1620.62	0.10	1620.52	165	Steel	Monitoring
B5	29.46445	-26.09003	1605	1603.71	0.10	1603.61	165	Steel	Monitoring
B6	29.47714	-26.09550	1626	1625.13	0.27	1624.86	165	Steel	Monitoring

It is known that in similar geological terrains a relationship exists between the groundwater table and the topography. This relationship, which is known as the Bayesian relationship assumes that the groundwater table mimics the topography. This relationship was confirmed by plotting topographic elevation against groundwater elevation. A strong relationship exists between topography and groundwater level as indicated by a 99.96% (**Figure 5**). Contoured data generated from undertaking a Bayesian interpolation indicates a predominant flow in a northerly direction (**Figure 6**). Groundwater flow in the study area occurs along a topographical gradient of approximately 1:70.

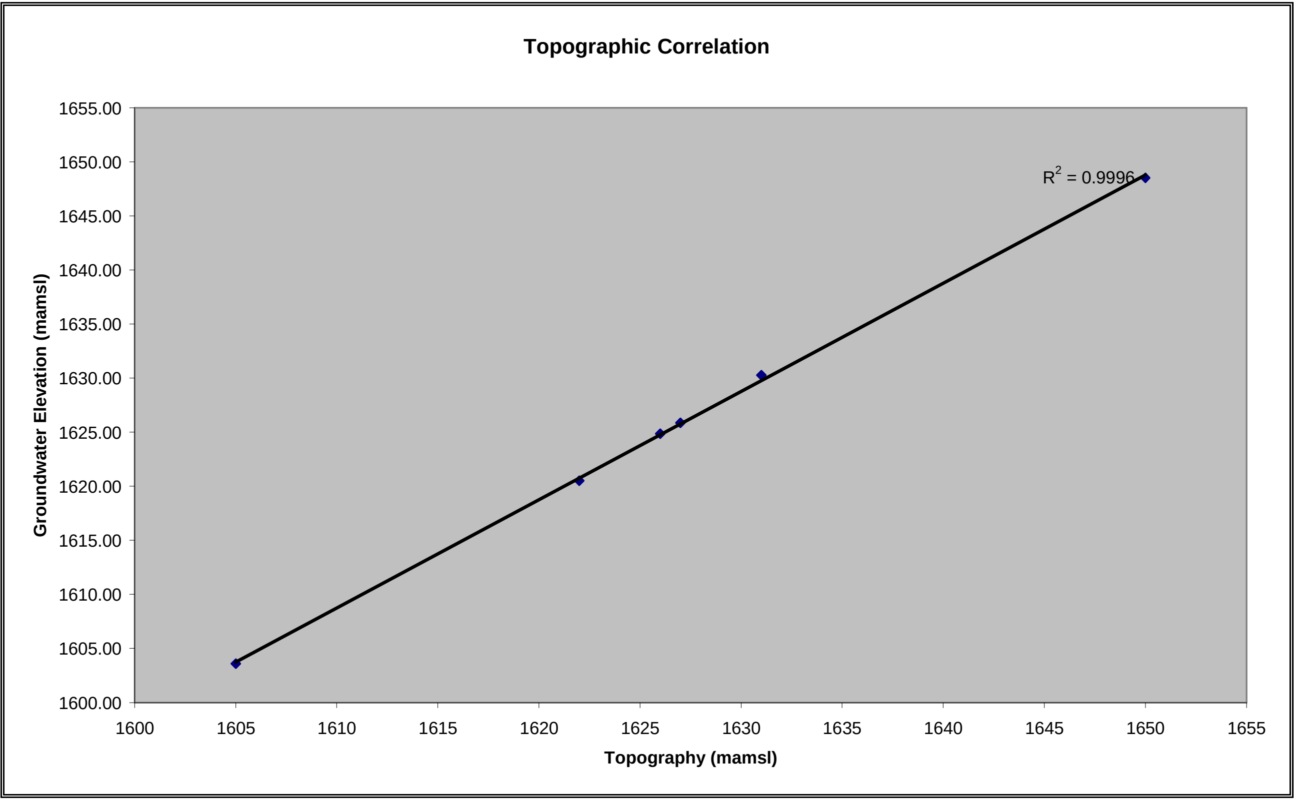


Figure 5. Correlation between topography and groundwater elevation (mamsl).

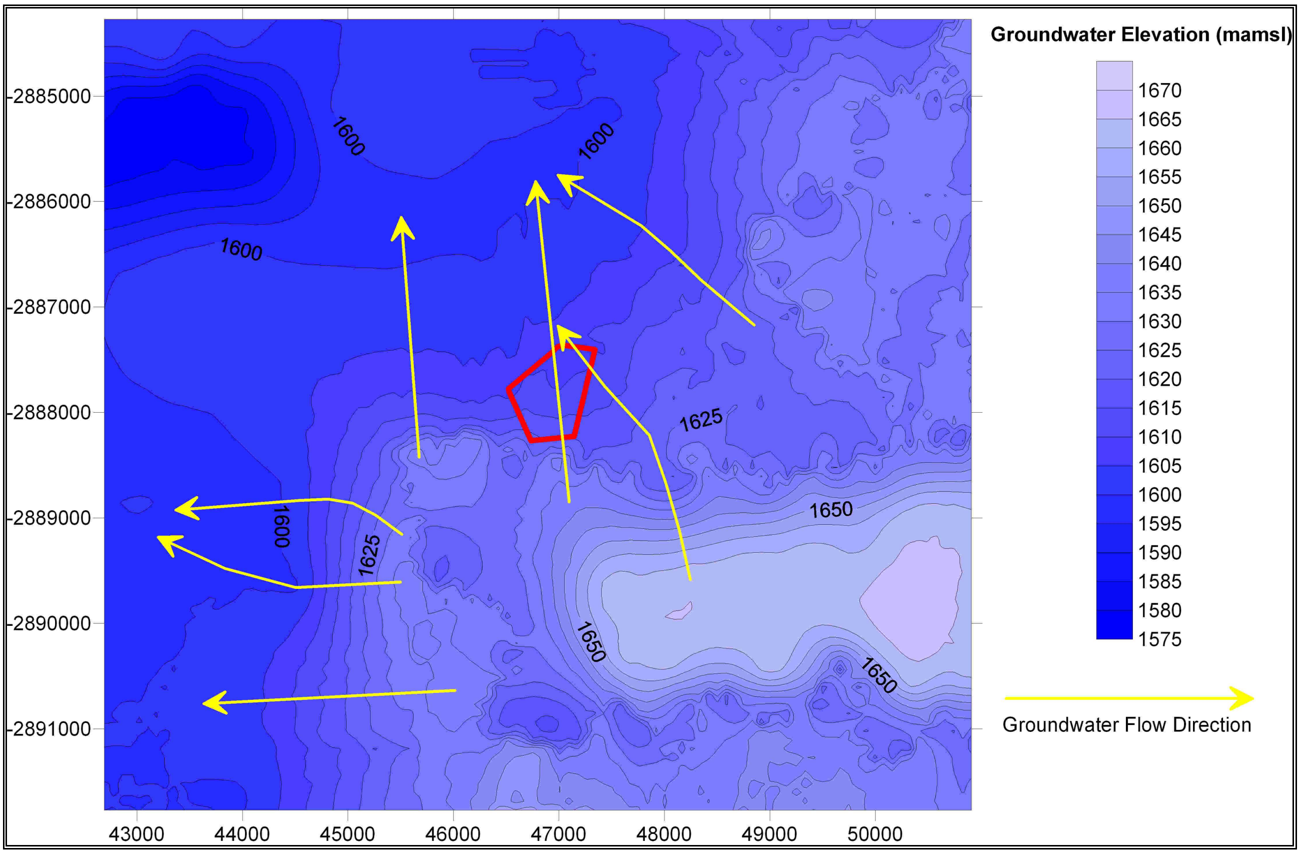


Figure 6. Interpolated local groundwater gradients and flow directions.

3. REGIONAL GROUNDWATER QUALITY

Historical groundwater data from 2004/5 were made available by Synergistics (Annexure B). To supplement the data set, additional samples were taken at B1 – B6. Samples collected at Komati Power Station were analysed by DD Science which is a SANAS accredited laboratory (Annexure C).

Selected boreholes were sampled according to the standard sampling protocol as defined by Weaver (1992). Each borehole was first purged prior to sample collection. Samples were then contained in sterile 2 litre plastic bottles and kept on ice packs in a cooler box. Results of the most recent Komati Power Station sample analysis are presented in

Table 3. Groundwater quality at Komati Power Station.

