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

Our Ref: BOH.06.121 G

Your Ref:

63 Wessel Road Woodmead
PO Box 2597 Rivonia 2128
South Africa
Tel: +27 (0)11 803 5726
Fax: +27 (0)11 803 5745

21 September 2006

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

Attention: Mr. Greg Seymour

HYDROGEOLOGICAL SCREENING REPORT
FOR THE PROPOSED ESKOM PUMPED STORAGE PROJECT
PROJECT LIMA

Herewith please find the hydrogeological investigation pertaining to the environmental screening for the above-mentioned project in the Steelpoort area, Limpopo Province.

Yours faithfully

Johannes van der Walt
Geohydrologist

Mark Stewart
Senior Hydrogeologist

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HYDROGEOLOGICAL SCREENING REPORT THE PROPOSED ESKOM PUMPED STORAGE SCHEME PROJECT LIMA

HYDROGEOLOGICAL SCREENING STUDY

PROJECT LIMA

REPORT NO: BOH.06.121 G

Client: Bohlweki Environmental (Pty) Ltd
PO Box 11784
Vorna Valley
MIDRAND
1686

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By

GCS (PTY) LTD
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EXECUTIVE SUMMARY

ESKOM 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 and store hydroelectric power.

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.). Each one of these three candidate sites lends itself to on-channel and off-channel options. From these the most indicative/meaningful were selected, quantified, and organised into ten main site options.

Although option A3 were preliminary selected as a preferred option (Option A3 is at the same site as the current scheme, but with off-channel upper and lower reservoirs), the other options were assessed from a groundwater perspective. The purpose of this report is specifically to evaluate all the site options against this variable.

No field visits or groundwater quality sampling was conducted; therefore, no site-specific background data was obtained for the study area. All hydrogeological data was based on preliminary literature review and desktop analyses for the purposes of the Screening Study. The "*Project Lima Supplementary Feasibility Study- Phase 1 Site Selection Study Main Report Volume 1"* conducted by BKS Palace Consortium during May 2006, was consulted for the purposes of this study. In addition thereto, the Geohydrological unit for Department of Water Affairs and Forestry (DWAF) in Pretoria were contacted for providing geohydrological data pertaining to the three main sites.

This report only covers potential impacts that this proposed development may have on groundwater resources, for which the following can be concluded: -

- Site C is located on the most complex geology, which has resulted in enhanced groundwater potential
- Groundwater, associated with geological structures, intercepted during construction will result in groundwater ingress into the workings. Dewatering will be required which will impact on groundwater uses and resources on the sites.
- All three sites have incidents of shallow groundwater, thus no one site is more vulnerable than the next.

- Site C has high yielding aquifers and enhance groundwater potential, due to underlying geological structures, and is thus recognised to be of more value than the lower yielding aquifers on sites A and B.
- No preferential site can be selected based on the available hydrochemical data.
- Site A is the preferred site when compared to sites B and C, based on geological stability, groundwater / aquifer development, and potential dewatering impacts.

In summary, the preliminary groundwater assessment of the three candidate sites indicates that site A or B could be considered for evaluation in the EIA process, from a groundwater perspective.

1 INTRODUCTION

ESKOM 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, which can be used during periods of peak demand.

Three candidate sites (labelled 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.)[1]. Each one of these three sites lends itself to on-channel and of-channel options. Each candidate site has several dam site options.

Although option A3 has been preliminary selected as a preferred option (Option A3 is at the same site as the current scheme, but with off-channel upper and lower reservoirs), the other dam options were still taken into consideration from a groundwater perspective. The purpose of this report is specifically to evaluate all the options against this variable.

No site-specific data was compiled during this screening study. All hydrogeological data was based on available data from various sources including maps, reports, and databases. The report, entitled "*Project Lima Supplementary Feasibility Study- Phase 1 Site Selection Study Main Report Volume 1",* compiled by BKS Palace Consortium (May 2006) provided geological data for the purposes of this study. In addition, the Geohydrological unit for Department of Water Affairs and Forestry (DWAF) in Pretoria were contacted for providing geohydrological data pertaining to the three main sites.

This report only covers potential impacts that this development may have on groundwater resources.

