SISHEN MINE GROUNDWATER INVESTIGATION REPORT

NW – ZONE

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1 TERMS OF REFERENCE

The UNESCO Chair Centre for Geohydrology was appointed by the Department of Water Affairs and Forestry to evaluate a report by Golder Associates with title *Sishen Mine Groundwater Investigation Programme – NW Zone Report* (Report no 5157/6867/4/G) dated August 2005.

The main objectives of the evaluation are to assess:

- If acceptable methods were used to determine the location and extent of groundwater compartments and boundaries
- The components of groundwater flow altered by de-watering and the role played by these compartments and boundaries must be evaluated
- The possible altered groundwater systems response to recharge and abstraction with time.
- The possible influence on groundwater availability to other groundwater users and estimate type, mode and scale of influence.
- Critical data and information that might have been omitted by this report.
- Any aspects that the Golder Associates report omitted or did not address sufficiently.
- And suggest additional investigations and methods to be used to improve the findings of the Golder Associates report.
- Whether the Golder associates report addressed the concerns of the Gamagara Monitoring Group and other interested and affected parties.

1.1 Terms of Reference of Golder Associates report

In this context it is important to consider the Terms of Reference (TOR) of the Golder associates report. From the report the following TOR was extracted:

- Determine the extent of the dewatering cone of depression to the west, northwest and north of the Sishen Mine.
- Establish the groundwater levels in the area.
- As well as evaluate the locations of any geological features forming the boundaries of the impacted areas

1.2 Methodology

A desktop literature review of information available in the Sishen area was conducted prior to the site visit. The desktop study included:

- Golder Associates Phase III report
- Department of Water Affairs and Forestry's reports of area.
  - Reports on geophysical data in the area
  - Reports on recharge and its significance in the area.
  - Reports on pump test evaluations in the area.
- Groundwater and rainfall data of all the catchments.

The site visits included the farms to the southwest of Sishen mine as well as the mine itself. During the site visits interviews was conducted with the following individuals and groups:

- Land-owners to the south-west of mine
- Gawie van Dyk (Geohydrologist - DWAF)
- Ferdi Gousard (Sishen mine)
- J.Pretorius (Geotechnician for Golder Associates)

1.3 Literature Review

The Sishen aquifer is considered a fracture rock aquifer due to the information collected by Gilding (1979), and Willemink (1983). The Banded Iron Formation (Precambrain) consists mainly of thin layers of iron oxides which are either magnetite or hematite, alternating with bands of iron-poor shale and chert. Iron-ore is mined with open pit methods at Sishen mine where dewatering is taking place at depths in the excess of 350m below the earth's surface (Nel et al, 2002). This is done to maintain dry working conditions during the removal of the iron-ore.

According to Gilding (1979), the aquifer supplying water to Sishen mine consists of weathered dolomite with overlying Kalahari gravels. Gilding (1979) reported that the aquifer is unconfined, except in areas where the Kalahari formations contain low permeability clays a locally confined aquifer is formed. Willemink (1983) indicated that the Kalahari sediments are approximately 100-120m thick at the Dwyka Formation between Sishen and Kathu and that the basement formations are fractured to great depths. High yield can be expected on the contacts between formations (Willemink, 1981), with the weathered Ongeluk lava contact yielding 2l/s (Leskiewiecz, 1981).

Various investigations focused on the possible boundaries for Sishen mine. Dziembowski (1974) expressed his concerns on the impact of Sishen dewatering on Dibeng. Willemink (1981) concluded that the dwyka do not seem to be a groundwater boundary and that under natural conditions the Kathu dyke does not act as a groundwater boundary (Willemink, 1983).

According to the DWAF groundwater level data of the Sishen area, there is a significant decrease in groundwater levels over approximately the past 30 years. Willemink (1981) already reported 34m drop of borehole SW270 relative to pre-mining water levels. Recharge to the Sishen area is described as sporadic after high rainfall events and occurs in areas with bedrock outcrops and in river canals (Dziembowski, 1975; Willemink, 1983; Dziembowski, 1986).

