APPENDIX K
GEOHYDROLOGICAL REPORT

12 February 2007

Bohlweki Environmental (Pty) Ltd.
P.O Box 11784
Vorna Valley
MIDRAND
1686

Attention: Mr. Greg Seymour

GEOHYDROLOGICAL SECTION FOR THE ENVIRONMENTAL IMPACT ASSESSMENT (EIA) AT THE PROPOSED ESKOM PUMPED STORAGE PROJECT IN THE STEELPOORT RIVER: PROJECT LIMA.

With reference to our proposal (GCS ref. MSJ.06.121), dated 18 April 2006, please find our report detailing the groundwater resources, for inclusion in the proposed Steelpoort Pumped Storage Scheme Environmental Impact Assessment (EIA) for Escom at site A3.

GCS conducted an assessment of the groundwater conditions in the study area, specifically the proposed upper and lower reservoir sites and additional infrastructure that may possibly have an impact on groundwater resources.

The possible impacts of the reservoirs and associated dam infrastructure on the groundwater have been assessed and mitigation or risk reduction management options have been compiled.

Should you require any additional information please contact our Rivonia office, 011 – 8035726.

Yours faithfully
Johannes van der Walt

TABLE OF CONTENTS

Ta
Ta
Ta
Ta
Ta
Ta
Ta

LIST OF TABLES

Fi
Fi
Fi
Fi
Fi
Fi

EXECUTIVE SUMMARY

Escom is currently in the process of planning the construction of a 1 000 MW pumped storage scheme along the escarpment between the Nebo Plateau and the Steelpoort River valley, close to the town of Roossenekal in the Limpopo Province. The main purpose of the scheme will be to generate hydroelectric power.

During phase 1 of the feasibility study that was undertaken by BKS (PTY) Ltd three possible sites (A, B, and C) for the pumped-storage scheme were identified at various locations along the escarpment, taking into account various parameters (geology, topography, vertical head etc.) From these options A3 came out as the preferred option (with off-channel upper and lower reservoirs). GCS (PTY) Ltd was requested to provide the specialist input from a geohydrological point of view into the Environmental Impact Assessment (EIA) investigation, which this report covers.

The study area is underlain by rock formations of the Bushveld Igneous Complex and from a geohydrological point of view it is classified as minor-aquifer system. No large scale groundwater abstraction occurs within the study area.

Several dyke-intrusive features of late Karroo age have been mapped to strike WNW - NNW over the plateau area between the two reservoir sites. Their groundwater bearing capabilities are not known. The Steelpoort Fault that strikes in a

The north-east and south-west striking Steelpoort fault is situated just north of the proposed pumped storage facility, which runs parallel to the escarpment.

converge over the proposed pumped storage facility. These geological structures can enhance the groundwater potential in the area by increasing the permeability and transmissivity of the host rock. Secondary processes, such as faulting and fracturing, can create secondary fractured rock aquifers. Should these structures be water bearing, short term groundwater related impacts are foreseen during the construction phase of the tunnel, as dewatering will be required.

The following impacts were identified:

- Sources of artificial recharge, which include seepage through the grout curtains in the damwalls and unlined dam basin into the underlying fractured and alluvial aquifer including the intergranular fractured aquifer.
- Sources of artificial recharge with possible poor quality water, associated with wastewater treatment plants, solid waste sites, and fuel storage facilities.
- Temporarily dewatering of groundwater from various sections of the pumped storage scheme that will be located underground, in order to enable construction work to continue.
- Groundwater losses as a result of decant into open pit areas should excavations exceed the static groundwater level within the specific area.
- Borehole losses.

- Golder Associates (2007). Hydraulic Fracturing Stress Measurements at Steelpoort Pumped Storage Scheme, South Africa.
- Hobbs, P.J., (2005) Determination of the ecological water requirements for the Dwars River in quaternary catchment B41G groundwater component. CSIR, ENV-S-C 2005-060
- The National Groundwater Database, Department of Water Affairs and Forestry, Pretoria
- Odendaal, C.L., (1983). Kroondal – Marikana ondergrondese water beheergebied, Technical Report GH. 3263, Directorate Geohydrology, DWAF.

3.2 Site visit

According to Mr. Richard Weppelman, who is sub-contracted by Escom to undertake drilling of boreholes for the geotechnical investigations, no productions boreholes are situated within close proximity of the proposed upper reservoir or lower reservoir sites.

Land owners within a 2 km radius from the proposed lower reservoir development were also contacted, to ascertain their water use. Borehole yields may possibly be affected by the lower reservoir development, caused by artificial recharge and basting during the damwall excavations. After detailed discussions, a site visit was undertaken access site conditions, and to obtain the following detail information with regard to existing production boreholes:

- GPS locations;
- Borehole depth and yields;

The following findings were made which are indicated in Figure 1:

- Dr. Berry from portion 4 of the farm Luiperdshoek does not make use of any boreholes.
- Mr. Pieter Joubert hires farm portions 1 & 7 of the farm Luiperdshoek 149 JS, from Dr. Louis Kritzinger. On the respective portions water for both domestic use and irrigation is abstracted from the Steelpoort River. No abstraction boreholes exist.
- Dr. Enslin is land owner of portion 1 of Steynsdrift 145 JS. A 40m deep borehole (BH 1) is located on portion 1 which provides a lodge, he only occupies during weekends, with drinking water. To his knowledge the hole is 40 m deep. No additional data is available
- Mr. Nick Gouws from the farm Steynsdrift 145 JS, has a 2000 l/h borehole that he uses for domestic use. The hole is 32m deep.

4 PROJECT DETAILS

The site layout, covering approximately approximately ± 15, 8 km^2 'is outlined in Figure 1, which is a portion of the 1: 50 000 topographical sheet 2529BB Steelpoort in Mpumalanga.

These activities will be enveloped within the following co-ordinates: -

25° 6'S to 25° 85'S
29° 47'E to 29° 58"E

4.1 Desktop study

All available geological and hydrogeological data for the study area was compiled from various sources and analysed.

4.2 Fieldwork

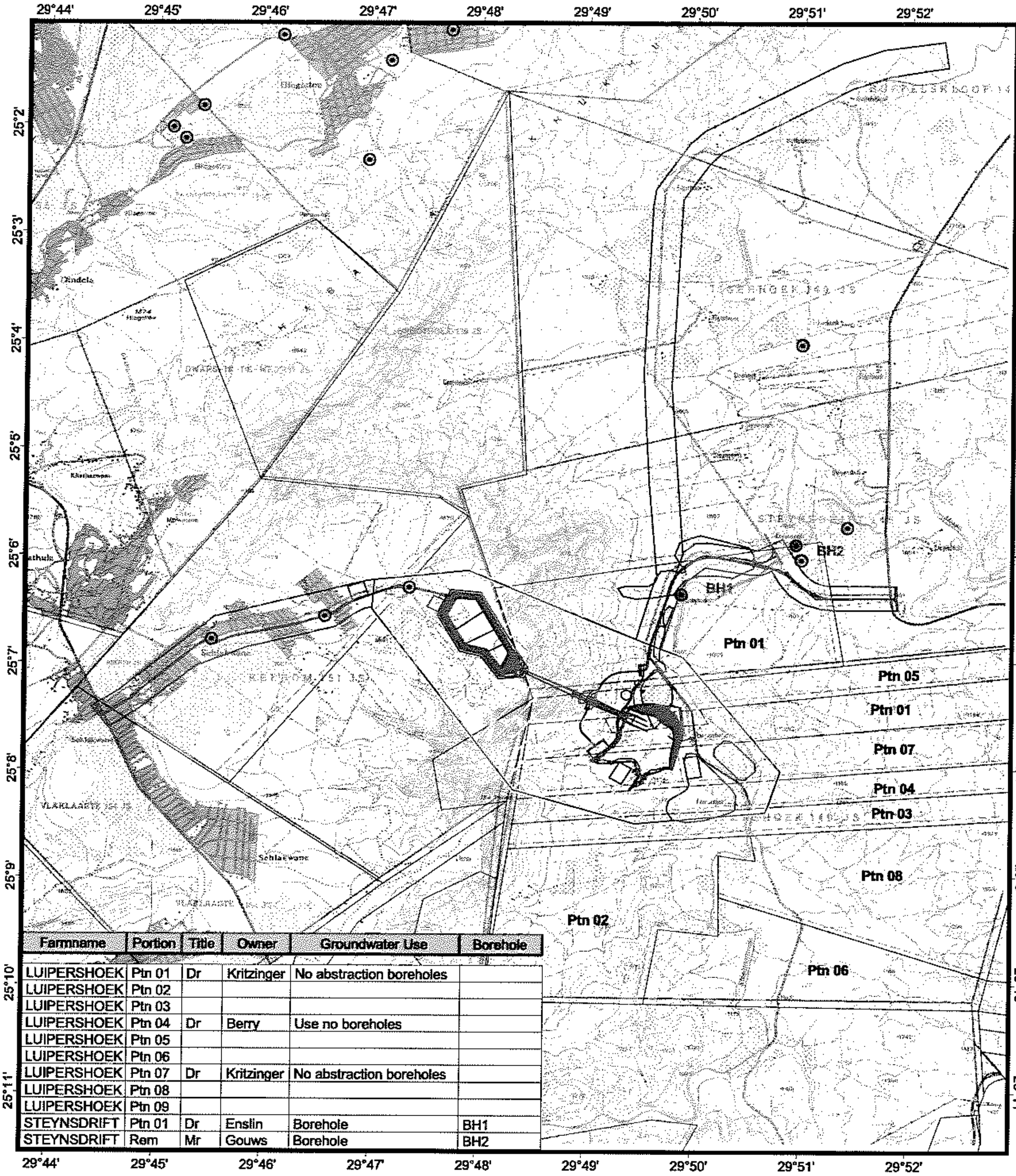
During the site visit, the following field work was undertaken:

- Borehole census, including the recording of coordinates
- Static water level measurements
- Borehole depths
- Yields
- Farmers comment

Drilling records from drilling contractors currently located on the site was also obtained.

FIGURE 1 - TOPOSHEET

LOCALITY AND BOREHOLES



Farmname	Portion	Title	Owner	Groundwater Use	Borehole
LUIPERSHOEK	Ptn 01	Dr	Kritzinger	No abstraction boreholes	
LUIPERSHOEK	Ptn 02				
LUIPERSHOEK	Ptn 03				
LUIPERSHOEK	Ptn 04	Dr	Berry	Use no boreholes	
LUIPERSHOEK	Ptn 05				
LUIPERSHOEK	Ptn 06				
LUIPERSHOEK	Ptn 07	Dr	Kritzinger	No abstraction boreholes	
LUIPERSHOEK	Ptn 08				
LUIPERSHOEK	Ptn 09				
STEYNSDRIFT	Ptn 01	Dr	Enslin	Borehole	BH1
STEYNSDRIFT	Rem	Mr	Gouws	Borehole	BH2

LEGEND:

- Farm boreholes
- NGDB boreholes
- Site layout of Project Lima Phase II
- Proposed reservoir areas (15,806 km2)
- Farms (some portions)

Image Wgs2429dc.sid
Image Wgs2429dd.sid
Image Wgs2529ba.sid
Image Wgs2529bb.sid

Area in 2D as from above - not 3D into consideration.