	Units	SABS Guideline			Komati B1	Komati B2	Komati B3	Komati B4	Komati B5	Komati B6
		Class 0	Class 1	Class 2						
pH	@25°C	6 - 9	5 - 9.5	4 - 10	7.30	6.70	6.60	7.20	7.40	7.60
Ec (mS/m)	mS/m @25°C	<70	70 - 150	150-370	263.00	93.00	129.00	122.00	86.00	38.00
Total Alkalinity	mg/l $CaCO_3$	NS	NS	NS	375.00	72.00	165.00	291.00	96.00	151.00
Chloride as Cl	mg/l	<100	100-200	200-600	205.00	31.00	58.00	78.00	67.00	20.00
Nitrate	mg/l N	<6	6 - 10	10 - 20	0.70	0.80	0.60	0.60	0.60	0.60
Sulphate as SO4	mg/l	<200	200-400	400-600	779.00	331.00	1240.00	877.00	411.00	<50
Fluoride as F	mg/l	<0.7	0.7-1	1-1.5	0.50	0.30	0.60	0.60	0.40	0.10
Iron as Fe	mg/l	<0.01	0.01-0.2	0.2-2	1.90	1.90	0.30	2.10	0.50	0.90
Magnesium as Mg	mg/l	<30	30-70	70-100	118.00	35.00	174.00	123.00	40.00	16.00
Manganese as Mn	mg/l	<0.05	0.05-0.1	0.1-1	0.30	0.30	1.40	0.30	0.10	0.50
Calcium as Ca	mg/l	<80	80-150	150-300	151.00	90.00	255.00	253.00	74.00	26.00
Potassium as K	mg/l	<25	25-50	50-100	25.00	14.00	46.00	11.00	10.00	4.70
Sodium as Na	mg/l	<100	100-200	200-400	231.00	42.00	90.00	80.00	112.00	25.00
Ammonium	mg/l N	-	-	-	2.20	1.10	1.60	3.40	10.00	0.70
Mercury	mg/l	<1.0	1-2	>2.0	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

In each instance the groundwater chemistry is compared to SANS classification for domestic use. Values indicated in black meet the requirements for Class 0 water (ideal) whereas values high-lighted in red exceed the standard.

The inorganic groundwater quality is between Class 1 and Class 2 as it shows definite signs of contamination.

The chemical character of the groundwater samples is determined with the aid of the Piper diagram. The Piper diagram, introduced by Arthur Piper in 1944, is one of the most commonly used techniques to interpret groundwater chemistry data. This method proposed the plotting of cations and anions on adjacent trilinear fields with these points then being extrapolated to a central diamond field. Here the chemical character of water, in relation to its environment, could be observed and changes in the quality interpreted. The cation and anion plotting points are derived by computing the percentage equivalents per million for the main diagnostic cations of Ca, Mg and Na, and anions Cl, SO_4 and HCO_3.

Different waters from different environments always plot in diagnostic areas. The upper half of the diamond normally contains water of static and disordinate regimes, while the middle area normally indicates an area of dissolution and mixing. The lower triangle of this diamond shape indicates an area of dynamic and co-ordinated regimes. Sodium chloride brines normally plot on the right hand corner of the diamond shape while recently recharge water plots on the left-hand corner of the diamond plot. The top corner normally indicates water contaminated with gypsum (often related to coal and gold mining activities).

In general the top half of the diamond contains static waters and other unusual waters high in Mg/Ca Cl_2 and Ca/Mg SO_4. The lower half contains those waters normally found in a dynamic basin environment. Mixtures of any two waters in any proportion plot along a line joining their respective points in each of these diagrams.

Water therefore being invaded by an industrial effluent will plot as a vector towards the analysis of the invading fluid. The Piper Diagram for all samples collected at Komati Power Station is presented in **Figure 7**.

The predominant water-type is a reverse ion exchange water ($CaCl_2$) which is typical of contaminated water (**Figure 8**) Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions.

The second groundwater-type is classified as a recharging water ($Ca(HCO_3)_2$) as indicated by B6. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively.

Figure 7. Piper diagram showing hydrochemical classification.

Figure 8. Groundwater-type classification.

4. GROUNDWATER FLOW MODEL

HYDROGEOLOGICAL SETTING AND CONCEPTUAL MODEL

The conceptual model for the study area is based on the geological setting; hydrogeological parameters obtained from the aquifer tests undertaken for the study as well as the groundwater flow patterns. Two aquifers are included in the conceptual model, namely a shallow perched and a deeper fractured rock aquifer:

The shallow perched aquifer is developed in the weathered zone. Based on the logs of test holes from Jones & Wagener (April 2006), this aquifer extends to depths of between 8 - 10 metres below surface and is restricted to the soil and sub-soil horizons. The aquifer is formed by the direct recharge of rainwater that collects along the transition from weathered to fresh rock. This transition between weathered and competent rock, in places associated with clay or ferricrete, forms the base of the perched aquifer. The perched aquifer is typically unconfined or semi-confined. Groundwater levels are not available for this aquifer, but seepage was encountered at 2 – 3 m below surface by Jones & Wagener (April 2006). It is anticipated that the static water level in this aquifer would be similar to those measured in the fractured rock aquifer, as discussed below. The hydraulic conductivity for this aquifer could not be calculated with available information, but typically varies between 0.001 and 0.1 m/d. Jones & Wagener (March 2007) suggests that the hydraulic conductivity of the soil underlying the existing ash dams is 7.06 x 10^{-5} to 0.006 m/d. The porosity of the perched aquifer could not be calculated with available information, but is typically 3 - 7%. Often the perched aquifer is not laterally extensive and is therefore not considered to be a significant aquifer. However, it often makes a contribution to the baseflow of streams.

A deeper fractured rock aquifer formed by bedding planes, fractures and faults in the weathered and competent sediments of the Ecca Group is developed from approximately 10m. This aquifer is also replenished by rainfall recharge and will be semi-confined to confined in nature. Results from the drilling and pump-testing programme suggest that this aquifer is heterogeneous and not well developed in the vicinity of the project. This information suggests that the aquifer has a low transmissivity of <1 m^2/d. There is insufficient information available to calculate the storage coefficient, but values of 1 x 10^{-5} to 1 x 10^{-2} are typical. The porosity for the fractured rock aquifer could not be calculated from available information, but it is typically in the order of 1 - 3%. The depth of groundwater, based on monitoring borehole information, in this aquifer is similar to the perched aquifer and is less than 0.5m below surface. This suggests that the two aquifers are interconnected and that groundwater seeps from the perched aquifer into the fractured rock aquifer. The saturated thickness of the fractured rock aquifer is typically 10 – 80 m.

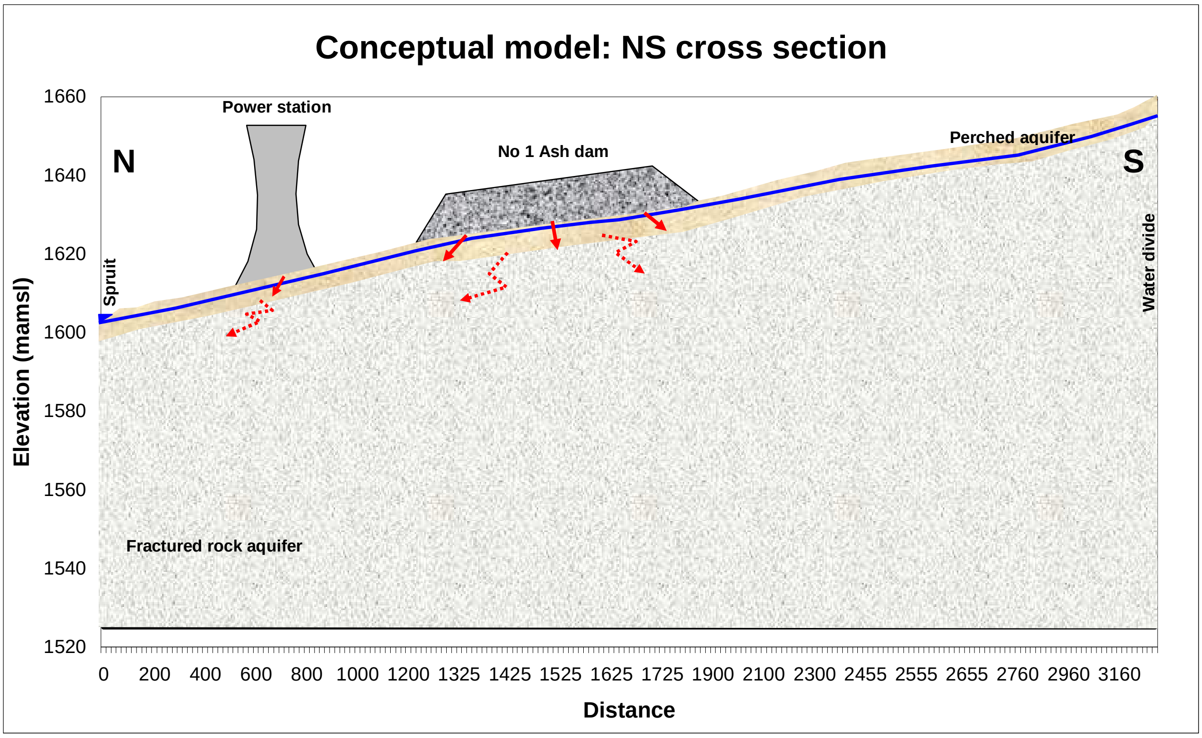


Figure 9. Conceptual groundwater model of the current situation.