2 Concerns by Water Users

Despite the fact that in 2006 there was exceptionally high rainfall the farmers who were situated towards the southwest (Ongeluk lava's overlain by thin Kalahari sediments), were still left with empty boreholes. These farmers are dependant on shallow groundwater found in the Kalahari layers, riverbed sediments and weathered lava. Water pools and reed beds were once found in the riverbed, but are dry now. The water levels in these farmer's boreholes are now 6,69m below the earth's surface in a borehole of 7m deep. These farmers reported that those boreholes once had a yield of 200 000 liters per hour. Due to the dewatering of the mine, the cone of depression has extended so far that the boreholes on private property are not productive anymore.

The farmers stressed their concerns about the fact that the mine is not considering the Ga-magara river in there investigation at all. They indicted their concerns about sinkhole like structures in the Ga-mogara River observed towards the south of the mine capturing the flow of the Ga-mogara River before it reaches them.

The farmers referred to the Golder Associates report (III) where it is indicated that the dewatering in the NW compartment is not as extensive as the S compartment, and that no private property has been influenced. According to the report the dewatering of property towards the southwest is not taking place because there is a dyke who is said to act as an impermeable barrier, and therefore no dewatering further than the dyke will occur.

The farmers asked questions related to pump test monitoring and evaluations. They indicated that no aquifer tests (or hydrocensus) were performed on their land and that according to their information the dyke that is supposed to act like a boundary has been weathered and does not fulfill this function.

3 Report Evaluation

3.1 Specific Comments

Section 1.2

Considering Figure 1 there is and area to the southwest of Sishen mine that is not covered by Phase II or III. This is the area where the farmers are observing impacts due to mine dewatering activities.

Section 3.2

One of the objectives of the remote sensing investigation is stated as the identification of features that could provide preferential flow paths for groundwater. There is no further comment regarding this in the rest of the report.

Section 3.5

The positions of the boreholes relative to the geophysics are not shown in the report. The edges of dykes are well known targets for higher yielding boreholes in many types of host rock. Dykes often form preferential pathways along the contact zone as well as a flow boundary across the dyke. It is therefore difficult to evaluate whether the borehole positions were sited correctly for the type of assessment performed.

Section 3.6

There are inconsistencies between Table 1 and the Drilling logs in Appendix 2. The drilling log for Gamagara 1 shows lava and shale – no limestone. Interesting to note here the high yielding Kalahari zones in the form of pebble beds.

Mention is made of perched water levels, no data is shown to prove these statements. The drilling logs do not show where the piezometers were constructed.

Section 3.7

In Section 3.7.2 data from a 12 hour aquifer test is used to confirm dewatering in the Dwyka tillite and make deductions of the impact of recharge. The method applied to do this assessment can be very usefull, but is not shown. The dewatering of the Dwyka is inconsistent with other statements in the report indicating that dewatering is not occurring. (I suspect definitions of words are used outside of context in this section and the definitions as used would benefit the reading).

Table 2 shows the static water levels for Ga-mogara 1 and 2. From the water levels and drilling logs it is clear that these boreholes do not intercept the same fracture horizons. It is not surprising that they do not influence each other.

Table 3 shows static water levels for the various boreholes tested and observed. For Sacha 1 there is a range of values between 26.06 and 36.40 mbgl. There is no mention of rainfall, so it can only be assumed that water levels were not static at the time of the start of the aquifer tests. This makes the use of standard analytical aquifer test methods useless. Statements of influence between boreholes now become questionable.

Section 4.1

Why is the discussion here limited to the boundaries of the NW compartment? This is not what the objectives set out to do.

The distances between the production borehole and the observation borehole could not be found in the report. From Figure 6 it seems to be quite large distances in general. If the maximum zone of influence is calculated from the average Transmissivity and Storage values obtained in the Golder Report, observation boreholes further than 300m will probably not show any drawdown after 72 hours. The duration of most of these tests therefore could not evaluate the influence of the dykes.

The water level contours and flow directions (Figure 7) do not correlate well with the discussion of the boundaries. The property of Kumba Resources is not shown on the maps. From these contours the impact of the mine dewatering is far more extensive than the NW compartment. It is therefore not possible to comment whether any private property is affected. Based on the field visit and making some assumptions on the property extent of Kumba, there is probably impact on property owners to the southwest and to the north (north of the Dwyka) of the mine (based on contours of Figure 7).