Figure 1

Project: Boh.06.121
Steelpoort Pumped Storage Scheme

Date Printed: 9/2/2007

0.8 0 0.8 Kilometers

N

GCS PTY LTD
WATER, ENVIRONMENTAL, ENGINEERING & EARTH SCIENCE CONSULTANTS

GIS
Tel (011) 803-5726 Email: jhb@gcs-sa.biz Web: www.gcs-sa.biz

© Copyright GCS (Pty) Ltd.

5 GEOLOGY

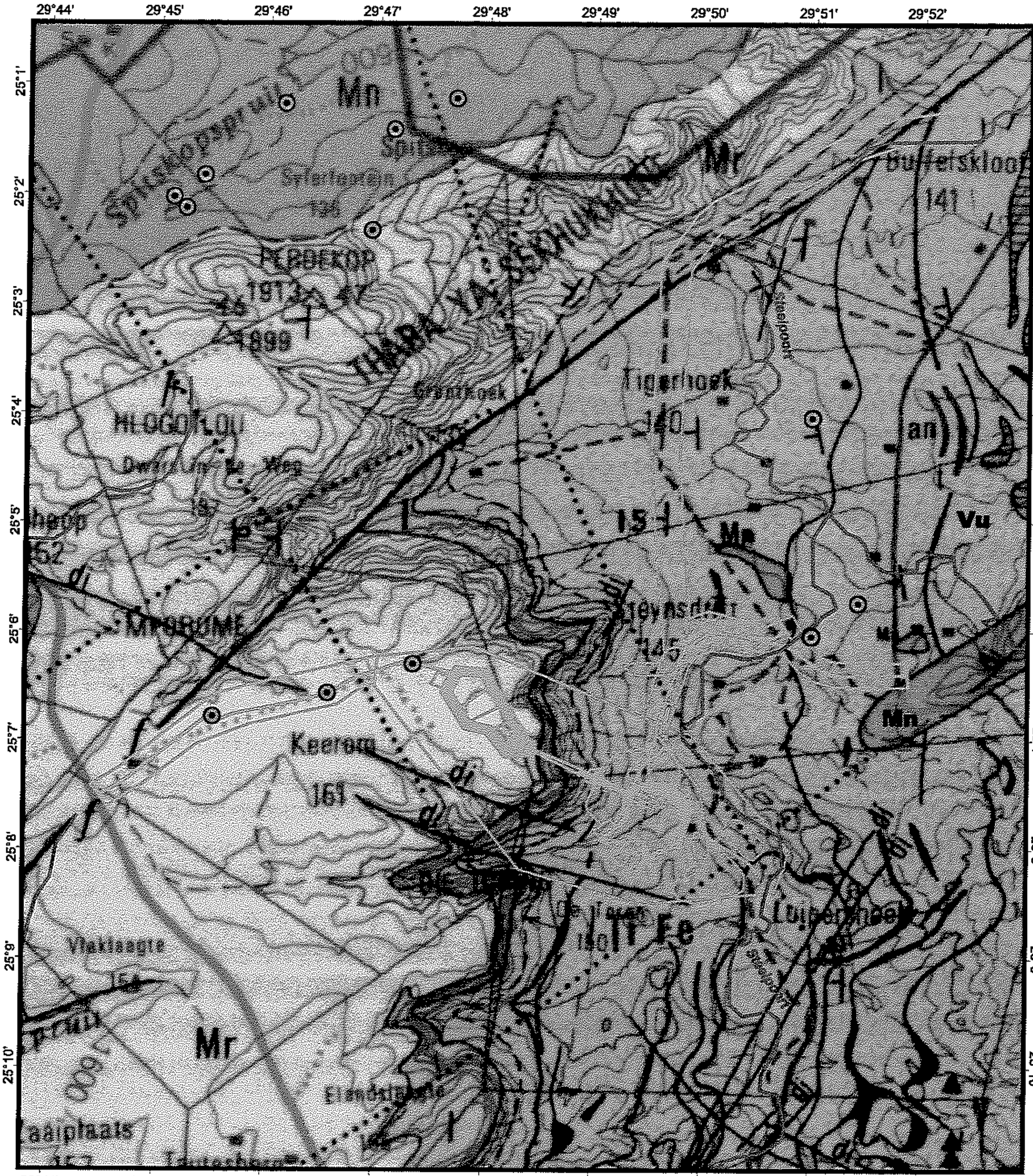
The geology within the A3-site study area (upper and lower reservoir sites) comprises intrusive lithology. Associated with the Bushveld Igneous Complex. Figure 2, a portion of the 1:250 000 geological map 2528 Steelpoort, shows the study area geology. Table 1 presents the lithostratigraphy of the area.

Table 1 – Lithostratigraphy

Age	Supergroup / Group	Formation	Alternative Name	Lithology
Jurassic				Dolerite Dykes
Mogolian	Bushveld Complex	Lebowa Granite Suite	Nebo Granite	Grey-pink coarse grained granite, red, medium grained near top
		Rashoop Granophyre Suite		Granophyre, Pseudogranophyre, microgranophyre,granite porphyry
Vaalium				Leptite
Vaalium		Rustenburg Layered Suite	Upper Zone	Ferrogabbro, ferrodiorite, diorite, Magnetite Layer, Tracolite layer
		Rustenburg Layered Suite	Upper Zone	Ferrogabbro, ferrodiorite, diorite, Magnetite Layer, Tracolite layer

FIGURE 2 - GEOLOGY

GEOLOGY



LEGEND:

NGDB boreholes

Site layout of Project Lima Phase II

Rivers

Image Gw_2528.tif

GEOLOGY:
di = Dolerite Dykes
f = Fault Zone
l = Leptite
Mn = Nebo-Granite
Mr = Granophyre
Vu = Ferrogabbro

Figure 2

Project: Boh.06.121
Steelpoort Pumped Storage Scheme

Date Printed:
9/2/2007

0.8 0 0.8 Kilometers

N

GCS (PTY) LTD
WATER, ENVIRONMENTAL, ENGINEERING & EARTH SCIENCE CONSULTANTS
GIS
Tel (011) 803-5726 Email: jhb@gcs-sa.biz Web: www.gcs-sa.biz

© Copyright GCS (Pty) Ltd.

5.1 Site specific (A3) geology

The Bushveld Igneous Complex rocks underly the study area and comprise felsic (granitic) rocks overlying the mafic (gabbroic) rocks. The high plateau is underlain by granitic rocks and which form the steep scarp slopes. Below the bottom of the scarp at the base of the felsic rocks is a leptite formation reported to be approximately 250 m thick. This is in turn underlain by diorite beneath the pediment slope, grading into olivine-bearing diorite and gabbro beneath the valley floor. The upper zone contains bands of anorthosite, magnetite and anorthosite/magnetite-rich diorite. From outcrop mapping the horizons reportedly dip at shallow angles towards the west. The rocks on the site are generally highly weathered at the surface. The weathered profile may very up to tens of metres. The unweathered rocks are strong to extremely strong (competent). In addition, the various rock types grade almost imperceptibly into one another with the boundaries not readily apparent.

All of the rocks discussed above have been intruded by dolerite/lamprophyre dykes, generally trending northeast (roughly parallel to the Steelpoort fault) and west of northwest, roughly perpendicular to the Steelpoort Fault (BKS (Pty) Ltd, 2007).

5.1.1 Upper Reservoir

Indications at present are that the south-eastern corner and the central part of the reservoir area is underlain by predominantly competent granitic bedrock, either on surface or below a thin cover of boulders. The remaining areas are generally covered by topsoil overlying weathered granitic rock (BKS Pty Ltd, 2007).

5.1.2 Lower Reservoir

The left flank is underlain by a 0.5 m to over 15 m thick layer of colluvium which is underlain by 8 m-20 m thick layer of moderately to highly weathered diorite bedrock. The right flank is underlain by a 4.5 m to 19 m thick layer of highly weathered diorite which is underlain by unweathered rock. The river section is underlain by a layer of alluvium above diorite bedrock with some outcrops (BKS Pty Ltd, 2007).

5.1.3 Intake surge shaft

No shaft drilling was carried out during this investigation phase. Borehole BH 6 (Feasibility Report of November 2000) was drilled 200 m south of the present proposed shaft position (BKS Pty Ltd, 2007).

5.1.4 Pressure tunnel

From borehole log PT 01 which was drilled (angle of 60° to a depth of 400 m) indicates diorite with occasional bands of magnetite or mixed ("zebra-striped") magnetite-rich and anorthosite-rich diorite. A distinctive "zebra-striped" band approximately 20 m thick is situated where the borehole crosses the pressure tunnel. A number of very closely fractured zones do occur in the borehole over limited lengths, however, a fairly large very closely fractured zone was encountered in borehole between approximately 235 m and 250 m (BKS Pty Ltd, 2007).

5.1.5 Machine and Transformer Halls

Two boreholes were drilled within the area the machine and transformer halls will occupy that provided geological background information.

Borehole MH 01 immediately northwest of the machine hall was vertically drilled to a depth of 350 m and borehole SC 01 immediately southeast of the machine hall was drilled to a depth of 300 m.

The distinctive "zebra-striped" band of mixed anothosite and magnetite approximately 20m thick (recorded in angled borehole PT 01), occurs at similar elevations in these two boreholes, as well as in angled borehole TR 01approxiately 450 m to the southeast, and in the Feasibility Study borehole BH 1, approximately 380 m to the northeast. The planar relationship between the elevation of intersection with the different boreholes is being analysed to determine the orientation of this marker band as an aid in identifying possible shear/fault zones by interpolation and extrapolation.

The band is very competent and appears to occur in the upper levels of the machine and transformer halls. The band does not appear to form a discontinuity with the adjacent competent diorite, i.e. no obvious weakness appears to occur between the rock types (BKS Pty Ltd, 2007).

5.1.6 Surge Chamber

No geological information exists for the area the surge chamber will occupy. Borehole log data from SC 01 represents geological information for the previously identified site, the Machine and transformer halls will now occupy.

5.1.7 Tailrace, Access and Emergency Tunnels

Boreholes TR 01 and TR02 were drilled on the previously proposed alignment of the tailrace tunnel and outfall portal, respectively. These holes provide an indication of likely tunneling conditions as well as an indication of the founding for the outfall structure and likely portal and trench excavation slope requirements.

Since the locations for the proposed infrastructure have moved, no exact geological information exists for the current locations.

5.2 Structural Geology

Information with regard to the structural geology was obtained from the 1:250 000 Geological sheet "2825" , Pretoria. According thereto the study area is underlain by mafic and felsic units of the Rustenburg Layered Suite. According to G. Campbell and S. Johnson (2006), a generalized NS strike and dip flatly to the west at between 5° and 15° is present. The latter are cross-cut by NNE and WNW striking dolerite dykes and at NE-striking faults.

The Steelpoort fault lies to the north and west of the upper reservoir (BKS, phase 2 Feasibility Study)(Figure 2).

The geological structures can enhance the groundwater potential in the area by increasing the permeability and transmissivity of the host rock. Secondary processes, such as faulting and fracturing, can create secondary fractured rock aquifers.

The following geophysical surveys and *in situ* testing investigations have been undertaken to determine the extent of localized faulting and fracture zones:

5.2.1 Airborne Aero magnetic Surveys

The above-mentioned investigation was performed by GAP-Geophysics in Johannesburg during 2006.