1.1 Study Area

All three sites are located within the Limpopo Province. Site C is located on the 1:50 000 topographical sheet 2429DD, and Sites A and B are located on the topographical sheet 2529BB. All of the sites are located on the eastern escarpment of the Nebo, to the west of the Steelpoort River.

The high-lying Nebo Plateau to the west of the Steelpoort Valley comprises gently undulating terrain at elevations of ± 1700 mamsl at site A in the south, rising to 1900 mamsl at Site B in the middle and descending again to ± 1500 mamsl at Site C.

[1] The report "*Project Lima Supplementary Feasibility Study- Phase 1 Site Selection Study Main Report Volume 1" BKS Palace Consortium (May 2006)* contains all relevant data and figures.

All three candidate sites are located in the vicinity of the proposed De Hoop Dam on the Steelpoort River.

The major river in the B4 sub-drainage region is the Steelpoort River and its smaller tributaries. The Steelpoort River forms the western border of the region. The Spekboom River drains the eastern part of the region and has its origin near the town of Lydenburg, and flows into the Steelpoort River near the end of the region. The Dwars River drains the area between the Steelpoort and Spekboom River.

1.2 Regional Geology

Geologically the formations within the study area belong to the Bushveld Igneous Complex and comprise felsic rocks of the Rashoop Granophyre Suite overlying the mafic rocks of the upper and main zones of the Rustenburg Layered Suite.

The high lying plateau areas comprise granophyre (competent alkali feldspar and quartz rocks) in the south and a mix of granite and granophyre in the north. These felsic rocks are several hundred meters thick and form scarp slopes.

At the base of the felsic rocks is a leptite formation, ± 250 m thick, which dips at approximately 10º to the west.

The leptite formation is underlain by diorite beneath the pediment slope. The diorite grades into an olivine-bearing diorite and gabbro beneath the valley floor. These mafic rocks underlying the leptite formation contain bands of anorthosite and magnetite. These horizons also dip at around 10º to the west.

All of the rocks discussed above have been intruded by dolerite and lamprophyre dykes, which generally trend northeast (roughly parallel to the Steelpoort fault) and west of northwest (roughly perpendicular to the fault).

1.3 Hydrogeology

Three (3) groundwater-related maps have hydrogeological data pertaining to the area. The data is based on regional studies and gives an indication of the regional groundwater regime.

The maps include: -

- The Groundwater Resources of the Republic of South Africa map series, scale 1: 2 500 000
- The Groundwater Harvest Potential of the Republic of South Africa Map, scale 1: 3 000 000
- The Hydrogeological Series Map – Nylstroom 2428, scale 1: 250 000

Much of the data is duplicated on the maps, however, the main hydrogeological points are: -

- Geologically the formations underlain by the study area belong to the Bushveld Igneous Complex and comprise felsic rocks of the Rashoop Granophyre Suite overlying the mafic rocks of the upper and main zones of the Rustenburg Layered Suite. The high plateau is underlain by granophyre in the south of the area by mixed granite and granophyre in the north.
- The aquifer type is intergranular (i.e. weathered) and fractured.
- Groundwater occurs typically in faults and shear zones.
- The average borehole yields are recognised as between 0.8 and 1.5 l/s although optimally sited boreholes can yield in excess of the average.
- The probability of drilling a borehole with a yield > 2 l/s is 30 - 40%.
- The probability of drilling a successful borehole (yield > 0.1 l/s) is < 60% (based on randomly sited as well as scientifically sited boreholes).
- The mean annual recharge is between 27-37 mm per annum.
- The contribution of groundwater to the base flow of streams and rivers in the area is considered negligible.
- The average depth to groundwater is between 10 and 20 m.
- The storage coefficient is < 0.001 with fractures restricted principally to a zone directly below the groundwater level.
- The recommended drilling depth below groundwater level is < 20 m.
- The Geometric Mean Concentration of the Total Dissolved Solids is between 500-750 mg/l
- Two hydrochemical water types exist within the study area:
    - That with Ca^{2+} and Mg^{2+} as dominant cations and HCO_3^- as dominant anion.
    - That with Na+ and K+ as dominant cations and SO42- as dominant anion.
- The harvest potential[2] for the Steelpoort area is seen to be between 10 000 and 15 000 m^3/km^2/annum.
- The factor restricting the harvest potential in this area is the limited effective storage. Recharge occurs regularly most years but cannot all be absorbed into the aquifer because of low storage. The limiting factor is how much groundwater can be storing the wet season to bridge abstraction during the drier season.