The conceptual groundwater model for the study area is shown in **Figure 9**. A water divide to the south of the existing ash dams forms the upper groundwater flow boundary, whilst the tributary of the Koringspruit forms the lower groundwater boundary. Both the perched and fractured rock aquifers are heterogeneous in nature. There is however currently insufficient information available to characterise this feature of the aquifers.

A 99% correlation exists between groundwater levels and topography. The perched and fractured rock aquifers therefore discharge to the Koringspruit and its tributary. Groundwater flow contours were inferred from the existing monitoring information as well as the topography and are shown in **Figure 6** and **Figure 10**. It is shown that groundwater flows in a northerly direction towards the Koringspruit and its tributary at a gradient of approximately 1:70.

Typically a groundwater mound forms around ash dams as a result of on-going seepage from the tailings dam to the underlying aquifers. Jones & Wagener (March 2007) estimates that some 1700m^3/d to 1800 m^3/d of ash water seeps from No 1 and 2 ash dams to the aquifers. Insufficient information is however currently available to confirm the presence of a recharge mound around the ash dams. Shallow groundwater seepage intersected in the Jones & Wagner test holes (April 2006), however suggests that it is likely that a groundwater mound is present around the ash dams.

Figure 10. Groundwater flow contours.

MODEL DESIGN

The numerical model for the project was constructed using Processing MODFLOW Pro, a pre- and post-processing package for MODFLOW and MT3D. MODFLOW is a modular three dimensional groundwater model published by the United States Geological Survey. MODFLOW and MT3D uses 3D finite differences discretization and flow codes to solve the governing equations. MODFLOW and MT3D is a widely used simulation code and is well documented.

RELATIONSHIP BETWEEN THE CONCEPTUAL AND NUMERICAL MODEL

The conceptual model discussed in Section 4.1 and illustrated in **Figure 9** was discretized into a two dimensional numerical model consisting of two layers. The upper layer representing the perched aquifer and the lower layer the fractured rock aquifer. The model grid is illustrated in **Figure 11**. The model boundaries are:

- The Koornfonteinspruit and its tributary forms constant head boundaries, shown in dark blue along the northern boundary of the model area.
- The southern boundary is a no-flow boundary formed by a water divide separating the Koornfonteinspruit from the catchment of the Olifants River. The model area is therefore isolated from the Olifants River by the water divide.
- Groundwater flow lines, also no-flow boundaries, were chosen for the western and eastern boundaries. These boundaries were chosen far from the area of interest (>1000m) to ensure that the boundary conditions do not interfere with the simulations.

The model area was divided into block cells varying in size from 80m along the western and eastern boundaries to a finer grid of 10 and 20m around the ash dams and pump tested boreholes. The finer grid will allow more detailed simulations around the areas of interest. The non-perennial stream draining from Gras dam to the sewage works maturation ponds was included with the MODFLOW River Package. More details are provided below. All units used during simulations were presented in metres (length) and days (time).

ASSUMPTIONS

The following assumptions were made during simulations:

- There is currently no information available on the presence of dykes, sills or large faults in the study area. No geological features were therefore included in the model.

Figure 11. Komati Ash Dam numerical model grid.

- Aquifer parameters were inferred from existing monitoring and pump test data, as summarised in **Table 1**. It must be noted that no information on aquifer storativity is currently available and values were inferred during model calibration, as discussed below.

- There is currently no information available on regional private groundwater use. The impact on private boreholes could therefore not be determined. Information from the National Groundwater Database suggests that private boreholes were drilled to an average depth of 52m. The thickness of the model was therefore assumed to be 55m.

- No information on the extent of the impact of mining on groundwater was available during the study and mining could therefore not be included during simulations.

- It was assumed that there are no mining voids beneath the dams and this fact was confirmed by Synergistics.Thus no subsidence has taken place or will take place in future due to undermining of the project area. Should subsidence ever be identified, it is strongly recommended that the numerical simulations be revised.

- The model was allowed to calculate transmissivity based on the calibrated hydraulic conductivity and the saturated thickness during simulations.

- It was assumed that recharge to the aquifers is < 1%, which is typical for Karoo type aquifers. Recharge from the ash dams was assumed to be >1%, based on the rate of seepage from the ash dams, presented by Jones & Wagener (March 2007). Calibrated values are discussed below.

- The impact of the sewage works was excluded from this study.

- The main point sources to groundwater contamination, based on information presented by Jones & Wagener (April 2006) include the ash dams, the return water dam and the coal stockpiles. Sulphate (which is not characteristic of the impact of ash on groundwater quality), sodium and electrical conductivity were evaluated during modelling. Elevated sulphate concentrations were measured in most of the monitoring boreholes and therefore included. Sodium is considered characteristic of the impact of ash and electrical conductivity provides a general indication of dissolved salts. Contamination from the ash dams, coal stock piles and return water dams was simulated using the recharge source package in MT3D.

- Groundwater quality was inferred from available monitoring information. No specific source characterisation information was available at the time of the study. Characterisation of the impact of the ash dams, the coal stockpile and the return water dams used during simulations were inferred from monitoring information, as detailed in **Table 4**. Background groundwater quality was inferred from borehole B6. During simulations, maximum concentrations were used as starting concentrations, based on the assumption that the source quality has to be at least equivalent to the highest concentration observed in monitoring boreholes. This assumption must be re-evaluated, once source characterisation has been undertaken.

Table 4. Source characterisation, based on available monitoring information.

Ash Dams				Coal stockpile area				Return water dam			
BH ID	EC	SO4	Na	BH ID	EC	SO4	Na	BH ID	EC	SO4	Na
	mS/m	mg/l	mg/l		mS/m	mg/l	mg/l		mS/m	mg/l	mg/l
TH8	82.3	311	87	TH2	225	1343	102	TH9	2096	9305	157
TH10	224	1016	196	TH3	197	954	114	Ash Water (avg)	126	393	125
TH12	357	1066	523	TH4	561	2241	208	**Average**	**1111**	**4849**	**141**
TH14	99	416	123	TH5	175	693	145	**Maximum**	**2096**	**9305**	**157**
B1	263	779	231	TH6	103	409	44				
Average	**205**	**718**	**232**	B8 (avg)	106	272	106				
Maximum	**357**	**1066**	**523**	B9 (avg)	264	982	90				
				Average	**233**	**985**	**116**				
				Maximum	**561**	**2241**	**208**				

NOTE:

Groundwater quality information for the TH-samples represent 2006 J&W analyses
Groundwater quality information for the B1 - B6 samples represent 2007 Rison analyses
Groundwater quality information for the B8 - B9 samples represent average ESKOM 2004/05 monitoring info
The Ash Water sample represents average ESKOM monitoring information for the ash dams

- Advection was included during simulations according to the parameters provided in **Table 5**. These parameters were inferred from previous experience with similar projects in Karoo aquifers and common practice.

Table 5. Advection parameters used during simulations.

PERCEL	WD	DCEPS	NPLANE	NPL	NPH
0.75	0.5	10^{-5}	2	0	2
NPMIN	**NPMAX**	**SRMULT**	**NLSINK**	**NPSINK**	**DCHMOC**
1	4	1	2	2	0.001

- Dispersion was also included during simulations. It was assumed that horizontal and vertical transverse dispersivity is 0.1, that the effective molecular diffusion coefficient is 0.01 m^2/d and that the longitudinal dispersivity is 20m. These parameters were also inferred from previous experience with similar projects in Karoo aquifers and common practice.

- No chemical reaction was taken into consideration during simulations. There is currently insufficient information available to quantify chemical reaction within the aquifers.

MODEL CALIBRATION

The model was calibrated in both steady state and transient state to quantify aquifer parameters. Only recent information from boreholes B1 – 6 was used during calibration. Historical information from boreholes B7 – 9 was not comparable to the rest of the monitoring borehole information and was therefore excluded from the calibration process. Calibration for hydraulic conductivity, specific storage (or storativity) and recharge was undertaken, as these parameters are key to the simulations. These parameters were systematically varied to improve the match between simulated and measured groundwater levels. Due to the fact that the aquifers are heterogeneous and that values for these parameters were assigned globally, it was not possible to match simulated and measured water levels exactly. A good match was however achieved with the available information. The results from the calibration process are presented in **Table 6** and **Figure 12**.

Table 6. Results of the calibration process.