According to the investigation several dyke-like features of late Karroo age have been mapped along WNW to NNW strike trends over the plateau area (Figure 3), which exhibit moderate to steep southerly dips (highlighted in red). The true width of these structures cannot be confirmed, due to the altitude the surveys were undertaken. Dykes could enhance groundwater potential in these contact areas due to contact metamorphosis.

Also a NE striking fault (F1) and NW-striking fault F3 converge within the study area, which may be of concern as these structures may be water bearing that could cause groundwater related impacts if intersected by the pressure tunnel (Campbell, G & Johnson, S, 2006).

Figure 3: Aero magnetic survey interpretation indicating locality of faults and dykes (Campbell. G, & Johnston, S., 2006)

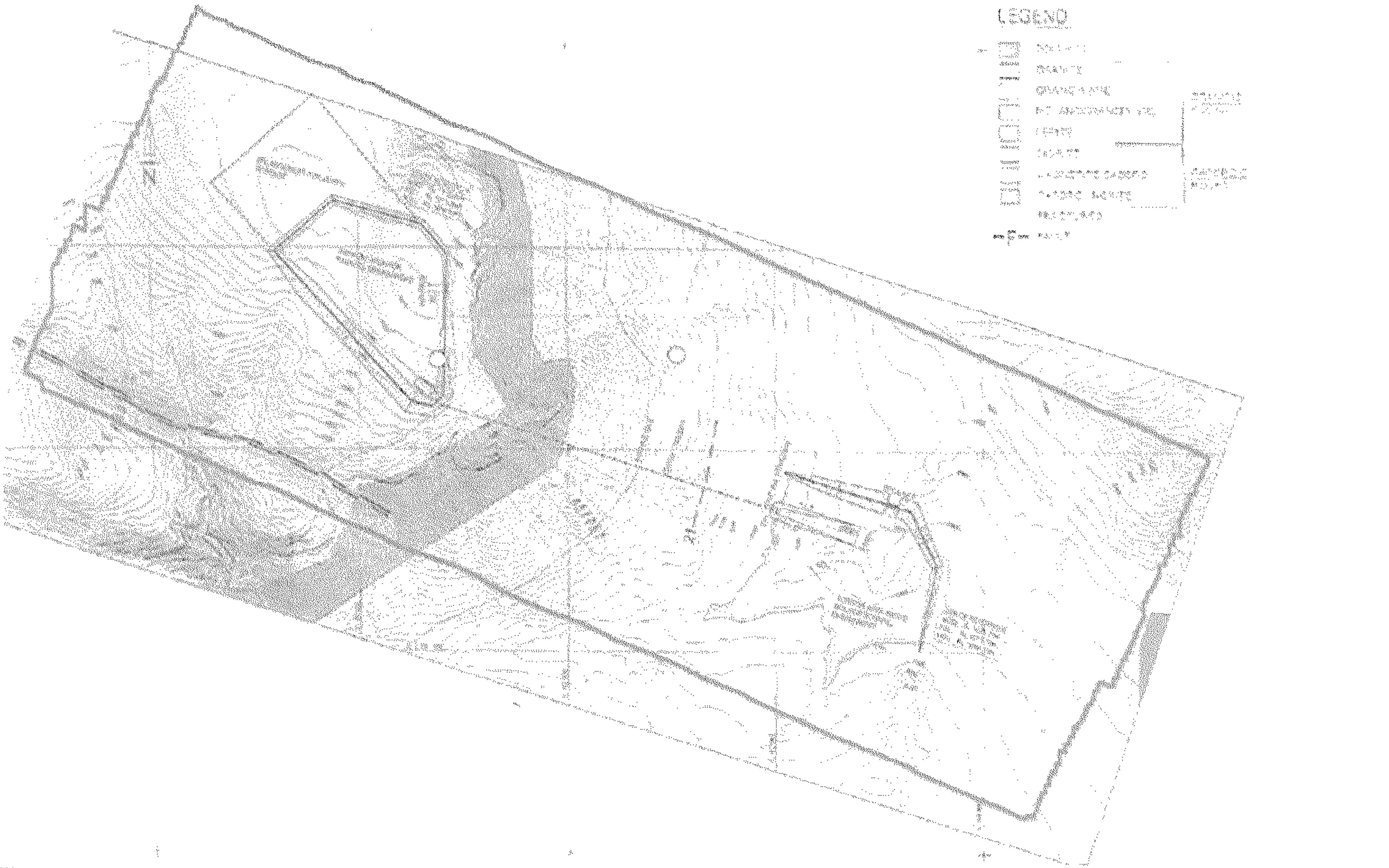


Figure 3

GCS (PTY) LTD

WATER, ENVIRONMENTAL ENGINEERING & EARTH SCIENCE CONSULTANTS

5.2.2 Seismic and Resistivity Surveys

The above-mentioned study investigation was performed by Mr. Alten du Plessis form Global Geophysics in Johannesburg during December 2006. The purpose of the study was to identify changes in the depth-of-weathering, and location of potential structured features like faults and/or fracture zones.

A total of 5 traverses were conducted. The positions of previously drilled boreholes are also indicated (du Plessis, A., 2006). For borehole positions outlined compared to the extent of the upper and lower reservoir sites view Figure 5.

The following traverses indicated zones of deep weathering that may be associated with shear/fracture zones:

- Traverse 1: Two pronounced zones of inferred deeper weathering were identified.
- Traverse 3: Shallow and predominantly horizontal bedrock was inferred between 0 and 200 m chainage, with potential zones of deeper weathering (possibly faulty fracture zones) observed at 240 m and 280 m chainage (no drilled boreholes exists within this portion of the dam).
- Traverse 4: The seismic results indicated a prominent zone of very low seismic velocities which indicated a deeper weathering profile.
- Traverse 5: Indicated deeper weathering up to a depth of 30 m. A zone of potentially even deeper weathering can be observed between 300 and 450 chainage.

Figure 4: Existing borehole positions at Upper and Lower Reservoir sites (du Plessis, A., 2006)

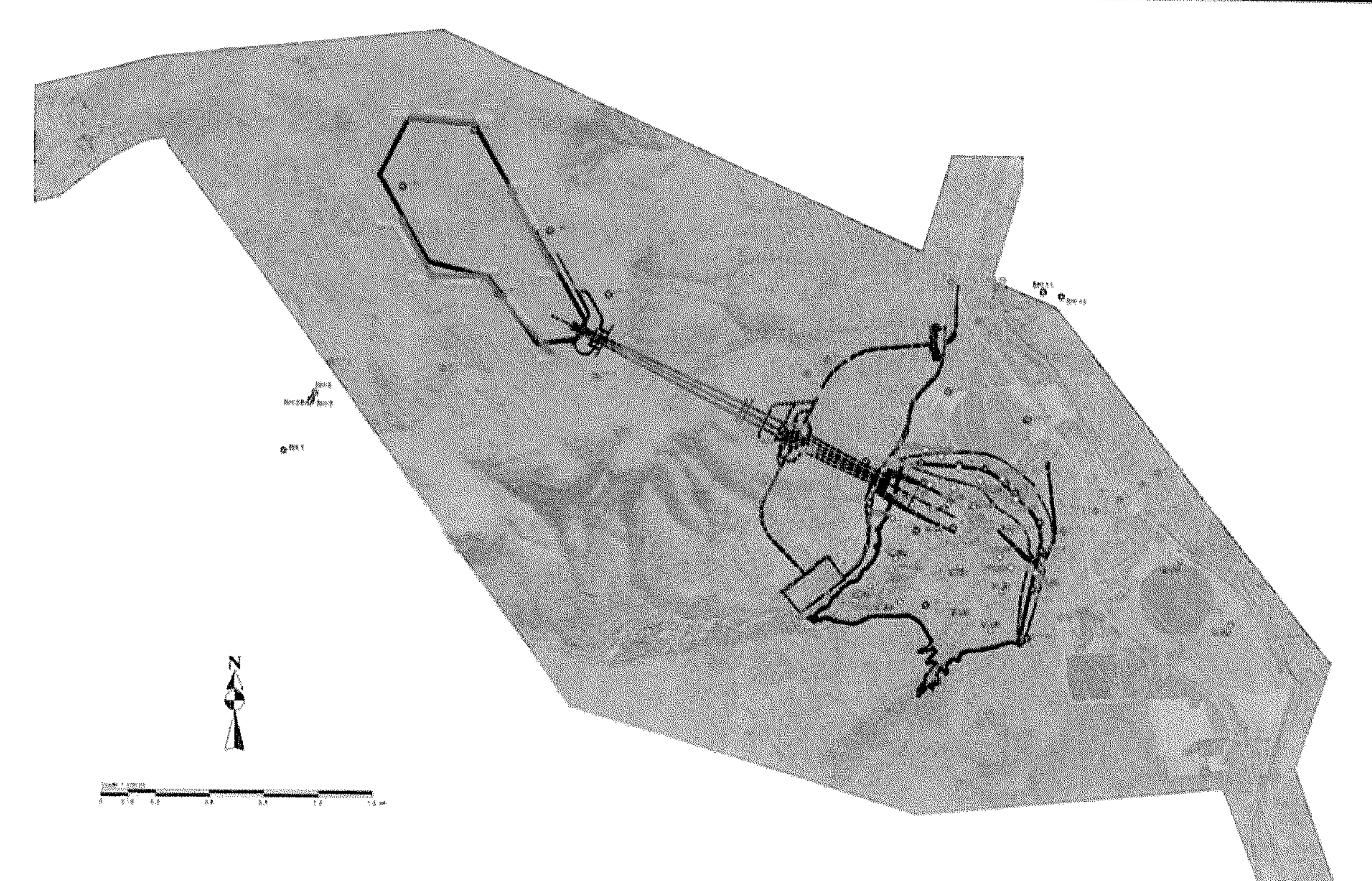


Figure 4

GCS (PTY) LTD
WATER, ENVIRONMENTAL ENGINEERING & EARTH SCIENCE CONSULTANTS

5.2.3 Hydrofracture testing and hydraulic Jacking tests

Golder Associates undertook hydro-fracture stress measurements at borehole locations PT 01 and SC 01. The two borehole locations are as outlined in Figure 4. The boreholes are located in the vicinity of the proposed pressure tunnel and power house complex. The following additional information applies:

- Borehole PT 01 is an incline borehole, 60° to the horizontal and approximately 400 m long.
- Borehole SC 01 is a vertical borehole, drilled approximately 350 m deep to investigate the conditions throughout the height of the power station complex.

Hydro-fracturing tests that were performed at both PT 01 and SC 01 indicated competent to very competent rock conditions at the various depths the tests were performed. These competent rock zones were specifically identified for the purpose of establishing the tensile strength of solid/unweathered rock, not associated with the occurrence of weathered/fractured zones. According to the hydrofracturing report (Golder Associates, 2007), some fractures may have been pre-existing to the hydraulic fractures tests performed, although not visible in the core logs.

5.2.4 Wireline Borehole Surveys

Wireline borehole surveys were carried out, together with the hydro-fracture testing, in order to map hydro fracture orientations. According to the study (Golder Associates, 2007), the orientation of fractures is consistent running, almost north-south, parallel to the regional trend of the escarpment.