[2] The harvest potential is defined as "the maximum volume of groundwater that may annually be abstracted per surface area of an aquifer system to preserve a sustained abstraction".

Isolated alluvial aquifers are recognised to form in association with Steelpoort River. The regional mapping and data sources do not indicate any alluvial aquifers on any of the three candidate sites. These aquifers, if present, will be assessed during the EIA phase of work, i.e. when site-specific data is compiled.

2 DWAF – GEOHYDROLOGICAL DATA BASE

The Geohydrological division at the Department of Water Affairs and Forestry was requested to provide borehole locations, measured yields, drilled depths, and chemistry data for any existing boreholes from their data base within the proposed study area (reference block coordinates S: 24° 55’ - 25° 08 ‘ and E: 29° 45’ - 30° 00’)

This data provided additional information for use in the geohydrological screening study.

Although all the available borehole information within the provided grid coordinates were provided by DWAF, only the applicable farms on which the three actual options (Site A, B, and C) are located, were considered.

2.1 Static Water Levels

Static water levels for all boreholes within the two quarter-degree grids, within site C in 2429DD, and Sites A and B in 2529BB, were provided by DWAF. The information provided was with the exception of the farm names or coordinates and consequently no unnecessary information, not being applicable to the three sites, could be discarded.

In the instance of quarter-degree grid 2429DD, 550 static water level measurements from 33 boreholes were provided. The shallowest recorded static water level was 2.46 meters below ground level (mbgl), the deepest recorded static water level was 72.82 meters below ground level (mbgl), and the average was 30.93 mbgl. Please note that this represents measurements taken throughout the year during which time static water levels normally greatly vary. It is normally shallower during the raining season when groundwater recharge occurs and deeper during the dry season when no aquifer recharge occurs.

In the instance of quarter-degree grid 2529BB, 35 static water level measurements for 31 boreholes were provided. The shallowest recorded static water level was 1.59 meters below ground level (mbgl), the deepest recorded static water level was 91.44 meters below ground level (mbgl), and the average was 20.17 mbgl.

The wide variation in water levels is due to: -

- Large topographical differences in the study areas
- No distinction between static and dynamic water level records
- Seasonal variation
- Piezometeric differences associated with different aquifers

Areas of shallow groundwater levels, typically located in the valley, within the alluvial and weathered (shallow) aquifers are more vulnerable to surface contamination. All three sites have incidents of shallow groundwater, thus no one site is more vulnerable than the next.

2.2 Yields

In the instance of quarter-degree grid 2429DD, 221 yield values from 25 boreholes were provided. The lowest recorded yield was 0.2 l/s, the highest yield was 41.20 l/s and the average was 16.27 l/s.

The enhanced groundwater potential may be as a result of secondary processes, such as faulting (the Steelpoort Fault).

In the instance of quarter-degree grid 2529BB, 37 yield values from 35 boreholes were provided. The lowest recorded yield was 0.01 l/s, the highest yield was 19.81 l/s and the average was 1.58 l/s.

Site C has enhance groundwater potential, due to underlying geological structures, these resultant high yielding aquifers have the potential to be utilised in the future and are thus recognised to be of more value than the lower yielding boreholes on sites A and B.

2.3 Groundwater Chemistry

Although all the available borehole chemistry results within the requested grid coordinates were provided by DWAF, only the applicable farms covering the three actual sites (Sites A, B, and C) were investigated. Data covering farms that would not be affected by the 10 preliminary options for Sites A-C were discarded. Unfortunately, DWAF were also not able to provide borehole chemistry results for boreholes within Site A.

As is outlined in Table 1 (Site B), only the arsenic concentrations for the two Syferfontein monitoring boreholes exceed the SABS 241 acceptable water quality range value. However, according to the South African water Quality Guidelines for Domestic Use (Second Edition, 1996) this concentration is still considered tolerable with only a low risk of skin cancer in highly sensitive individuals over a long time.

As is outlined in Table 2 (Site C), the arsenic concentration for the two Eenzaam monitoring boreholes exceeds the SABS 241 acceptable water quality range value. The same criteria apply to that concentration as mentioned-above.