3.2 Discussion of Report

3.2.1 Groundwater Compartments

The distance between the production and monitoring boreholes seems unsuitable for the duration of the tests to evaluate possible boundaries. The Theis method can be used to elaborate on the statement (Kruseman and De Ridder; 1992):

$$r = \frac{\sqrt{2.25\,(T)\,t}}{S}$$

Where : r is maximum distance of influence from borehole

T is Transmissivity

t is time in days

S is Storativity

For example Ga-mogara 1 : T = 2.3m^{2}d and S = 0.003 over a duration of 3 days, the maximum distance of influence from borehole value would be 71.94m.

$$r = \frac{\sqrt{2.25(2.3)3}}{0.003} = 71.94m$$

These values do not correlate itself with Figure 6 of the phase III investigation report that shows the monitoring boreholes several kilometers apart from each other.

When determining aquifer properties in a dewatered fractured aquifer one should be very careful. If the borehole intercepts a fracture connected to the dewatering zone the water levels will be deep, with a reasonable yield. If the borehole does not intercept a fracture it will be low yielding with a shallow water level. Boreholes where the shallow fractures are dewatered (or boreholes not connected to fractures) would be low yielding and will not be further affected by a short aquifer test.

3.2.2 Groundwater Balance

The mine is dewatering the mine pit for mining and removing a large percentage of the water from the catchment. Comparing Golder III Figure 10 with the data from Dziembowski (1975) the dewatering of the mine changed the flow directions of the groundwater of the catchments. The dewatered zone also extend through the Ga-mogara riverbed and causes surface flow in the Ga-mogara River to be captured by the mine, creating massive recharge to the mine (Bredenkamp et al, 1995, Dziembowski 1975)and preventing recharge of the downstream aquifers.

Recharge and inflow is an essential part of the water balance in any aquifer. Users downstream of Sishen S compartment and west of the open pit the mine could be affected due the capturing of groundwater to down gradient users as well as capturing surface water flow to downstream users.

The water balance for a water user to the *west and southwest* can be written as:

$$S\Delta V = RE_{river} + RE_{precip} + I_{aquifer} - D_{river} - Q_{abstraction}$$

$S\Delta V$	-	Change is volume – related to water level
RE_{river}	-	Recharge of river runoff through the river bed.
RE_{precip}		Recharge through Precipitation (
$I_{aquifer}$		inflow component of the surrounding aquifer (driven by hydraulic head potential).
D_{river}	-	Discharge of the aquifer to the river
$Q_{abstraction}$	-	Abstraction of the groundwater.

The water balance would have changed from assumed natural conditions relative to observed current conditions (Table A).

Table A Comparison of natural and current water balance components for a user southwest of the mine.

	Natural	**Current**
RE_{river}	River drains surface and groundwater from the area	River is captured by mine and creates a source of water to the mine.
RE_{precip}	High recharge to outcrop areas. Limited recharge to thick unsaturated Kalahari layers.	Dewatering will reduce recharge of the surrounding aquifers as depth to water level plays a role. The open pit will increase recharge but this is not available to users
$I_{aquifer}$	Inflow from the dolomite aquifer would have reached the users	Inflow from the dolomite aquifer will be captured by the mine pit. Water level gradiants of all areas surrounding the mine towards the mine.
D_{river}	The aquifers seems discharge to the river under natural conditions.	No current contribution to the river west of mine.
$Q_{abstraction}$	Stock watering and household use	Dewatering of the Sishen mine
Change in water level	Probably no major changes	Large scale drop in water levels

3.2.3 Influence on Groundwater Users to the Southwest of the Mine

The groundwater availability of users to the southwest of the Sishen mine is limited due to the dewatering of the mine. Not only has the mine been abstracting most of the water, but also captures the possible channel recharge south of the mine.

If we consider the satellite imagery for the area southwest of Sishen mine (Figure A) we will notice several very prominent SW-NE striking lineaments.

Figure A Satellite image of possible groundwater flow lineaments in the area southwest of Sishen mine.