6 REGIONAL HYDROGEOLOGY

Based on regional data, as compiled on the 1:500 000 hydrogeological map 2526 Johannesburg the following hydrogeological information is available for the formations on site: -

Rashoop Granophyre :	-	Intergranular & fractured rocks
	-	Intergranular and fractured aquifers
	-	Borehole yields 0.5 to 2.0 l/s
Bushveld Complex – Upper Zone	-	Intergranular & fractured aquifers
	-	Borehole yields 0.5 to 2.0 l/s

The alluvial aquifer, which stretches the depth of the weathered zone up to the solid base rock material, may yield some groundwater, depending on the depth of the alluvium and the storativity of the alluvial material.

No large-scale groundwater abstraction occurs in the study area, even along the numerous faults.

There are no artesian boreholes located within the study area.

6.1 Regional groundwater occurrence and aquifers

Based on the geology within the study area, the structural geology, and the geomorphology the following conditions can arise to enhance aquifer development within the study area: -

- The fractured transition zone between weathered and fresh bedrock within the upper and lower reservoir locations.
- Fractures along contact zones between dykes and the host rocks due to heating and cooling of rocks involved with the intrusions.
- Contacts which may be open, enlarged, and loosened by weathering.
- Openings on discontinuities formed by fracturing.
- Stratigraphic unconformities.
- Zones of deeper weathering.
- Fractures related to tensional and decompressional stresses due to off-loading of overlying material
- Dolerite/lamprophyre dykes that have introduded into the older host rock formations, generally trending northeast (roughly parallel to the Steelpoort fault) and west of northwest, roughly perpendicular to the Steelpoort Fault.

Barnard (2000), concluded the following with regard to the water bearing capabilities of the two formations:

- Rashoop Granophyre:

  Groundwater occurs in association with the transition zone from weathered to more solid rock. Breccia and joint zones as well as lithological and dyke zones may store and yield some groundwater. The groundwater yield potential is classified as poor on the basis that 92% of the boreholes on record produce less than 2 ℓ/s. The depth to groundwater rest level seldom exceeds 30 m below the surface.

  As far as the chemistry is concerned, the average EC values recorded within the study area is 31 mS/m and the mean pH values is 7.3. Elements that show a substantial coefficient of variation are sulphate, chloride, and fluoride.

- Rashoop Granophyre:

  Groundwater occurrence is associated mainly with deeply weathered and fractured mafic rocks. Odendaal (1983) reports that some of the norite zones weather more easily than the other rock types. 81% of the boreholes produce less than 2 ℓ/s. Even stronger yields may be associated within weathered pyroxinite zones.

Groundwater yield potential is classified as poor, the depth to groundwater rest water level typically occurs between 5 m and 40 m below surface.

As far as the chemistry is concerned, the average EC values recorded within the study area is 105 mS/m . Significant coefficients of variation are indicated for potassium, sulphate , and nitrate.

Since the upper reservoir will for the majority of the time be operated at full storage capacity, the consequent pressure head associated with the overlying water mass, may cause a decrease in the permeability and hydraulic conductivity in horizonthal orientated fractures and faults. Since the lower reservoir will most of the time be operated at a lower storage capacity, such an influence of water pressure will be less.

No tectonic forces are foreseen associated with the Steelpoort fault that could possibly enhance groundwater development, as it is considered inactive (Campbell, G., Johnson, S., 2006).

The hydraulic pressure of the water mass within in the De Hoop Dam, and its influence on the stability of the underlying rock, requires to be questioned. Specialist studies may reveal this information.

6.2 National Groundwater Database (NGDB) Information

Borehole information derived from the Department of Water Affairs and Forestry's (DWAF) National Groundwater Database (NGDB) was assessed to provide hydrogeology, aquifers, and water levels information within the regional study area.

Figure 5 shows the location of the boreholes that have been registered within the data base that are within close proximity to the proposed pumped storage scheme. The borehole yields and static water level measurements have also been provided.

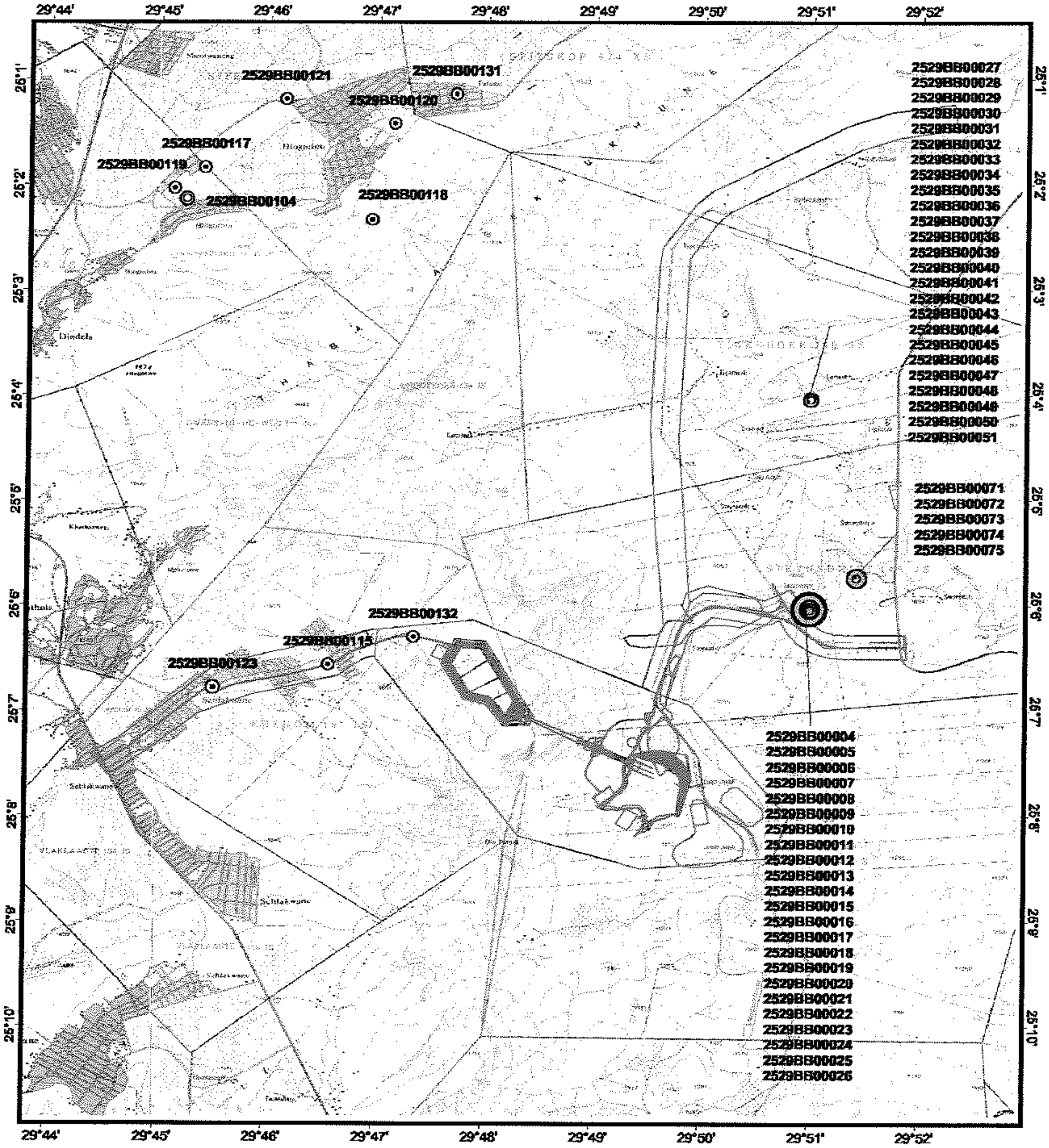
Unfortunately the NGDB borehole co-ordinates are not very accurate, and hence some of the boreholes plot in close proximity to one another. Each borehole record, however, provides individual geological and hydrogeological information.

A summary of the borehole (drilling) records is as follows: -

- The majority of boreholes drilled within the study area have very low sustainable yields.
- Three boreholes have a yield > 7.3 l/s. These high yields are as a result of boreholes that intercepted dolerite dykes.
- Borehole depths are very varies between 15m and 33m.
- Groundwater levels are variable due to the different piezometeric pressures associated with the units intersected during drilling.

FIGURE 5 – NGBD Data Base Boreholes

NATIONAL GROUNDWATER DATABASE (NGDB) AVERAGE WATER LEVELS & DISCHARGE RATES



LEGEND:

No Data

Water Levels:
- 1.59 - 6.95
- 6.95 - 13.72
- 13.72 - 20
- 20 - 28.3
- 28.3 - 42.01
- 42.01 - 91.44

Yield (l/s):
- 0.01 - 5
- 5.1 - 10
- 10.1 - 15
- 15.1 - 20
- 20.1 - 25
- 25.1 - 35

Site layout of Project Lima Phase II

Proposed reservoir areas
Area = 15,806 km2 = 15 806 399,720 m2
in 2D as from above - not 3D into consideration

Figure 5

Project: Boh.06.121
Steelpoort Pumped Storage Scheme

Date Printed:
14/2/2007

0.8 0 0.8 Kilometers

N

GCS
WATER, ENVIRONMENTAL, ENGINEERING & EARTH SCIENCE CONSULTANTS

GCS
Tel (011) 803-5726 Email: jhb@gcs-sa.biz Web: www.gcs-sa.biz
© Copyright GCS (Pty) Ltd.

6.3 Groundwater use

The Upper Reservoir study area, falls within a rural area. Groundwater to a large extent gets used providing villages with potable water. Community projects such as the Zamazama vegetable project on the farm Keerom also makes use of this source.

Below the escarpment limited groundwater abstraction occurs within the study area due to: -

- The general availability of surface water from the Steelpoort River;
- Stock and game farming which have free access to surface water bodies; and
- Low sustainable borehole yields;
- Low population density in valley.

6.4 Ambient hydrochemistry

No Groundwater quality data within close proximity to the proposed development or adjacent farms were recorded by the DWAF's national groundwater database.

The nearest recorded data points are on Paardeplaats, Syferfontein and Spitskop, situated directly north of the proposed development. Being situated too far away from the proposed pumped storage scheme, these records do not apply to the proposed development.

According to Mr. Richard Weppelman from RWBE Geotechnical Drilling all the Escom geotechnical boreholes that were drilled in the upper and lower reservoir basins are 75 mm in diameter and currently equipped with piezometers, with the exception of TR 01 which was drilled at a 60° angle to 150 m depth. An effort to bail a water sample from this hole for analysis failed. The PVC-bailer could not exceed the casing depth beyond 40 m when it was lower into the hole, as a result of the friction against sidewall of the borehole that was damp.

As no activities that can impact on water quality exist within the study area, the water chemistry is expected to be within the range as discussed in section 6.1.

6.5 Water level monitoring

Groundwater level monitoring data was obtained from RWBE drilling contractors who undertake groundwater level measurements by means of piezometers that have been installed into the core-drilled geotechnical boreholes at the lower and upper reservoir sites.

6.5.1 Lower Reservoir Static Water Levels

As can be seen from Table 2, groundwater levels within the proposed lower reservoir site did not only vary markedly within the same borehole for the period under review (19 October 2006 till 13 December 2006), but also different boreholes. The static groundwater levels at boreholes LR 6, and LR 7 remained unchanged at 25 meters below ground level (mbgl). That of LR 5 also indicated little variation, but at a higher elevation (9.2 mbgl and 10 mbgl).

Static groundwater levels at boreholes LR 2, LR3, and LR 8 varied markedly over short time intervals, which are an indication of high aquifer parameters (tranmissivity), appose to the area's with boreholes where the water levels remained more constant.