Parameter	Estimated value
Hydraulic conductivity: perched aquifer (m/d)	0.06
Hydraulic conductivity: fractured rock aquifer (m/d)	0.05
Vertical conductivity (m/d)	0.005
Specific storage: perched aquifer (1/m)	0.005
Specific storage: fractured rock aquifer (1/m)	0.00005
Effective porosity: perched aquifer (-)	0.03
Effective porosity: fractured rock aquifer (-)	0.01
Recharge: general (m/d)	0.7% of MAP: 1.36E-5
Recharge: ash dams (m/d)	1% of MAP: 1.95E-5

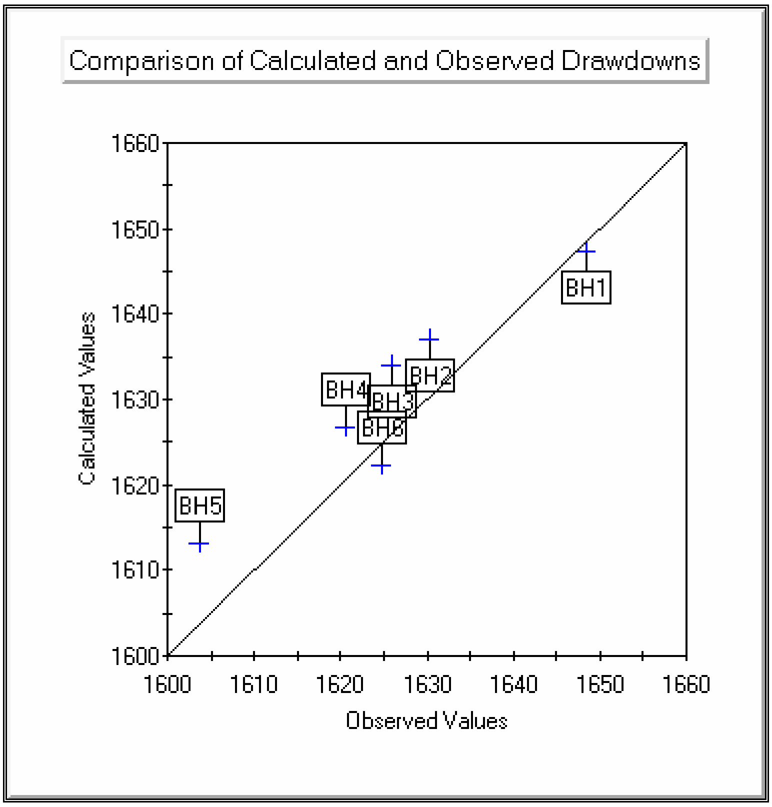


Figure 12. Comparison of calibrated and observed drawdown.

In order to improve the confidence in the results of the calibration process, it is recommended that the model is verified with monitoring information. Water level, rainfall and aquifer test information will be required. It is recommended that water levels are monitored for at least one wet and dry season on a monthly basis, rainfall on a daily basis and that longer term aquifer tests are undertaken on monitoring boreholes on a once off basis to calculate hydrogeological parameters with more confidence.

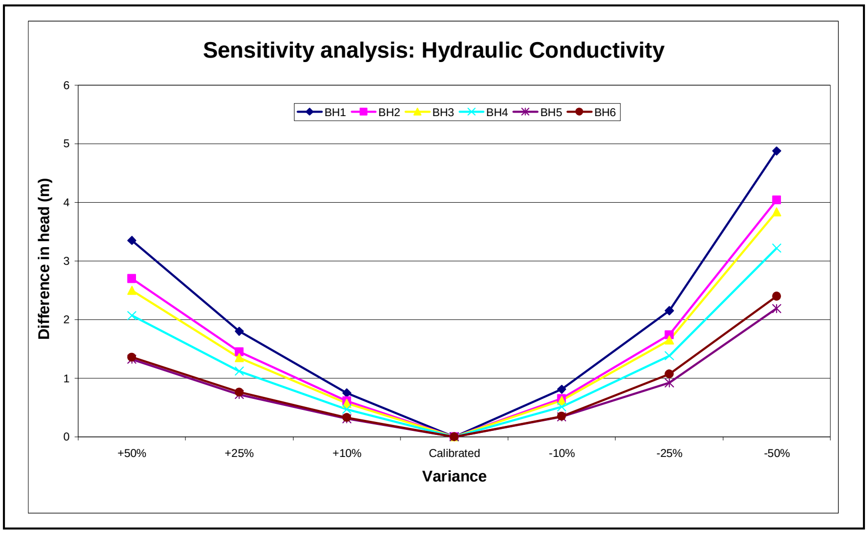
SENSITIVITY ANALYSIS

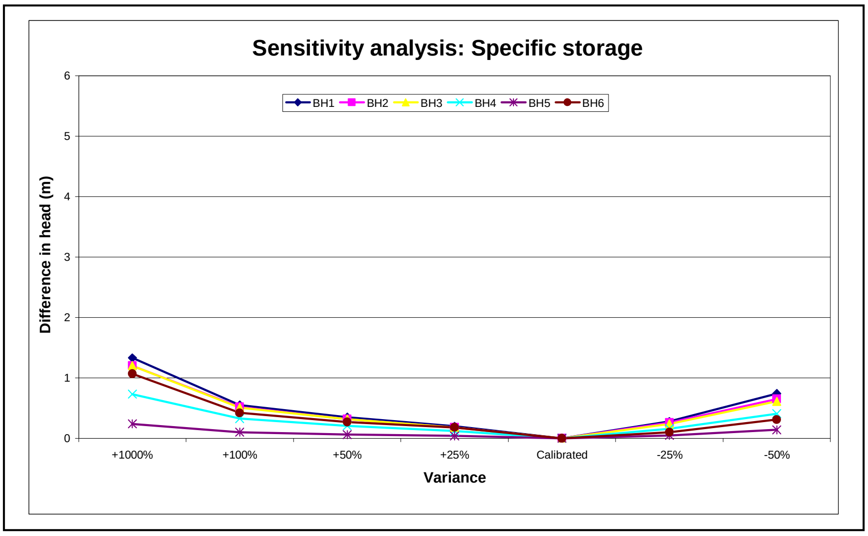
The sensitivity analysis recognises that the calibrated model may not represent a unique match to the calibration target. Work was therefore undertaken to determine the sensitivity of the results to variations in key parameter values, including hydraulic conductivity, storage coefficient and recharge. The results of the sensitivity analysis are presented in **Table 7** and **Figure 13**. The larger the difference in head is as a result of changes in a parameter, the more sensitive the model is to that parameter. It is shown in **Figure 13** that the model is sensitive to large variations in the hydraulic conductivity and recharge parameters, but not very sensitive to large variations in specific storage (or storativity). Hydraulic conductivity used during simulations is based on the results of the available aquifer tests and are typical of Karoo aquifers. It is however recommended that longer term pumping tests are undertaken on the existing boreholes to determine hydraulic conductivity with more accuracy. The hydraulic conductivity of the aquifers can further be confirmed through model verification once additional monitoring information is available.

In order to improve the confidence in recharge rates assumed for the model, it is recommended that groundwater levels are monitored over at least one hydrogeological season (including a wet and dry season). Fluctuations in groundwater levels can be used with daily rainfall information to estimate the rate of recharge. As with the hydraulic conductivity for the aquifers, the rate of recharge can also be confirmed through model verification.

Table 7. Results of the sensitivity analysis.

BH ID	HYDRAULIC CONDUCTIVITY Sensitivity variations							
	+50%	+25%	+10%	Calibrated	-10%	-25%	-50%	
BH1	3.35	1.8	0.75	0	0.81	2.15	4.88	
BH2	2.7	1.45	0.61	0	0.65	1.74	4.04	
BH3	2.5	1.35	0.57	0	0.62	1.65	3.84	
BH4	2.07	1.12	0.47	0	0.51	1.38	3.22	
BH5	1.32	0.72	0.31	0	0.34	0.92	2.19	
BH6	1.36	0.76	0.33	0	0.35	1.07	2.4	
BH ID	SPECIFIC STORAGE Sensitivity variations							
	+1000%	+100%	+50%	+25%	Calibrated	-25%	-50%	
BH1	1.33	0.55	0.35	0.2	0	0.28	0.74	
BH2	1.2	0.52	0.32	0.18	0	0.26	0.65	
BH3	1.2	0.51	0.32	0.18	0	0.24	0.61	
BH4	0.73	0.33	0.21	0.12	0	0.16	0.41	
BH5	0.24	0.1	0.06	0.04	0	0.05	0.14	
BH6	1.07	0.42	0.27	0.18	0	0.1	0.31	
BH ID	RECHARGE Sensitivity variations							
	+100%	+50%	+25%	+10%	Calibrated	-10%	-25%	-50%
BH1	4.8	2.4	1.2	0.48	0	0.47	1.19	2.39
BH2	4.44	2.22	1.11	0.45	0	0.44	1.11	2.21
BH3	4.28	2.14	1.08	0.43	0	0.42	1.06	2.13
BH4	3.86	1.93	0.97	0.39	0	0.38	0.96	1.92
BH5	2.82	1.41	0.71	0.28	0	0.28	0.7	1.4
BH6	2.54	1.3	0.68	0.3	0	0.19	0.56	1.18