The nitrate (NO_3) and nitrite (NO_2), as N concentrations, at Uitvlugt and Eenzaam exceeded the SABS 241 acceptable water quality range value. According to the South African water Quality Guidelines for Domestic Use (Second Edition, 1996) at this concentration Methaemoglobinaemia may occur in infants (upon absorption, nitrite combines with the oxygen-carrying red blood pigment, haemoglobin, to form methaemoglobin, which is incapable of carrying oxygen). No effects in adults are foreseen.

Table 1: Site B chemistry data

Determinant	SABS 241 Acceptable Water Quality Standard (mg/l)	Syferfontein (H06-1937)	Syferfontein (H06-2146)
Al	0.15-0.3	0.05	0.055
As	0.010-0.050	0.0835	0.064
B		0.006	0.006
Ba		0.004	0.007
Ca	80-150	12.118	3.647
Cd	0.003-0.005	0.0045	0.004
Cl	100-200	5.316	5
Cr	0.050-0.100	0.003	0.003
Cu	0.5-1.0	0.006	0.006
DMS		87.767	51.255
EC (mS/m)	70-150	12.765	7.09
F	0.7-1.0	0.4495	0.249
Fe	0.010-0.2	0.0045	0.003
K	25-50	1.979	2.269
Mg	30-70	2.1595	0.5
Mn	0.050-0.100	0.001	0.001
Mo		0.011	0.006
NH_4 as N	0.2-1.0	0.02	0.02
NO_3+NO_2 as N	6.0-10.0	2.413	1.531
Na	100-200	7.424	5.995
Ni	0.050-0.150	0.0105	0.008
PO_4 as P		0.023	0.014
Pb	0.010-0.050	0.045	0.036
SO_4	200-400	2	2
Si		16.8065	16.311
Sr		0.0305	0.016
TAL		37.353	20.298
V	0.1-0.2	0.006	0.004
Zn	3.0-5.0	0.0505	0.509
pH		7.022	6.804

Table 2: Site C chemistry data

Determinant	SABS 241 Acceptable Water Quality Standard (mg/l)	Eenzaam	Uitvlugt	Eenzaam (H06-1779)	De Hoop
Al	0.15-0.3			0.091	0.01
As	0.010-0.050			0.064	
B				0.013	
Ba				0.007	
Ca	80-150	19.8	18.8	27.392	80.6
Cd	0.003-0.005			0.005	
Cl	100-200	4.5	27.2	10.88	35.3
Cr	0.050-0.100			0.008	0.002
Cu	0.5-1.0			0.022	
DMS		334	462	225.111	728
EC (mS/m)	70-150	38.5	60.5	30.1	90.1
F	0.7-1.0	0.46	0.33	0.542	0.15
Fe	0.010-0.2			0.014	0.002
K	25-50	6.61	1.26	3.375	0.15
Mg	30-70	10.2	38	2.705	52.9
Mn	0.050-0.100			0.006	0.001
Mo				0.019	
NH_4 as N	0.2-1.0	0.02	1.29	0.015	0.02
NO_3+NO_2 as N	6.0-10.0	0.302	11.36	10.107	3.699
Na	100-200	46.2	45.3	26.295	32.7
Ni	0.050-0.150			0.016	
PO_4 as P		0.058	0.043	0.012	0.007
Pb	0.010-0.050			0.063	
SO_4	200-400	2	13.1	3	32.3
Si		33.75	39.83	2.344	31.2
Sr				0.168	
TAL		197.5	218.2	87.04	391.6
V	0.1-0.2			0.011	0.045
Zn	3.0-5.0			0.3	
pH	5.0-9.5	8.03	8.36	8.014	8.26

Incidents of poor quality groundwater, due to geology and land use, was recorded on sites B and C. No hydrochemical data was available for site A.

Available groundwater chemistry indicates that treatment should be conducted on the groundwater prior to use for domestic purposes. The impact of artificial recharge from the proposed project could have a positive impact on the groundwater quality in the area.

No preferential site can be selected based on the available hydrochemical data.

2.4 Impact Assessment - Hydrogeological factors

The three possible sites (Site A, B, and C) which have been identified during the pre-feasibility study, are discussed for their significance from a hydrogeological point of view: -

- **Site A:**

  Possible seepage through the bedrock at the upper reservoir position for option 1 as a result of dolerite dykes (resulting in contact metamorphism and enhanced groundwater potential) makes this a less favourable option than the upper off-channel option which is not situated on such structures.