The degree of fluctuation in the groundwater levels along the right flank boreholes (LR 06, LR 05, LR 04, and LR 03) corresponds to the weathering depth of diorite, as the water table occurs at the contact between the weathered and unweathered rock.

The same can be concluded with regard to the difference and degree of fluctuations in static water levels of LR 2 and LR 7, situated within close proximity to one another.

Table 2: Static Groundwater Levels for Lower Reservoir boreholes

	Static Water Level (meters below ground level)								
Borehole number	**LR1**	**LR2**	**LR3**	**LR4**	**LR5**	**LR6**	**LR7**	**LR8**	**LR9**
Date									
19-Sep-06	13								
12-Sep-06		4.5							
11-Sep-06			7.5						
06-Oct-06				14.8					
11-Oct-06					5.6				
28-Sep-06							20.3		
10-Oct-06								12.5	
29-Sep-06									4.2
19-Oct-06	16.9	5.43	9.06	16.2	8.9		24.8	12.8	4.6
26-Oct-06	17	16.4	11.6	16.5	10	25.6	24.4	20.2	8.8
02-Nov-06	19.1	16.1	14.2	18	9.2	25.8	24.2	20.2	9.2
10-Nov-06	22.6	18.1	13.6	17	9.3	25.4	24.9	20.4	6.7
16-Nov-06	20.9	10.1	13	16.9	9.3	25.5	25.2	21.4	7.7
23-Nov-06	17.8	4.43	8.37	14.7	8.8	25.4	24.9	13.1	3.3
01-Dec-06	17.3	4.05	8.31	16.5	9.2	25.5	24.9	12.5	3
10-Dec-06	17.3	4.12	9.15	17	9.5	25.4	24.9	13.4	3.4
13-Dec-06	17.4	4.15	8.4	16.5	9.5	25.7	25	12.7	3.7

6.5.2 Upper Reservoir Static Water Levels

As can be seen from Table 3, groundwater levels within the proposed upper reservoir site vary within boreholes, yet the static water level measurements remained greatly constant for the period under review, unlike those measured at the lower reservoir site.

Table 3: Static Groundwater Levels for Upper Reservoir boreholes

	Static Water Level (meters below ground level)				
Borehole number	**UR 1**	**UR 2**	**UR 3**	**UR 4**	**UR 5**
Date					
21 October 2006	10.2	11.7	23.75	14.3	12
05 November 2005	10.5	11.9	23.75	14	12.35
13 December 2006	10.74	12.13	24.34	14.3	13.25

6.6 Groundwater Reserve (Quality)

For the purpose of establishing an ecological reserve for the B41G catchment, the pumped storage scheme is situated in, borehole chemistry data obtained from two boreholes on the farm Richmond 370 KT (ERM/GMS, 2004) was used as a baseline (boreholes RU 1 & RU 2) to determine the water quality requirements for catchment (Hobbs, P.J., 2005).

The RDM Directorate quantified this determination by escalating the median concentration of each chemical element by 10%, and then applying whichever is the lesser of the escalated value and the Class I drinking water standard value (DWAF/DoH/WRC, 1998) as the Reserve groundwater quality. Another approach employed by Hobbs (2004) escalates the mean concentration of each parameter by 10% of the respective standard deviation value before applying the comparison with the Class I value criterium. The latter approach accounts more appropriately for the variability associated with individual groundwater quality parameters.

The result of both the afore-mentioned approaches is presented in Table 4 and 5 and reveals the weighting the alternative approach affords to those parameters that exhibit the greatest coefficients of variation. Nevertheless, the result provided by the current approach followed by the RDM Directorate is applied in determining the groundwater quality component of the Reserve.

Table 6 presents a comparison of this component of the groundwater Reserve for quaternary B41G with that recorded in the DWAF template for secondary catchment B4. It is evident that the groundwater quality component of the Reserve as determined by this study is more appropriate than that determined and recorded for secondary catchment B4's RU1.

Table 4. Preliminary determination of the Reserve for groundwater quality, RU1

Descriptor	Unit	Class I Standard	Median value	Median Value (+10%)	Mean value	S.Dev	Mean value + 0.1 S dev
pH	pH units	4.5-10	7.9	4.5-10.0	7.8	0.3	4.5-10.0
Total Dissolved Solids	mg/l	< 1 000	346	381	348	62	355
Electrical Conductivity	mS/m	< 150	59	65	58	11	59
Calcium	mg/l	< 150	54	60	54	10	55
Magnesium	mg/l	< 100	34	38	34	8	35
Sodium	mg/l	< 200	23	26	21	5	22
Potassium	mg/l	< 50	0.6	0.7	0.5	0.3	0.6
Total Alk.	mg/l	< n.s	310	341	306	60	312
Sulphate	mg/l	< 400	5	6	8	8	9
Chloride	mg/l	< 1 000	9	10	10	6	11
Nitrate	mg/l	< 10	0.1	0.2	0.2	0.2	0.2

Table 5. Preliminary determination of the Reserve for groundwater quality, RU2

Descriptor	Unit	Class 1 Standard	Median value	Median Value (+10%)	Mean value	S.Dev	Mean value + 0.1 S dev
pH	pH units	4.5-10	7.5	4.5-10.0	7.6	0.4	4.5-10.0
Total Dissolved Solids	mg/l	< 1 000	364	401	354	132	368
Electrical Conductivity	mS/m	< 150	59	65	57	20	59
Calcium	mg/l	< 150	51	57	57	30	60
Magnesium	mg/l	< 100	31	34	30	8	32
Sodium	mg/l	< 200	20	22	19	6	20
Potassium	mg/l	< 50	1.4	1.6	1.2	0.8	1.2
Total Alk.	mg/l	< n.s	280	308	278	110	289
Sulphate	mg/l	< 400	16	18	29	25	32
Chloride	mg/l	< 200	17	19	16	7	17
Nitrate	mg/l	< 10	0.01	0.01	0.01	0	0.01

Table 6. Comparison of the Reserve groundwater quality, quaternary catchment B42G and secondary catchment B4

Descriptor	Unit	Quarternary catchment B41G		Secondary Ctachment B4
		RU 1	RU 2	RU 1
pH	pH units	4.5-10	4.5-10.0	6.5-8.5
Total Dissolved Solids	mg/l	381	401	246
Sodium	mg/l	26	22	15
Magnesium	mg/l	38	34	25
Calcium	mg/l	60	57	35
Chloride	mg/l	10	19	18
Sulphate	mg/l	6	18	12

6.7 Aquifer classification

Based on the available hydrogeological data the overall aquifer system within the study area can be classified as a Minor-Aquifer System (Parsons, 1995[1]), where: -

> **Non-Aquifer System** occurs where the formations have negligible permeability and are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer as unusable. However, groundwater flow through such rocks, although imperceptible, does take place, and needs to be considered when assessing the risks associated with persistent pollutants. Groundwater

potential is enhanced along areas of secondary processes, such as faulting, fracturing, etc. allowing for the development of discrete minor aquifer systems, where: -

A **Minor Aquifer System** comprises fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important both for local supplies and in supplying base flow for rivers.

7 IMPACT ASSESSMENT FOR A3 STUDY AREA

The preliminary site suitability, for the development of a pumped storage facilities and infrastructure, was assessed based on hydrogeological criteria, taking into consideration the following components:

- Upper and lower reservoir pumped storage sites.
- Associated infrastructure such as the intake/surge shaft, pressure tunnel, machine and transformer halls, surge chamber, tailrace/access and emergency tunnels.
- Upper and lower reservoir construction sites and yards (with associated uses such as waste disposal and fuel storage)
- Borrow areas.

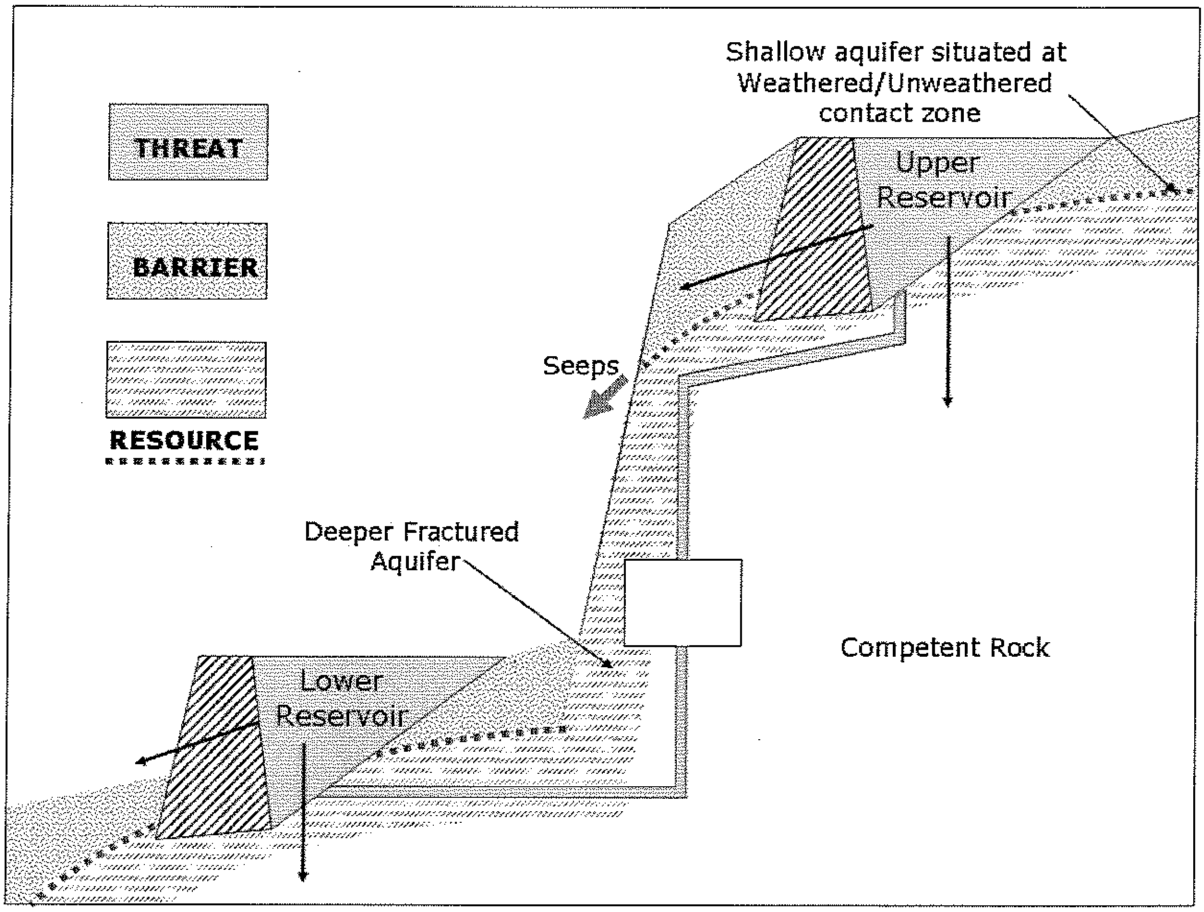
The proposed pumped storage facilities with infrastructure are envisaged to have a positive impact on the local hydrogeology by enhancing aquifer recharge during the operational phase (when structures are filled with water). The negative anticipated impacts that are foreseen is that of sewage disposal by means of irrigation and possible fuel spillages during the construction phase, unless mitigated measures as outlined under section 8.2 gets implemented.