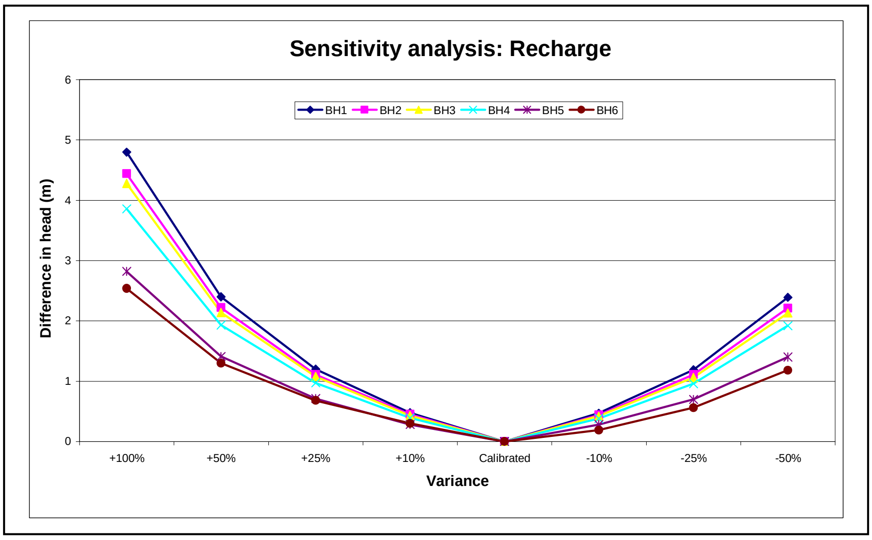


Figure 13. Results of the sensitivity analysis.

MODEL SIMULATIONS

The objective of the numerical model constructed and calibrated for the project area is to predict the cumulative impact the new Dam 3 may have on the groundwater quality as well as to determine the effect of remedial measures proposed by Jones & Wagener (April 2006 and March 2007). The simulations hinge around the impact of the existing and proposed expansion to the ash dams on groundwater quality.

PROPOSED REMEDIAL MEASURES

- That a shallow drain is installed to a depth of 4.5 m below surface downstream of the ash dams and return water dam to intercept contaminated groundwater. Seepage collected in this system will be pumped back to the return water dam.
- That the old return water dam is removed and that a new dam is constructed.
- That a new dirty water runoff dam is constructed and sized by upgrading Grass dam.
- To remove contaminated soil. Unfortunately no further details regarding the location and extent of this remedial measure is provided and could therefore not be included in simulations. Should additional information become available, this scenario can be included.
- To recommission the coal stockpile area to reduce seepage to groundwater. This will be achieved through an engineered lining and seepage collection system. As with the contaminated soil, there are unfortunately no additional design parameters available for this remedial measure. It was therefore assumed that a 4.5m drain will be installed below the coal stockpile area and that seepage will be returned to the process water system. Should additional information become available for this option, the simulation can be updated.
- To remove the coal stockpile along the western boundary of the cooling towers and to ensure that all coal is stockpiled on the designated pad along the northern boundary of the power station.

CURRENT CONDITIONS WITH NO REMEDIATION IMPLEMENTED

The model was used to determine the impact of current sources of contamination to groundwater, without including remedial measures proposed by Jones & Wagener. Three scenarios, including increases in sulphate, sodium and electrical conductivity, were run over a 100 year period. The results of simulations are shown in Figures 14, 15 and 16. The most significant source of contamination for sulphate and increased electrical conductivity is expected to be the return water dams, as shown. The ash dams generate most of the sodium pollution.

Contamination is expected to move in a northerly direction towards the tributary of the Koringspruit to the north of the power station. Contamination is however expected to move relatively slow through the aquifers. Available information suggests that contamination from the ash dams will probably only reach the unnamed tributary within 50 years. It is anticipated that sulphate concentrations at this time in groundwater that contributes to the baseflow in the stream could exceed 200 mg/l that sodium concentrations could exceed 50 mg/l and that electrical conductivity could increase to more than 100 mS/m. It is unlikely that any of the existing farm homesteads in the area would be affected by the impact of the ash dams, coal stockpiles and return water dam on groundwater quality.

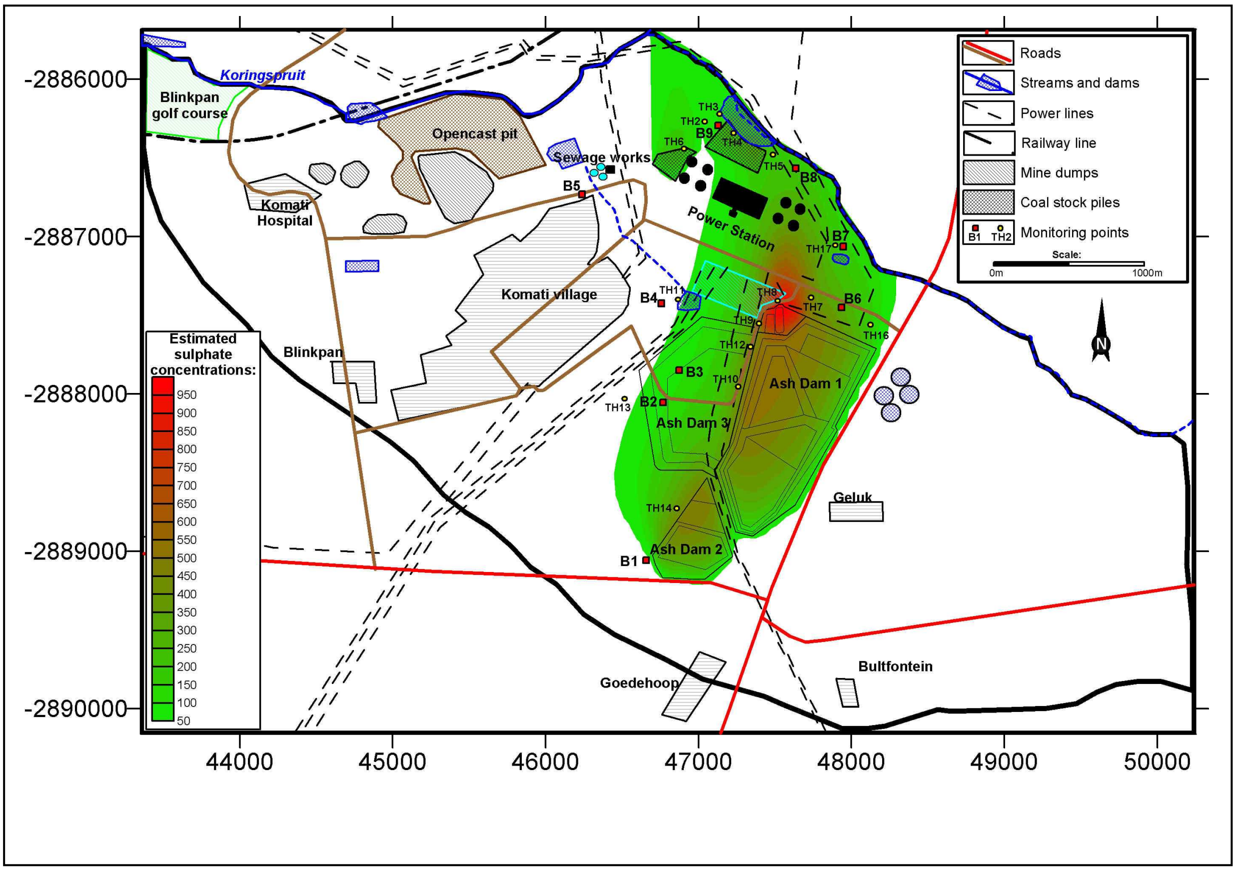


Figure 14. Simulated sulphate concentrations (mg/l): Current situation.