These lineaments might be groundwater barriers for flow across them under natural flow conditions in a northwest direction (Dziembowski et al., 1979) or like when an aquifer test is performed with observation holes on the other side. But when flow directions are changed due to the dewatering of the mine pit, these lineaments might become high transmissive conduits to flow due to flow along them instead of across them. The very flat water level contours (Figure 10) in this zone supports this possibility. Water users along these lineaments will be affected by the mine. The groundwater users in this area are mainly farm owners and terrestrial ecosystems.

Water levels to the north of the Dwyka show a change in gradient from natural conditions showing a northwest flow direction (Dziembowski et al., 1979) to a southern flow direction towards the mine. This is very possible considering the high yielding boreholes in this area and the banded iron stone aquifer extending below the Dwyka Formation (Figure 5). In figure B you can see a definite drop in water levels. The drop in water levels is the dewatering of the Kalahari sediments, and as soon as it reaches the dwyka it becomes constant it (Figure B, borehole D4N0634).

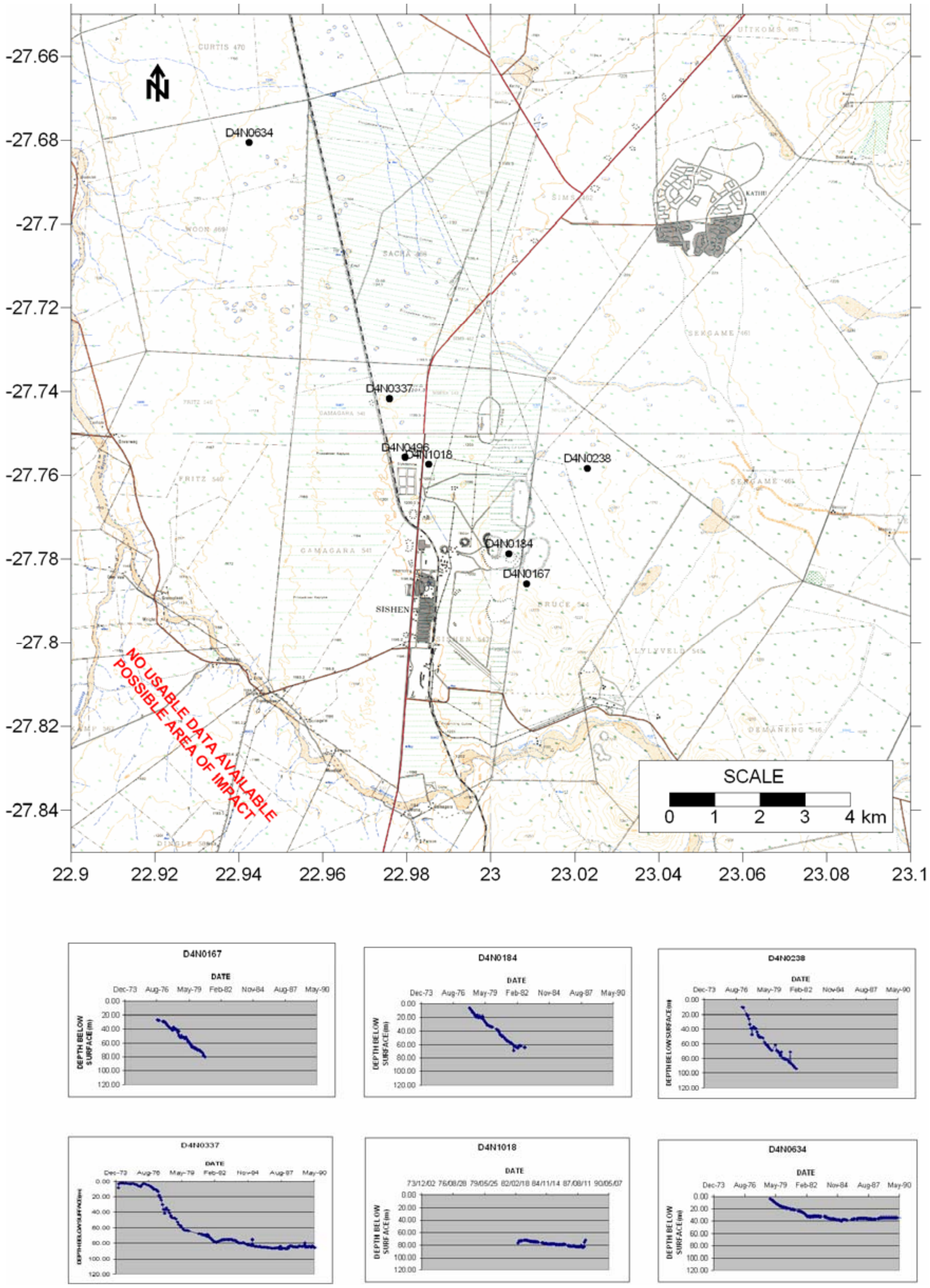

Figure B A map of the Sishen Area showing selected boreholes and their water level data.

3.2.4 Improvement of Results

The zone of impact of the mine is a different concept than the measurable water level cone of depression. The change in water levels due to the mine dewatering can affect aquifer components such as borehole yield, flow direction and recharge, affecting water availability to the user and ecosystems. An integrated approach is recommended and should included all social issues together with surface water and groundwater processes that may occur in the catchment.

From the borehole logs and the geological cross section data it seems that at least 3 aquifer systems is present at any single position. The Golder report mentions that the Kalahari water level data is removed from the contour and cross section data sets. Mention is made of perched water levels. Since these aquifers are locally important to users the separate monitoring of the 3 aquifers can provide valuable information.

Shapiro (2001) warns that fractured rock aquifers may yield ambiguous analysis when accumulating data. This is because the borehole imitates an abundantly permeably pathway, which now unlike other times connects the fractures. In this case the water will flow from the fractures to the borehole because water flows from high to low concentrations.