In order to assess the sites from a groundwater perspective an assessment of each site has been conducted based on the following criteria, as outlined in Figure 6:

- The *threat* posed by the pumped storage facilities and infrastructure
- The *barrier* between the pumped storage facilities and the groundwater resources
- The groundwater *resource*.

The vulnerability of the groundwater and risk to the current groundwater users (for future use) was identified using available data, including additional specialist studies undertaken. Additional information may be required once the project gets initiated.

Figure 6: Schematic representation of the anticipated, impact, barrier and groundwater resource.



7.1 Threat factor

The threat to the groundwater resources posed by the proposed pumped storage facilities, and temporary activities with associated infrastructure has been based on specialist studies, recorded data, and the recognition of potential sources of contamination.
These include: -

- Sources of artificial recharge, which include seepage through the dam wall grout curtains and unlined dam basin into the water table and fractured rock aquifer.
- Sources of artificial recharge with poor quality water, associated with wastewater treatment plants, solid waste sites, and fuel storage facilities.
- Temporarily dewatering of groundwater from various sections of the pumped storage facilities that will be located underground, in order to enable construction work to continue.
- Groundwater losses as a result of decant into open pit areas should excavations exceed the static groundwater level within the specific area.
- Borehole losses.

The threat factor is considered positive in the instance where seepage from the dam walls (grout curtains) will occur. The water source is the De Hoop Dam, where water quality is expected to be good (if not negatively impacted upon by mining related activities). Artificial aquifer recharge that may result from this seepage will enhance the sustainability of groundwater resources, which is currently classified as poor based on limited recharge and storitivity. This seepage will also enhance base flow in the tributaries downgradient of the lower reservoirs site, for the purpose of complying with the requirements of the ecological reserve.

Dewatering in order to enable construction of certain components of the underground pumped storage facilities is only seen as a temporary negative impact, which will cease during the operational phase.

Unless prevented, seepage from pollution sources (fuel, sewage and waste) is considered the only long term negative impact.

7.2 Barrier factor

The unsaturated zone represents the barrier between the proposed pumped storage facilities, associated infrastructure and facilities and the groundwater. Both the lower groundwater aquifer situated between the weathered zone and solid rock and the deeper fractured rock aquifer represents the groundwater resources. It is within this zone that attenuation will occur. The attenuation processes can include chemical precipitation, adsorption, dilution, dispersion, and biodegradation.

Attenuation is a set of complex and often inter-related processes governed by a number of factors. The modelling of attenuation processes is hence extremely difficult. It is therefore necessary to assess the time taken for poor quality water to migrate through the unsaturated zone, from the surface contaminant source to the groundwater level.

The travel time through the unsaturated zone is dependent on the depth of the groundwater and the porosity and permeability of the unsaturated material. Preferential pathways, such as faults, fractures or weathering, can increase the travel time and reduce the attenuation.

The vulnerability of the groundwater is determined by assessing the unsaturated zone at each of the candidate sites. Localities within the proposed scheme with identified geological structures, which may act as preferential pathways for contaminant movement from surface to groundwater, are identified as less suitable for the location of possible contaminant sources such as waste disposal facilities, wastewater treatment works and fuel storage facilitates.

7.3 Resource factor

The groundwater resource at each location within the A3-proposed pumped storage facility site is assessed to determine the significance of the groundwater in terms of current and potential use.

The resource assessment identifies both the current groundwater usage and hydrochemistry, and the groundwater potential for possible future use.

8 RISK ASSESSMENT

8.1 Rating system

8.1.1 Criteria

A rating system that was obtained from Bohlweki Environmental (Pty) Ltd was used to determine the potential impact on the receiving environment and includes an objective evaluation of the mitigation of the impacts. In assessing the significance of each issue the following criteria (including an allocated point system) is used .

Table 7: Criteria for assessing significance of each issue

Extent (distribution)	National 4	Regional 3	Local 2	Site 1
Duration (Time Period of Impact)	Permanent 4	Long-term 3	Medium-term 2	Short-term 1
Intensity	Very High 4	High 3	Moderate 2	Low 1
Probability of occurrence	Definite 4	Highly Probable 3	Possible 2	Improbable 1

Table 8: Criteria for the classification of environmental Impacts:

CATEGORY	DESCRIPTION OF DEFINITION
Nature	A brief written statement of the environmental aspect being impacted upon by a particular action or activity.
Extent (Scale)	The area over which the impact will be expressed. Typically, the severity and significance of an impact have different scales and as such bracketing ranges are often required. This is often useful during the detailed assessment phase of a project in terms of further defining the determined significance or intensity of an impact. For example, high at a local scale, but low at a regional scale.
Site	The construction site and within a 2km radius of the construction site.
Local	In a radius of between 2 km – 10km of the construction site
Regional	Provincial.
National	The whole of South Africa.
Duration	Indicates what the lifetime of the impact will be.
Short-term	The impact will last for the period of the construction phase, where after it will be entirely negated
Medium-term	The impact will last for 6 months after the construction phase and will be mitigated by direct human and/or natural processes thereafter.
Long-term	The impact will continue or last for the entire operational life of the development, but will be

CATEGORY	DESCRIPTION OF DEFINITION
Permanent	mitigated by direct human action or by natural processes thereafter The only class of impact which will be non-transitory. Mitigation either by man or natural process will not occur in such a way or in such a time span that the impact can be considered transient
Intensity Low Medium High Very high	Describes whether an impact is destructive or benign. Impact affects the environment in such a way that natural, cultural and social functions and processes are not affected Effected environment is altered, but natural, cultural and social functions and processes continue albeit in a modified way Natural, cultural and social functions and processes are altered to extent that they temporarily cease Natural, cultural and social functions and processes are altered to extent that they permanently cease
Probability Improbable Possible Highly probable Definite	Describes the likelihood of an impact actually occurring. It is not likely that the impact will occur Likelihood of the impact materialising is very low Likely that the impact will occur Impact will certainly occur

8.1.2 Significance

Significance is determined through a synthesis of impact characteristics. Significance is an indication of the importance of the impact in terms of both physical extent and time scale, and therefore indicates the level of mitigation required. The total number of points scored for each impact indicates the level of significance of the impact.

Table 9: Criteria for the rating of classified environmental impacts

Significance	Using the scoring in Table 5, the significance of impacts is rated as follows.
Low impact (4-7 points)	A low impact has no permanent impact of significance. Mitigation measures are feasible and are readily instituted as part of a standing design, Construction or operating procedure
Medium impact (7-10 points)	Mitigation is possible with additional design and construction inputs
High impact (10-13 points)	The design of the site may be affected. Mitigation and possible remediation are needed during the construction and/or operational phases. The effects of the impact may affect the broader environment..
Very high impact (13-16 points)	Permanent and important impacts. The design of the site may be affected. Intensive remediation is needed

	during construction and/or operational phases. Any activity which results in a "very high impact" is likely to be a fatal flaw.
Status • Positive (+) • Negative (-) • Neutral	Denotes the perceived effect of the impact on the affected area. • Beneficial impact. • Deleterious or adverse impact. • Impact is neither beneficial nor adverse. • It is important to note that the status of an impact is assigned based on the *status quo* – i.e. should the project not proceed. Therefore not all negative impacts are equally significant.

The suitability and feasibility of all proposed mitigation measures will be included in the assessment of significant impacts. This will be achieved through the comparison of the significance of the impact before and after the proposed mitigation measure is implemented. Accumulative Impacts will be evaluated and assessed in a separate chapter.

8.2 Impact Assessment

The impacts identified (positive or negative) with the proposed pumped storage scheme and associated infrastructure are related to the use of water that may possibly impact negatively on the groundwater regime. These impacts identified are as follow:

- Groundwater seepage from the upper and lower reservoir sites that will cause artificial aquifer recharge and baseflow enhancement down-gradient of these storage facilities.
- Groundwater decant into excavations, end dewatering thereof from the surge shaft, machine and transformer halls, pressure and emergency tunnels.
- Leachate generation from the solid waste disposal facility impacting on groundwater quality
- Irrigating sewage effluent or spillages thereof impacting on the groundwater quality.
- Fuel /oil spillages at the storage facilities impacting on the groundwater quality.
- Evaporative losses from groundwater decant into to open borrow pit area's

Each anticipated impact will be discussed in more detail, mitigation measures to be applied, and resultant impact after mitigation measures were applied:

8.2.1 Impact 1: Upper Reservoir Seepage

Permeability tests on overburden material (weathered zone), up to 25 m depth at the proposed upper reservoir site indicated permeability values of 10^{-7} m/s and 10^{-8} m/s (Hydrology Report, 2007). Groundwater moves vertically through the overburden material, until it reaches impermeable competent rock. From there it moves horizontally along the contact zone, where at appears as seepage points along the escarpment.

During the initial construction phase of the dam wall at the upper reservoir, the foundations will extend down into the more solid unweathered baserock. This will act as a barrier which will cut off the groundwater flow at the contact between the weathered/unweathered contact. This source currently appears as springs at the escarpment between the upper and lower reservoir sites. Blocking this source of groundwater flow during the construction phase will cause a **Low Negative Impact,** due to the temporary nature and the fact that the upper reservoir will not be situated in a stream or tributary (small area of impact).

However, when the reservoir is complete and stores water during the operational phase, it is expected that some 440 m^3/d of water will seep through the grout curtain along the perimeter wall (BKS Pty Ltd, 2007). This volume of water will supplement the baseflow requirement between the upper and lower reservoir position that would otherwise have been loss. The seepage loss will constitute a **Medium Positive Impact** after construction during the operational phase when the reservoir is operated at full storage capacity.

Table 10: Rating of pre- and post remediation impacts of seepage at the upper reservoir site

Criteria (pre-remediation)	**Rating**
Extent	1
Duration	1
Intensity	1
Probability of occurance	2
Total	**5**
This is rated as a **Low Negative Impact** before the implementation of mitigation and management measures	
Mitigation and management measures to minimize anticipated impact:	
During operational phase, seepage through damwall will contribute towards downgradient baseflow requirements (springs along mountain slope)	
Locate possible seepage paths for remedial grouting by installation of piezometers downstream of grout curtain, will reduce excessive seepage (<440 m^3/d)	
Install groundwater monitoring boreholes downgradient of damwall to monitor quality and water levels	
Criteria (post remediation)	**Rating**
Extent	1
Duration	3
Intensity	1
Probability of occurance	3
Total	**8**
This is still rated as a **Medium Positive Impact** after the implementation of mitigation and management measures	

8.2.2 Impact 2: Lower Reservoir Seepage

The negative impact associated with the loss of baseflow downgradient of the dam wall during the construction phase will be of a greater magnitude as that at the upper reservoir site, based on the likelihood that the reservoir will be situated in an unnamed tributary that currently transports a larger baseflow volume than the upper reservoir.

During the operational phase a smaller seepage volume through the grouting curtain is anticipated (68 m^3/d), due to the fact that the lower reservoir will most of the time not be operated at full storage capacity (BKS Pty Ltd, 2007). According to Hobbs (2005) the average recharge is 3.5% of the MAP (650 mm), which equated to 22.75 mm recharge per annum.

According to the Groundwater resources Map of South Africa, Sheet 2 (1995), 10 mm of this volume contributes to baseflow. Taking this baseflow contribution over 0.5 m depth over the entire length of the tributary, till its confluence of the Steelpoort (3 km), equates to 15 m^3 per annum. This volume is markedly les than the anticipated seepage volume, which implies the flow of the river (perennial) may become permanent throughout the year. This impact will have to be assessed from an ecological point of view, as there will be no longer be dry stress periods.