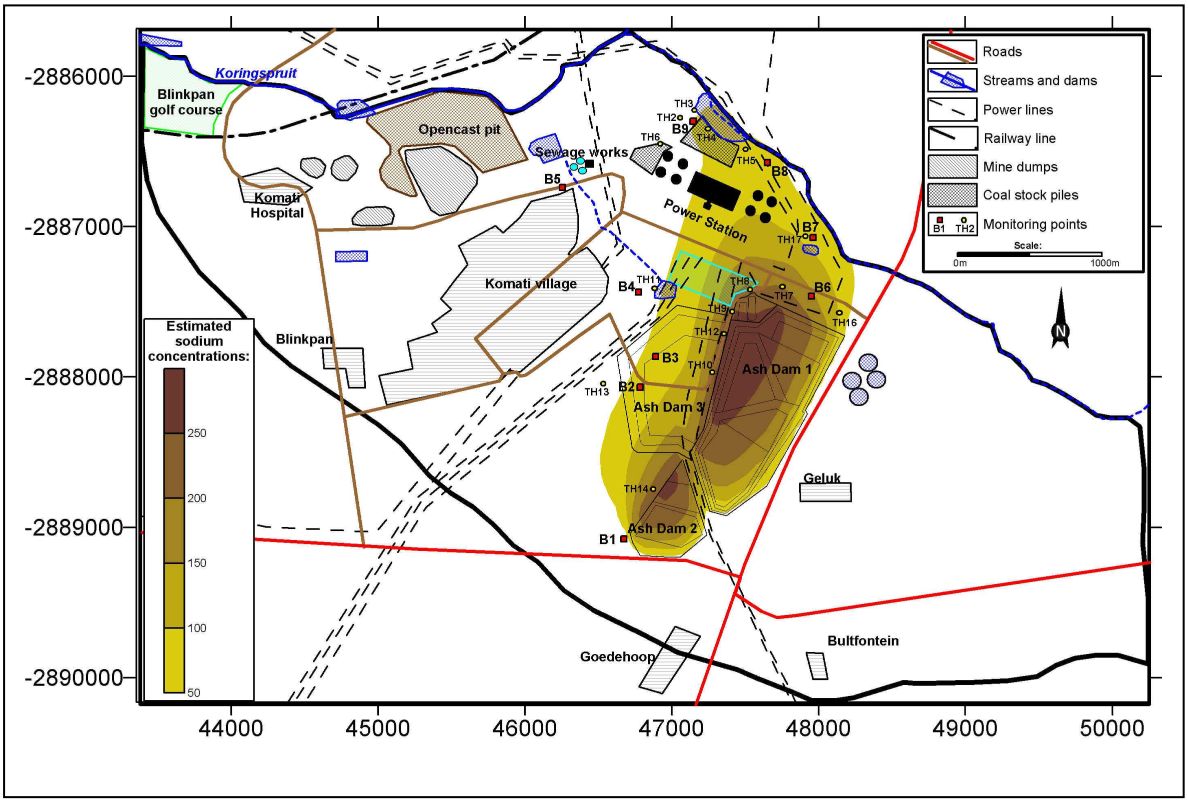


Figure 15. Simulated sodium concentrations (mg/l): Current situation.

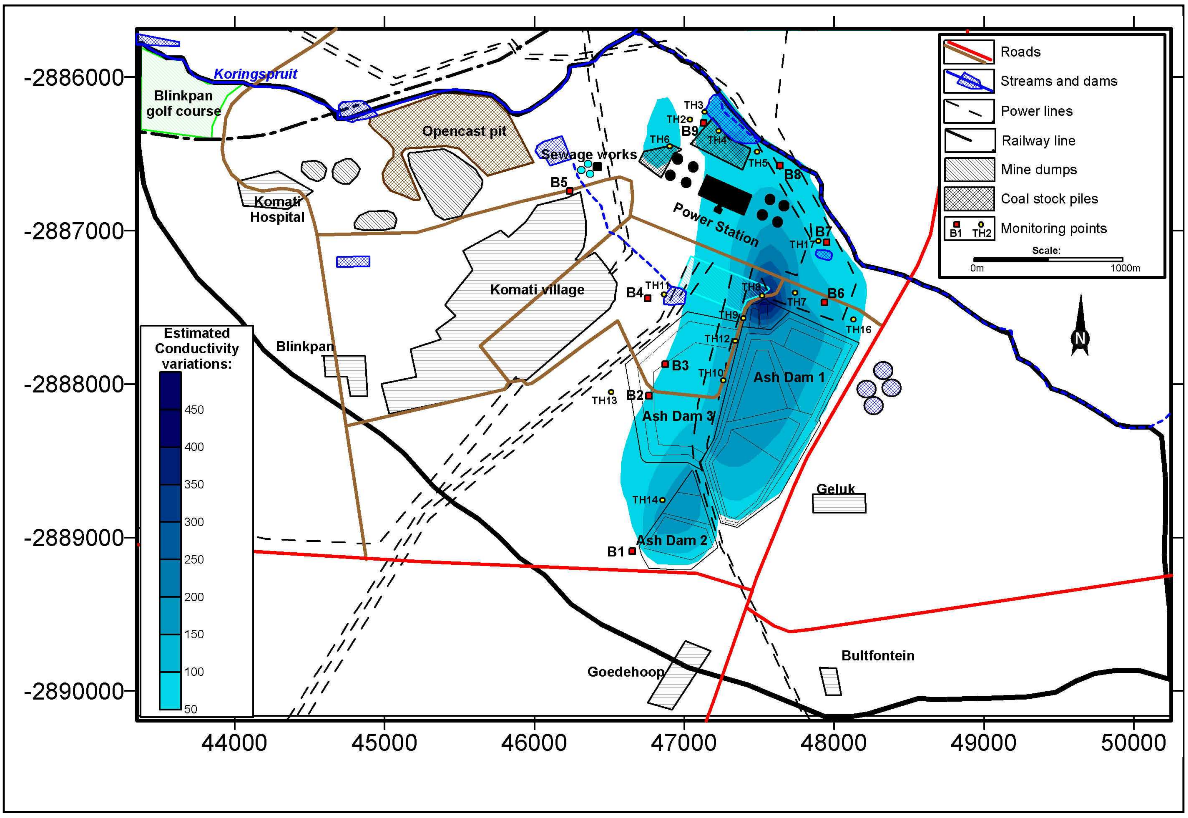


Figure 16. Simulated electrical conductivity increase (mS/m): Current situation.

SIMULATED IMPACT ON GROUNDWATER WITH REMEDIATION

The impact of the proposed extension to the ash dams (Ash Dam 3) as well as the implementation of remedial measures described previously on groundwater quality is discussed in this section. This simulation was also run over a 100 year period. A 4.5m deep drain was included downstream of the ash dams, return water dam and coal stockpile during simulations. The hydraulic conductance of the drain was assumed to be similar to that of the perched aquifer discussed in the model calibration section.

The extent of the cone of depression around this drain is not expected to be significant, probably not developing further than 100 – 150m around the drain. Groundwater levels are expected to be lowered by 2.5 – 3m within this zone of influence. Despite the limited extent of the zone of impact of the drain, it is anticipated to have a positive impact on the spread of contamination from the ash dams, return water dams and coal stockpile areas. This is illustrated in Figures 17, 18 and 19.

Simulations indicate that it is unlikely that all the contamination will be captured in the drains. Some contamination will escape underneath and migrate north towards the unnamed tributary. The effect of the drains will probably result in a reduction in concentration downstream as well as limit the aerial extent of the plumes. It is further anticipated that drinking water standards (i.e. 200 mg/l for sulphates, 100 mg/l for sodium and 70 mS/m for electrical conductivity) will not be exceeded in the vicinity of unnamed tributary for more than 50 years. The drains are expected to retard the spread of contamination.

Simulations indicate that the volume of potentially contaminated groundwater base flow to the unnamed tributary could vary between 50 and 100 m^3/d, once contamination reaches the stream. This may increase the salt load to the stream by an additional 10 – 20 kg/d of sulphate and 5 to 10 kg/d of sodium. The significance of this contribution must be evaluated against high and low flows and water quality in the stream. Despite the fact that rehabilitation for some sections of the ash dams is planned, it is anticipated that a residual impact on groundwater quality will remain in the long-term. Rehabilitation is however expected to reduce the rate of seepage from the ash dams to the underlying aquifers, which will have a positive effect.
None of the farm homesteads in the vicinity of the project will be affected by contamination from the extension to the ash dams.