4 Conclusion

The tests conducted in the Golder III report to evaluate the geological boundaries were inconclusive due to recovering water levels, short test times and long distances between production and observation boreholes. The literature review indicated that most of the dykes as well as the dwyka are not boundaries to groundwater flow under natural conditions, or current flow conditions. Water level data confirms that there is a definite decrease in water levels north of the dwyka. Unfortunately no usable data is available towards the southwest to prove or disprove the impact of the mine.

The Golder III report partly defined the extent of dewatering. Considering the geological cross sections, lineaments and water level contours we conclude that the cone of depression extends outside the property of Kumba Resources towards the southwest and the north of the mine.

The water balance for each of the groundwater users should be evaluated considering that the mine pit captures the flow of the Ga-mogara River as well as the capturing of the natural groundwater flow in a northwest direction.

5 References

Kruseman, G.P. and De Ridder, N. A., 1992. *Analysis and Evaluation of Pumping Test Data.* Second Edition. ILRI Publication 47. International Institute for Land Reclamation and Improvement. Wageningen, The Netherlands.

J.Willemink;1983, *Ondersoek na ontginbare Grondwaterpotensiaal in die Kathugebied, Distrik Kuruman*. Unpublished internal report, Directorate Geohydrology – GH 3257, Pretoria

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Nel.JM, Van Dyk, and Van Wyk, 2002; *Impact of Mine Dewatering on Groundwater Resources and Ecosystems Near Sishen Iron Ore Mine, South Africa,* IAH conference, Darwin Australia.

Hogan J.H., Phillips F.M., and Scanlon B.R., 2004. *Groundwater Recharge in a Desert A Environment, The Southwestern United States,* Water Science and Application 9. Library of Congress Cataloging-in-Publication Data. Washington DC.

Bredenkamp D.B., Botha L.J., Van Tonder G.J., and Van Rensberg H.J., 1995. *Manual on Quantitative Estimation of groundwater Recharge and Aquifer Storativity.* Water Research Commission Report TT73/95. WRC , Pretoria

Dziembowski Z.M., 1978. *Water From Sishen Mine as a Temperary source of supply.* Unpublished internal report, Directorate Geohydrology – GH 2998, Pretoria.

Shapiro A. M., 2001, *Characterizing Ground-Water Chemistry and Hydraulic Properties of Fractured Rock Aquifers Using the Multifunction Bedrock Aquifer Transportable Testing Tool (BAT^3)*: U.S. Geological Survey Fact Sheet FS-075-01, 4 p. http://toxics.usgs.gov/pubs/FS-075-01/