It is anticipated the impact after construction of the lower reservoir will be of a Medium Positive magnitude.

Table 11: Rating of pre- and post remediation impacts of seepage at the lower reservoir site

Criteria	**Rating**
Extent	1
Duration	1
Intensity	2
Probabillty of occurance	3
Total	**7**
This is rated as a **Low Negative Impact** before the implementation of mitigation and management measures	
Mitigation and management measures to minimize anticipated impact:	
Less seepage due to fluctuations in water level (Phase 2: Hydrology Study)	
Locate possible seepage paths for remedial grouting by installation of piezometers downstream of grout curtain	
Install groundwater monitoring boreholes downgradient of damwall to monitor quality and water levels	
Criteria	**Rating**
Extent	1
Duration	3
Intensity	1
Probabiliity of occurance	2
Total	**7**
This is still rated as a **Medium Positive Impact** after the implementation of mitigation and management measures	

8.2.3 Impact 3: Artificial groundwater recharge

During the construction phase of the two reservoirs, excavation work for damwalls and grouting curtains into the deeper-lying solid rock, will be undertaken to depths below the static groundwater table.

At the upper reservoir site, the downstream slope of the splinth will correspond with the slope of the concrete face on the embankment (1.5H: 1 V), while the upstream slope can vary from 0.5 H:1 to 1:1, depending on the characteristics of the material. Materials above the groundwater level appear to be stable at these slopes. The groundwater level is situated between 10.2 m and 18.2 m depth with an average of 12.5 m below ground surface (BKS, Pty, Ltd, 2007).

Based on borehole results at the lower reservoir, the depth of the cut-off trench will vary between about 12 m near the river, to a maximum of about 20m at boreholes LR 08 on the left flank and LR 06 on the right flank. The average depth for the cut-off along the left flank will be about 15m. During October 2006, groundwater level measurements, the groundwater table was located close to the base of the colluvium. The groundwater level is situated between 5.5m and 24.8m depth with an average at 15 m below the surface.

At the right flank, the groundwater level is situated between 8.92m and 24.8m depth with an average at 14.7m below ground level. It is anticipated that there will be no problem of slope instability due to groundwater condition during excavation.

A **Low Negative Impact** is foreseen with groundwater seeping into the dam wall excavations that below beyond the static groundwater table, due to the short duration of excavations.

During the operational phase, groundwater recharge from the reservoirs will occur through permeable soil and weathered zones (fracture zones). On condition that the recharge quality be of good nature, groundwater recharge is considered to have a **Medium Positive Impact,** contributing towards the baseflow requirement in terms of the reserve.

Table 12: Rating of pre- and post remediation impacts of artificial recharge

Criteria	**Rating**
Extent	1
Duration	1
Intensity	1
Probability of occurance	1
Total	**4**
During the construction phase a **Low Negative Impact** is foreseen	
Mitigation and management measures to minimize anticipated impact:	
Apply source in construction, appose to obtaining it from a more expensive/located source elsewhere	
Backfill existing geotechnical boreholes in dam basin with a mixture of bentonite and cement, trimmed and filled from the bottom, to prevent excessive losses through recharge	
Line reservoirs with clay baseses to minimise seepage losses	
Criteria	
Extent	2
Duration	3
Intensity	1
Probabiilty of occurance	2
After the construction phase a **Medium Positive Impact** is foreseen	
Total	**8**

8.2.4 Impact 4: Borehole loss as result of construction activities

No production boreholes are situated within the proposed upper and lower reservoir positions, therefore no impact is anticipated.

However, the NGDB data base indicated that three production boreholes are situated along the proposed pipeline intended to supply Sehlakwane with potable water from the de Hoop Dam. It cannot be confirmed if the pipeline excavations will impact/destroy these supply boreholes. However, if not destroyed, blasting that may be required in difficult terrain may enhance the aquifer parameters in close-by production boreholes.

Borehole related impacts are seen as temporary, as the pump storage facility will supply the area with water when operational. Mitigation measures to resolve this impact is to drill alternative boreholes or to provide the community with an alternative source of potable water. As a result a high positive impact is foreseen.

Table 13: Rating of pre- and post remediation impacts of borehole loss

Criteria	Rating
Extent	1
Duration	1
Intensity	3
Probabiilty of occurance	1
Total	**6**
During the construction phase a **Low Negative Impact** is foreseen	
Mitigation and management measures: Compensation for boreholes loos by providing alternative water source Redrilling boreholes to substituet loss	
Criteria	**Rating**
Extent	1
Duration	3
Intensity	3
Probabiilty of occurance	3
Total	**10**
Reservoirs will have a **High Positive Impact** on the water yields of down gradient boreholes due to artificial aquifer	

8.2.5 Impact 5: Dewatering of surge shaft decant during construction phase

Since no shaft drilling was carried out during the geotechnical investigation phase, there is no indication if any water-bearing fracture or shear zones will be intercepted during construction of the shaft. However borehole BH 6 (feasibility report 2000) that was drilled 200 m south of the present proposed shaft indicated that rock foundations should be good, which also indicates the likelihood if intercepting water-bearing structures is poor. Low incidents of deeper fracturing occurs in competent rock.

Should groundwater bearing structures be intercepted, the anticipated impact will be of a low negative magnitude, due to the short duration thereof. After mitigation measures were implemented, no additional impact is foreseen.

Table 14: Rating of pre- and post remediation of surge shaft dewatering during construction

Criteria	Rating
Extent	1
Duration	1
Intensity	1
Probabiilty of occurance	1
Total	**4**
During the construction phase a **Low Negative Impact** is foreseen.	
Mitigation and management measures to minimize anticipated impact: Drill 700m deep borehole at the proposed shaft position to establish presence of water bearing fracture zones Dewater inflowing groundwater during the construction phase Apply water in construction process, minimising the demand from more expensive sources Grouting side walls will prevent groundwater inflow during construction phase	
After mitigation **no impact** is foreseen.	

8.2.6 Impact 6: Dewatering of machine and transformer halls during construction phase

Borehole logs from boreholes MH 01 and SC 01 that have been drilled in the vicinity of the machine hall, and hydro fracture permeability tests undertaken, indicate the rock to be competent. No discontinuity appears between the rock types. Based on this unlikelihood that water bearing structures will be intercepted, and the short duration thereof (mitigation measures will prevent long term decant), a Low Negative Impact is foreseen.

After mitigation measures were implemented, no additional impact is foreseen.

Table 15: Rating of pre- and post remediation of dewatering of machine and transformer halls during construction

Criteria	Rating
Extent	1
Duration	1
Intensity	1
Probabiilty of occurance	1
Total	**4**
During the construction phase a **Low Negative Impact** is foreseen	
Mitigation and management measures to minimize anticipated impact: Dewater during the construction phase Apply water in construction process, minimising the demand from more expensive sources Grouting side walls will prevent long-term impacts after construction	
After mitigation **no impact** is foreseen.	

8.2.7 Impact 7: Dewatering of pressure tunnel during construction phase

According to the geotechnical investigations that were undertaken on borehole PT 01, a number of very closely fractured zones do occur in the borehole, including a fairly large, near vertical feature, between 235m and 250 m depth. This feature may intersect the tunnel over a length of approximately 10m within the steel lined section a short distance upstream of the bifurcations. This feature may be associated with water inflows (BKS Pty Lt, Phase 2 Feasibility Study, 2007).

Based on a higher likelihood that this feature may be watering bearing, apposed to other structures identified in borehole logs, the magnitude of negative impact, although still low, is of a higher value (6).

After mitigation measures were implemented, no additional negative impact is foreseen.

Table 16: Rating of pre- and post remediation of dewatering of pressure tunnel during construction

Criteria	Rating
Extent	1
Duration	1
Intensity	1
Probabiilty of occurance (Vertical feature/fracture identified in PT 01 borehole log between 235 m and 250m)	3
Total	**6**
During the construction phase a **Low Negative Impact** is foreseen.	
Mitigation and management measures to minimize anticipated impact:	
Dewater during the construction phase Apply water in construction process, minimising the demand from more expensive sources Grouting side walls and steel lining section will prevent groundwater intrusion after construction	
After mitigation **no impact** is foreseen.	

8.2.8 Impact 8: Dewatering of tailrace, access and emergency tunnels during construction phase

No major fracture or shear zones were detected in boreholes TR 01 and TR 02. Therefore the likelihood that major water bearing structures that get intercepted by excavations, causing decant is very low.

However, small scale seepage into these underground workings may be expected due to the storativity of a thick weathered zone (10 m thick colluvial deposits and 20 m of highly weathered diorite) at PT 01 and a 25 m thick weathered zone at PT 02 which that may act as groundwater storage medium (upper weathered aquifer).

Due to possible seepage problems dewatering will be required in order to grout the sidewalls of the structures. This water may be used for construction purposes, should the water be of suitable quality.

A Low Negative Impact is foreseen, as a result of the likelihood of groundwater inflows into these structures, as well as the short duration of the impact.

Table 17: Rating of pre- and post remediation of dewatering of tailrace, access and emergency tunnels during construction

Criteria	Rating
Extent	1
Duration	1
Intensity	1
Probabiilty of occurance	2
Total	**5**
During the construction phase a **Low Negative Impact** is foreseen	
Mitigation and management measures to minimize anticipated impact: Dewater during the construction phase Apply water in construction process, minimising the demand from more expensive sources Grouting side walls will prevent long-term impacts after construction	
After mitigation **no impact** is foreseen.	

8.2.9 Impact 9: Poor groundwater quality associated with wastewater treatment

Since no detailed information was made available on the type and size of the wastewater treatment works, it is difficult to determine an impact. If poor quality water, impounded in the sewage ponds, evaporation dams, and recovery dams, enters the groundwater the significance of the impact on the groundwater will depend on the quality of the recharge water and the volumes involved.

Should the proposed sewage system not have sufficient capacity to handle the wastewater from the construction village and yard, the capacity will need to be increased, without allowing to overflow.

Utilising a correctly designed and constructed facility will reduce the significance of this threat.

The significance of the hazard being realised will be reduced due to the limited groundwater use and resources on site due to the aquifer properties of the rocks.

Little or no groundwater use or users are located within the study area and the very slow possible pollution plume migration indicates reduced impacts.

Based on these factors a Medium Negative impact is foreseen. Dilution from seepage and natural recharge, and natural attenuation will also contribute towards an improvement of the water quality.

After the implementation of the mitigation measures the magnitude of the low/medium negative impact gets reduced to a value of 7.

Table 18: Rating of pre- and post remediation of groundwater quality associated with waste water treatment

Criteria	Rating
Extent	1
Duration	3
Intensity	2
Probabiilty of occurance	2
Total	**8**
During the construction phase a **High Negative Impact** is foreseen	
Mitigation and management measures to minimize anticipated impact: Exclude soak-aways and wastewater irrigation as methods of disposal Assess underlying geological structures prior to positioning of all evaporation/maturation ponds, if any In case of wastewater works as treatment method, ensure correctly sized, designed and constructed facility Construct all waste water dams to minimise seepage, i.e. lined dams Design ponds (if any) in such a manner to ensure sufficient capacity and prevent overflow / spillage Install monitoring boreholes to monitor groundwater quality	
Criteria	**Rating**
Extent	1
Duration	3
Intensity	1
Probabiilty of occurance	2
Total	**7**

8.2.10 Impact 10: Poor groundwater quality associated with seepage from solid waste disposal facility

The significance of this threat will depend on the volume of poor quality water generated within the solid waste area and whether this water can leave site or recharge the groundwater.