  Stripping of 0.5 m of overburden material at this preferred upper reservoir position also favours it more as more fill material will be available opposed to the in-stream option.

  From a groundwater point of view neither the off-stream nor the in-stream lower reservoir options will be more beneficial as no significant faults or shear zones occur within any of the two options that may influence groundwater recharge positively or negatively. Though the in-stream option may be more beneficial towards groundwater recharge during the drier months, as the impoundment is likely to contribute towards groundwater recharge and baseflow, as the water table will be situated lower than the dam. During the wetter months the opposite is likely to happen, the water table will be more elevated and likely to contribute flow towards the impoundment.

  Thus, either Option 3 or 4 is preferred.

- **Site B:**

  Options 5 and 6 are the least favourable options from a groundwater point of view, as the lower reservoir position is situated directly south-east of the Steelpoort Fault. The possibility, therefore, exists that faults or shear zones, associated and parallel to the main fault, may occur in the vicinity of the planned impoundments. This implies that grouting beneath the plinth of the rock fill embankment may be required in order to prevent large scale groundwater seepage losses.

  Constructing the tunnel line through the Steelpoort Fault and associated shear and fracture zones may result in groundwater inflows (and associated dewatering), which makes options B1 and B2 less favourable.

  Constructing the pressure tunnel, machine, and transformer halls for options 3, 5, and 7 may possibly intercept water bearing shear or fracture zones that may also result in increased groundwater ingress. This also applies specifically to the prominent lineation crossing the underground waterways for option 5, which should be avoided during the siting optimisation of the power station caverns and constructing the surge chamber.

The impact of the geological structures, which can act as preferential flow paths, can result in large inflows of groundwater into the workings and also the need for dewatering, which can impact on groundwater users and resources in the area.

This favours B4 and B8 as the two most favourable options.

The high incidence of geological structures and the location of the major Steelpoort Fault, in relation to site B, increase the probability that this project will impact on the groundwater resources in this area. These impacts can be both artificial recharge and dewatering.

- **Site C:**

Groundwater seepage through the trench at the lower reservoir overlying two limbs of the Steelpoort fault may be substantial.

Constructing the headrace tunnel, surge shaft, pressure shaft, and tunnel through potentially a number of northwest-trending fracture zones running parallel to the tunnel alignment may be troublesome if they are water bearing and high yields may be encountered.

The proximity of site C to the Steelpoort Fault (enhanced groundwater potential) and the proposed De Hoop Dam (isostacy) indicates that this site may impact more readily on the groundwater regime.

Site C is, from a hydrogeological perspective, the least favoured site.

3 CONCLUSIONS:

- Site C is located on the most complex geology, which has resulted in enhanced groundwater potential
- Groundwater, associated with geological structures, intercepted during construction will result in groundwater ingress into the workings. Dewatering will be required which will impact on groundwater uses and resources on the sites.
- All three sites have incidents of shallow groundwater, thus no one site is more vulnerable than the next.
- Site C has high yielding aquifers and enhance groundwater potential, due to underlying geological structures, and is thus recognised to be of more value than the lower yielding aquifers on sites A and B.
- No preferential site can be selected based on the available hydrochemical data.
- Site A is the preferred site when compared to sites B and C, based on geological stability, groundwater / aquifer development, and potential dewatering impacts.

- For Site A, options 3 or 4 are preferred to 1 or 2.
- For Site B, options B4 and B8 are the two most favourable options.
- The degree of faulting and shear zoning to be intercepted by construction activities at A3, A4, B4, and B8 will determine which of these four options are the least favoured.
- The Site C selection is from a geohydrological point of view the least favoured.

3.1 References

- BKS Palace Consortium. Project Lima Supplementary Feasibility Study Phase 1 Site Selection Study. Main Report Volume 1. May 2006.
- Howard, M.R., Teurlings, P., Maimane, M., (2006) Environmental Screening for Site Selection for Project Lima.
- South African Water Quality Guidelines for Domestic Use (Volume 1, Second Edition). Department of Water Affairs and Forestry, 1996.
- South African Bureau of Standards Specification for Dinking Water (Edition 5). SABS 241.