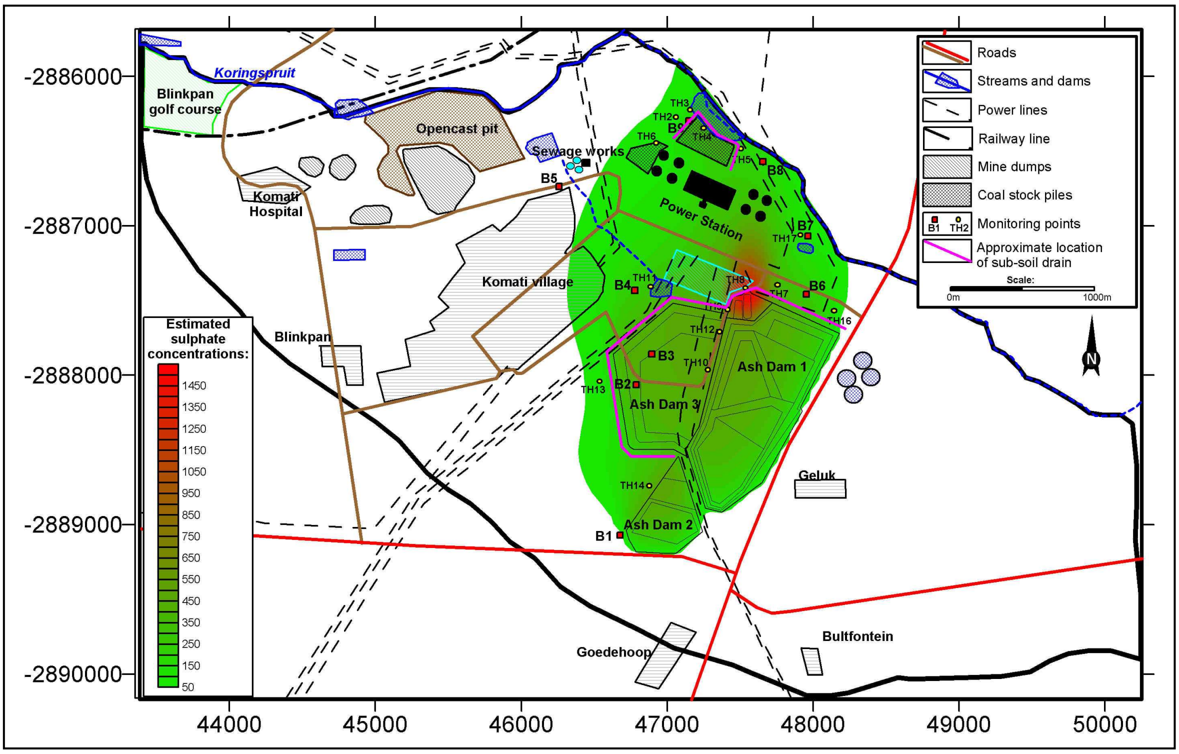


Figure 17. Simulated sulphate concentrations (mg/l): Potential future impact including extension to ash dams and remedial measures

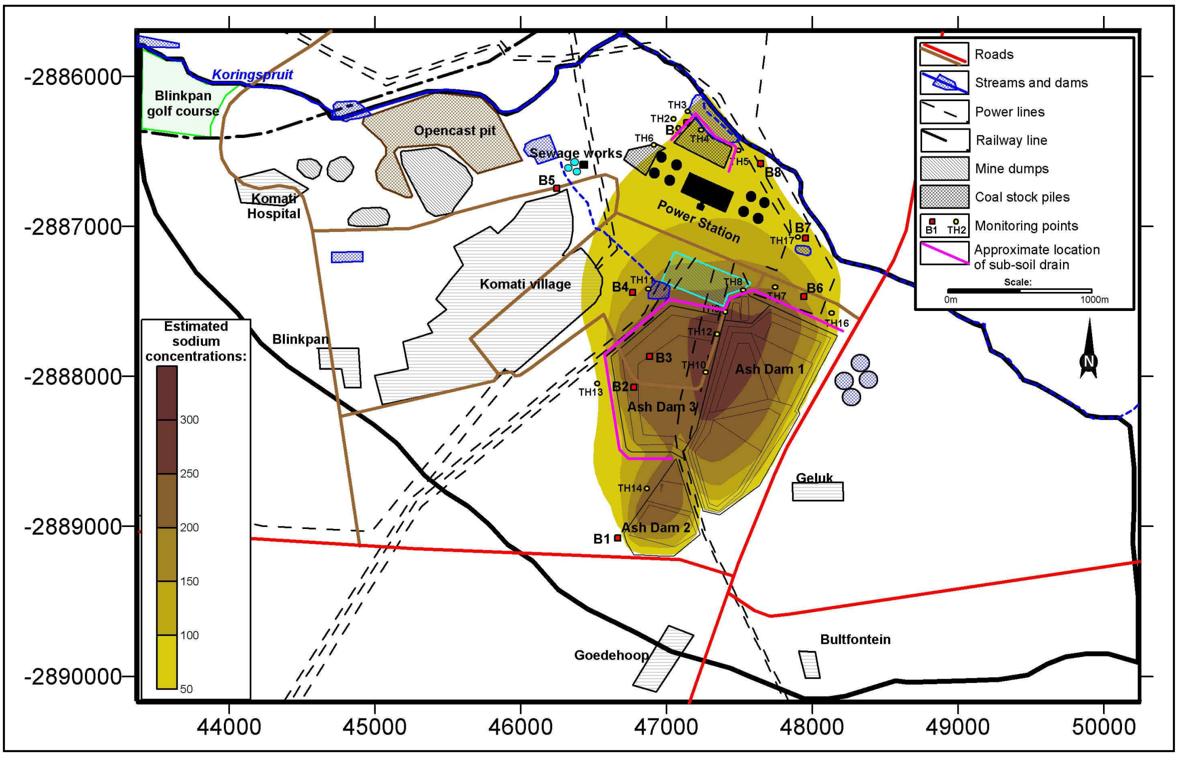


Figure 18. Simulated sodium concentrations (mg/l): Potential future impact including extension to ash dams and remedial measures.

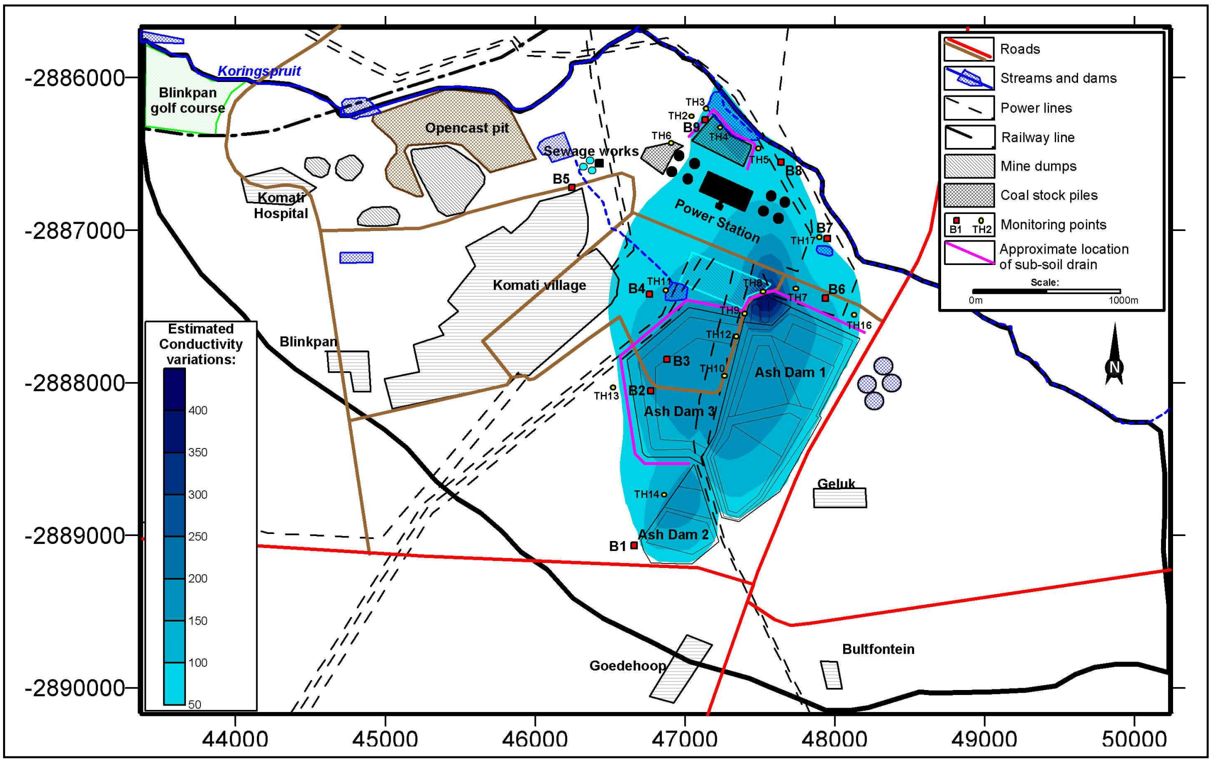


Figure 19. Simulated electrical conductivity increase (mS/m): Potential future impact including extension to ash dams and remedial measures.

SECTION 3 - CONCLUSIONS AND RECOMMENDATIONS

It is concluded that:

- Rison Groundwater Consulting cc (RGC) was contracted by Synergistics Environmental to undertake a geohydrological investigation at the Komati Power Station where a new ash dam is to be constructed. The site is located approximately 35km south of Middelburg in the Mpumalanga Province.

- The surrounding area is used predominantly for agriculture (crop farming) and coal mining activities. From the 1:50 000 topographic sheet (2629AB and 2629BA) there are no major surface water bodies in close proximity to the site. The general area consists of gentle undulating hills and valleys. The area is well vegetated with grasses, small shrubs and trees. Annual rainfall is in the region of 700 mm per annum.