The volume of leachate, is a direct function of the rainfall, waste site size, and whether the facility will get lined, a mitigation measure to preventing leachate from entering the aquifer (groundwater).

The significance of the hazard can therefore be reduced if the disposal facility gets position at a site with limited groundwater resources (non-aquifer system).

Based on the fact that no groundwater users are located within the study area, and the likelihood of biodegradation/attenuation will occur (medium negative impact). After mitigation measures were implemented, a low/medium negative impact is foreseen.

Table 19: Rating of pre- and post remediation of groundwater quality associated with waste disposal

Criteria	Rating
Extent	1
Duration	3
Intensity	3
Probabiilty of occurance	3
Total	**10**
During the construction phase a **Medium Negative Impact** is foreseen	
Mitigation and management measures to minimize anticipated impact: Area to be managed to prevent ponding of poor quality water Install a drainage system below the disposal facility Poor quality water to be diverted to lined recovery dams Line waste disposal facilty to prevent leachate from entering the groundwater Dispose of solid waste at an alternative licensed disposal facility Install groundwater monitoring boreholes to monitor groundwater quality down-gradient of disposal facility Prevent further groundwater use untill after remediation period	
Criteria	**Rating**
Extent	1
Duration	3
Intensity	1
Probabiilty of occurance	2
Total	**7**
After mitigation a **Low/Medium Negative Impact** is foreseen	

8.2.11 Impact 11: Poor groundwater quality associated with spillages (seepage) at proposed fuel/oil storage facilities.

The significance of this threat, if realised, is high should poor quality water migrate off site and impact on down gradient groundwater users. The likelihood of such an impact depends on the volume of fuel to be stored, design of the storage facility (provision for bunded areas), and clean-up and protocols to be implemented. The rating was based on the assumption that fuel generators will only be on site during the construction phase. Should buck-up generators (fuel storage) also apply to the operational phase, the negative risk will increase.

A medium negative impact is foreseen before the implementation of the mitigation measures, based on the likelihood that a proper fuel storage area will be designed, clean-up and protocols (including rapid response) will be adhered to as outlined in the management plan and that no groundwater users are located within the study area, and the very slow possible pollution plume migration indicates reduced impacts

Table 20: Rating of pre- and post remediation of groundwater quality associated with fuel spillages

Criteria	Rating
Extent	1
Duration	2
Intensity	3
Probabiilty of occurance	3
Total	**9**
During the construction phase a **Medium Negative Impact** is foreseen	
Mitigation and management measures to minimize anticipated impact: Contain oil and fuel in bunded areas Ensure clean-up protocols are in place and followed when required Install oil traps and separators Keep accurate oil/fuel records (purchased, disposal, and recycled) Install monitoring boreholes to monitor groundwater quality Remediate spillages Prevent further groundwater use untill after remediation period	
Criteria	**Rating**
Extent	1
Duration (Only applicable to constructing phase)	1
Intensity	1
Probabiilty of occurance	1
Total	**4**
After mitigation a **Low Negative Impact** is foreseen	

8.2.12 Impact 12: Groundwater losses caused by decant and evaporation from borrow pit areas.

Two preliminary borrow pit areas have been identified where clay material could be excavated for core material in the dam walls:

- An area directly north of the lower reservoir dam wall position, that is currently under irrigation farming.
- An area directly south-east of the lower reservoir position.

It is strongly recommended from a groundwater point of view the northern site does not get used for an open-pit borrow area. The extent of seepage from the lower reservoir entering the open pit area will be much more excessive than that for the south-eastern site, based on the difference in hydraulic head between the rest water level in the reservoir and the ground level in the pit after excavations. Taking into consideration that the borrow area will be situated down gradient of the reservoir site will also exacerbate the seepage problem.

An open pit area directly north of the dam wall will also serve as a cut-off mechanism for baseflow to the northern reaches of the tributary the dam will be situated in.

Should the site south-east of the reservoir that has been identified for a borrow pit be excavated, the degree of seepage can be limited, preventing the excavation of clay material to a level below the static groundwater level. Should excavation exceed this level, groundwater decant will occur into the open pit workings. This volume of water will be exposed to evaporative losses that will have a medium negative impact. Should mitigation measures be adhered to, the anticipated negative impact will be of a low order magnitude.

Table 21: Rating of pre- and post remediation of groundwater losses due to borrow pit areas.

Criteria	Rating
Extent	1
Duration	3
Intensity	3
Probability of occurance	2
Total	**9**
Should excavations exceed the depth of the static groundwater level a **Medium Negative Impact** is foreseen	
Mitigation and management measures to minimize anticipated impact: Excavations to remain above static groundwater level to prevent evaporative losses as a result of groundwater decant	
Extent	1
Duration	3
Intensity	1
Probability of occurance	1
Total	**6**
Should excavations not exceed the depth of the static groundwater level a **Low Negative Impact** is foreseen	

9 CONCLUSIONS

- The study area is underlain by formations of the Bushveld Igneous Complex.
- The regional hydrogeology can be classified as a minor aquifer system that comprises the following units:
  - A weathered zone aquifer, with the groundwater table typically at the contact between the weathered zone and the fractured rock aquifer.
  - A deeper lying fractured rock aquifer, that reaches up to the solid base rock.
  - Several dyke-like intrusions of late Karroo age that have been mapped along WNW to NNW strikes over the plateau area, which caused metamorphosis of the host rock at the contact zones, increased permeability, and containing fractures acting as preferential flow paths for groundwater.
- Geotechnical studies undertaken and rock samples that were analysed only provided information with regard to the likelihood of geological features, not their likelihood of being bearing water.
- A north-east and north-west striking fault converge over the study area. These geological structures can enhance the groundwater potential in the area by increasing the permeability and transmissivity of the host rock. Secondary processes, such as faulting and fracturing, can create secondary fractured rock aquifers. Should these structures be water bearing, short term groundwater related impacts are foreseen during the construction phase of the tunnel, as dewatering will be required.
- Static groundwater levels measured in piezometers at the lower reservoir site, indicated highly weathered zones with possibly enhanced aquifer parameters, as measured in boreholes LR 2, LR3 and LR 8. Aquifer recharge may be enhanced as a result of secondary processes (weathered zones) intersecting in these borehole sites.

- The degree of fluctuation in the groundwater levels along the right flank boreholes at the lower reservoir site (LR 06, LR 05, LR 04, and LR 03) relates to the weathering depth of diorite, as the water table occurs at the contact between the weathered and unweathered rock. The same can be concluded with regard to the difference and degree of fluctuations in static water levels of LR 2 and LR 7, situated within close proximity to one another.
- Artificial aquifer recharge that may result from seepage will improve the sustainability of groundwater, which is currently classified as poor based on their poor aquifer parameters. Seepage below and around the dam wall grouting curtain will allow for base flow to the tributaries downgradient of the lower reservoirs site. This will assist in complying with the catchments ecological reserve requirements.
- Dewatering in order to enable construction of certain components of the underground pumped storage facilities is only seen as a temporary negative impact, which will cease during the operational phase.
- Static groundwater levels in the boreholes at the upper reservoir site, remained constant within boreholes. This indicates limited recharge and transmissivity and kunductivity associated with weathering zones/fractures.
- Intercepting water bearing fractures during the construction phase of the pumped storage facility is considered as a short term negative impact. Grouting of these structures will prevent long-term impacts. There are no groundwater use in the expected zone of influence, that will be caused by dewatering.
- Unless prevented, seepage from pollution sources (fuel, sewage and waste) is considered the only long term negative impact. However, it needs to be established what closure requirements will be for the dams, if no longer used for power generation.
- Little or no groundwater use occurs within the area, however, persistent contamination by proposed waste- and fuel storage- as well as wastewater treatment facilities may have an impact on future groundwater users with time.
- Excavating borrow pits must extend below the static groundwater level in the study area to prevent dewatering and groundwater losses through decant and subsequent evapotranspiration.
- The correct site selection, construction and management of the infrastructure will ensure that the overall risk to the groundwater resources is tolerable.

10 RECOMMENDATIONS

- Boreholes located within the proposed reservoir sites need to be backfilled with a mixture of bentonite and cement, tremmed and filled from the bottom in order to prevent excessive seepage losses.
- In order to determine the likelihood of intercepting a major fracture when excavating the pressure tunnel, it is proposed a 165 mm diameter borehole is drilled to 250 m depth and a 24 hour constant rate pump test is conducted at the proposed site. This will provide information with regard to a possible influx rate of groundwater into the tunnel during construction, including aquifer parameters.
- Monitoring boreholes are to be drilled and constructed around the site. The groundwater monitoring points are to include a shallow (± 10 m) and a deep (± 30 m) pair of monitoring boreholes. The pair of monitoring boreholes are to be designed and constructed to allow sampling of the shallow weathered aquifer and the deeper fractured rock aquifers. The monitoring boreholes are to be located adjacent to the potential contaminant sources and approximately 30 to 50 m down gradient of the identified sources.
- Groundwater water levels and hydrochemistry are to be monitored on a quarterly basis. Parameters to be tested for, and compliance objectives to be adhered to, should be according to the reserve quality objectives as outlined under heading 6.6 of this report.
- All risk reduction recommendations must be considered during the planning of the new pumped storage scheme.

11 REFERENCES

BARNARD, H. C. (2000). An Explanation of the 1 : 500 000 Hydrogeological map, Johannesburg 2526. DWAF.

BKS (PTY) LTD (2006). Project Lima Supplementary Feasibility study. Phase 1: Site Selection Study.

BKS (PTY) LTD (2006). Project Lima Supplementary Supplementary study. Phase 2: Feasibility Study Report on Geotechnical Investigations draft report.

BKS (PTY) LTD (2007). Steelpoort Pumped Storage Scheme, Phase 2: Hydrology Report.

CAMPBELL G., JOHNSON S., (2006). Interpretation of high resolution aeromagnetic survey data over the project Lima area, Steelpoort pumped storage scheme, Roossenekal Locality, Mpumalanga Province, on behalf of, BKS (Pty) Ltd, Engineering Management.

DU PLESISSIS A. (2006). Lima Project: Seismic Resistivity Survey. Global Geophysics.

GEOLOGICAL SURVEY (1993). *1:500 000 Geological series 2528 Johannesburg geological map.*

GOLDER ASSOCIATES (2007). Hydraulic Fracturing Stress Measurements at Steelpoort Pumped Storage Scheme, South Africa.

HOBBS, P.J., (2005) Determination of the ecological water requirements for the Dwars River in quaternary catchment B41G groundwater component. CSIR, ENV-S-C 2005-060

ODENDAAL C.L., (1983). Kroondal – Marikana ondergrondese water beheergebied, Technical Report GH. 3263, Directorate Geohydrology, DWAF.

THE GROUNDWATER HARVEST POTENTIAL OF THE REPUBLIC OF SOUTH AFRICA *(1996).* Department of Water Affaires and Forestry, South Africa.

THE NATIONAL GROUNDWATER DATABASE (2007). Department of Water Affairs and Forestry, Pretoria