- The regional geology consists of various groups within the Karoo Supergroup as well as numerous dolerite intrusions, occurring as both dykes and sills. The most relevant Karoo Supergroup unit to this study area is the Permian aged Ecca Group. Although the Ecca Group is defined by 16 formations, only one dominates the immediate study area, namely the Vryheid Formation.

- The Karoo rocks are not known for the development of economic aquifers but occasional high yielding boreholes may occur. Generally these rock types can be divided into two distinct aquifers, namely a shallow weathered aquifer and a deeper fractured aquifer.

- The Komati Power Station falls within quaternary catchment B11B which has a surface area of approximately 482 km^2. The annual recharge is estimated to be 1% of the mean annual precipitation. This is equivalent to 3 374 000 m^3 per year.

- Aquifer testing was undertaken on three existing monitoring boreholes, namely B1, B2 and B4. The tests undertaken were of short duration to estimate the local aquifer parameters, namely transmissivity (T) and hydraulic conductivity (k).

- An important aspect of any groundwater study is to evaluate the groundwater flow directions. In order to evaluate the groundwater flow it is necessary to understand the groundwater flow mechanisms, of which the groundwater levels in the area is a starting point.

- It is known that in similar geological terrains a relationship exists between the groundwater table and the topography. This relationship, which is known as the Bayesian relationship assumes that the groundwater table mimics the topography. This relationship was confirmed by plotting topographic elevation against groundwater elevation. A strong relationship exists between topography and groundwater level as indicated by a 99.96%.

- Contoured data generated from undertaking a Bayesian interpolation indicates a predominant flow in a northerly direction. Groundwater flow in the study area occurs along a topographical gradient of approximately 1:70.

- Historical groundwater data from 2004/5 were made available by Synergistics. To supplement the existing data set, additional samples were taken at B1 – B6. Samples collected at Komati Power Station were analysed by DD Science which is a SANAS accredited laboratory.

- The inorganic groundwater quality is between Class 1 and Class 2 as it currently shows definite signs of contamination.

- The chemical character of the groundwater samples was determined with the aid of the Piper diagram. The Piper diagram, introduced by Arthur Piper in 1944, is one of the most commonly used techniques to interpret groundwater chemistry data.

- The predominant water-type is reverse ion exchange water ($CaCl_2$) which is typical of contaminated water. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions.

- The second groundwater-type is classified as a recharging water ($Ca(HCO_3)_2$) as indicated by B6. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively.

- Monitoring boreholes B2 and B3 need to be filled and sealed off prior to construction of the dam as they will act as conduits for rapid movement of contaminants into the aquifer.

Conclusions related to the numerical groundwater flow model:

- Two aquifers are present in the study area, namely a shallow perched and a deeper fractured rock aquifer.

- The hydrogeological boundaries for the study area is formed by the Koringspruit and an unnamed tributary, a water divide in the north and flow lines in the west and east. The study area is separated from the Olifants River catchment by the water divide.

- Groundwater flows in a northerly direction towards the streams at a gradient of approximately 1:70, following the topography.

- A numerical groundwater flow and solute transport model was constructed and calibrated with available information.

- An analysis was undertaken to determine the model's sensitivity to changes in hydraulic conductivity, storativity and recharge. Results indicate that the model is sensitive to large variations in hydraulic conductivity and recharge, but not sensitive to changes in storativity.

- The objective of the numerical model is to determine the possible impact that the ash dam extension (Dam 3) may have on the underlying aquifer as well as to determine the effectiveness of remedial measures proposed for the expansion of the ash dams at Komati Power Station.

- Based on available information, simulations over a 100 year period indicate that contamination from the ash dams, the return water dam and the coal stockpiles (which were identified to be the main sources of contamination to groundwater) will move in a northerly direction towards the streams. Increased salt content in groundwater will become noticeable at the streams after some 50 – 80 years.

- It is expected that if no remedial measures are implemented, that sulphate, sodium and electrical conductivity levels will exceed SABS Class 0 drinking water standards in the vicinity of the stream. It is however unlikely that groundwater at any of the existing farm homesteads would be affected.

- The implementation of the proposed remedial measures will have a significant positive impact on long-term groundwater quality in the area. The measures will retard the spread of contamination, reduce the areal extent of potential pollution plumes and could possibly prevent groundwater quality from exceeding drinking water standards in the vicinity of the stream.

- The significance of additional salt load originating from the study area needs to be measured against water flow and quality in the streams.

- An assessment of the impact of constructing Ash Dam 3 as an extension to the existing Ash Dams is shown in the table below. Based on the methodology presented in **Annexure D** and the criteria used, it is concluded that, without the implementation of the mitigation measures proposed, the impact of Ash Dam 3 on the groundwater environment could be highly significant. Without mitigation measures, Ash Dam 3 will cause deterioration of downstream groundwater quality as well as of the river water quality with time. With the implementation of the downstream drains as mitigation measures it is likely that the impact on groundwater quality downstream of the new ash dams would be reduced, but would still occur, due to the fact that potentially contaminated groundwater would escape underneath the drains. However, simulations indicate that river water quality further downstream may not exceed in-stream water quality objectives with the drains in place. The significance rating for Ash Dam 3, with mitigation measures, is therefore considered to be moderate. It must be noted that the proposed remediation measures would also reduce the impact of the existing Ash Dams on the groundwater and surface water environments.

Evaluation of the significance of the impact of Ash Dam 3 on underlying aquifers.

NEGATIVE IMPACTS	INT	EXT	DUR	PRO	FREQ	OS
Construction of Ash Dam Extension 3 without mitigation measures	3	2	4	4	5	18
Construction of Ash Dam Extension 3 with mitigation measures	3	2	4	3	5	17

It is recommended that:

- The remedial measures proposed by Jones & Wagener are implemented to reduce the impact of existing and future ash disposal and coal stockpiling on groundwater quality.

  The following measures are recommended to improve the confidence in simulations presented in this report:

- Longer term aquifer tests are undertaken on the existing monitoring boreholes to obtain information on the specific yield and/or the storativity of the aquifer. The drawdown tests should be at least 24 hours and recovery should be measured until at least a 90% rebound of groundwater levels are achieved.

- The groundwater monitoring programme must be maintained in all monitoring boreholes during the operation of the ash dams. It is important to include aluminium in the monitoring programme, as it is characteristic of the impact of ash on groundwater quality. This programme is detailed below:

Parameter	Monitoring interval
Groundwater levels	Monthly
Groundwater quality	Quarterly
Rainfall	Daily

- A regional hydrocensus is undertaken to identify and quantify private groundwater use in the vicinity of the project area. It is recommended that private boreholes are monitored (groundwater level and quality) on an annual basis.

- Representative samples of ash material and coal from the stockpiles must be taken for leach tests to improve confidence in source characterisation presented in this report. It is recommended that kinetic leach tests are undertaken to obtain information on the rate that contaminants will be released from the material. This information will also provide a full scan of the potential contaminants.

- Geochemical modelling is undertaken to determine the extent and to quantify chemical reaction in the aquifers. This information must be used to update existing solute transport modelling results.

- It is recommended that flow is measured during the wet and dry season in the unnamed tributary as well as the Koringspruit to quantify the significance of increased salt load originating from the ash dams, return water dams and coal stockpiles.

- The numerical model constructed for the project must be verified with monitoring information to improve confidence in the simulations. It is recommended that verification is undertaken once at least one hydrogeological season's information is available, including a wet and dry period.

- Two additional monitoring boreholes are required on the eastern side of the residential area in order to detect the contaminant plume before it reaches the residents.

SECTION 4 - REFERENCES

BARNARD H.C. (2000): AND EXPLANATION OF THE 1:500 000 GENERAL HYDROGEOLOGICAL MAP, JOHANNESBURG 2526. Department of Water Affairs and Forestry.

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (1996). SOUTH AFRICAN WATER QUALITY GUIDELINES, VOLUME 1: DOMESTIC USE. Second Edition.

HODGSON, FDI and KRANTZ, RM. (1998). GROUNDWATER QUALITY DETERIORATION IN THE OLIFANTSRIVER CATCHMENT ABOVE THE LOSKOP DAM WITH SPECIALISED INVESTIGATIONS IN THE WITBANK DAM SUB – CATCHMENT. Report to the Water Research Commission by the Institute for Groundwater Studies, University of the Orange Free State. WRC Report No. 291/1/98.

JONES & WAGENER. (April 2006). ESKOM Surface and groundwater study – Komati Power Station, Report No JW64/06/A611.

JONES & WAGENER. (March 2007).. ROSHCON (Pty) Ltd Komati Power Station – Recommissioning of Ash Dams, Report No JW49/07/A784 – Rev A

VEGTER, J.R (1995). A series o f Maps depicting the Hydrogeology of South Africa.

ANNEXURE A
AQUIFER TEST DATA

ANNEXURE B
HISTORICAL GROUNDWATER QUALITY

ANNEXURE C
LABORATORY CERTIFICATE

ANNEXURE D
IMPACT ASSESSMENT METHODOLOGY