A critical review on previous geohydrological studies at Sishen Iron Ore Mine.

Date: 2013/07/20
Report No.: 05/2013/PDV
EXECUTIVE SUMMARY

During 2012 Mine Water Consultants (MWC) were tasked by the Mine Manager of Sishen Iron Ore Mine to review all groundwater reports, supplied to us, produced for the mine by every consultant hired, as well as report produced by the department of water affairs, and to produce a condensed and unified answer regarding the groundwater issues with the farmers and to advise on scientific studies/investigations that still needs to be done.

The mine was visited on a number of occasions, and discussions were held with relevant mine personnel as well as farmers in the area which claims their groundwater has been affected by the dewatering activities of the mine. Field trips were undertaken to these farms, as well as to areas of concern in the Gamagara riverbed. Discussions were also held with the consulting companies responsible for some of the reports, as well as with some of the most well-known geohydrological experts in the country.

All relevant reports were read, and data of all the boreholes in the area was consolidated in a single project file, using the geohydrological program WISH, in order to set up a conceptual model of the groundwater and geology in the area of and around the mine. The consolidation of the data was a very ambitious task that took a few months to complete, but which enable us (and the mine personnel in the future) to interpret the data easier and to see early warning signs regarding water level and water chemistry changes.

MWC does not claim that it has read all geohydrological reports for the Sishen area; it has merely read all the reports passed on to us. It is therefore possible that some of the suggestions made in this report may have been addressed in a report that is not part of the reviewed reports studied. A list of reviewed reports can be found in the reference list. All the conclusions reached in this report are based on the available data in the reports studied, as well as data provided to MWC by Sishen Iron Ore Mine personnel to create a conceptual model.

Dewatering cone:

One of the most debated issues regarding groundwater at Sishen Iron Mine is the dewatering of the aquifers and the extent of the dewatering cone. MWC fully agree with the extent of Meyer’s dewatering cone as portrayed in his conceptual model report. However, we are of the opinion that a more detailed geophysical study be done to get more detail regarding dykes and faults. This may clear any uncertainty that occurs for certain parties and individuals and can help with interpretations – see discussion later in the report. A slightly larger area in the North-Western corner of the dewatering cone is the only difference in the author’s interpretation compared to Meyer’s dewatering cone.
A Dwyka glacial valley is present to the north of the dewatering cone. Some of the farmers suggested that dewatering will take place along this valley resulting in lower ground water yields for some of the farms to the west of the mine. A few investigations were done with the “Groundwater Flow” software. Three deep boreholes at the farm Wiscanton indicate flow away from the mine; however, the construction of these boreholes is unknown. At the farm Lanham a triangle of boreholes into the Dwyka is also available and gives identical flow direction as on Wincanton. This implicates that dewatering along the paleo-channel does not occur; no reverse gradient exists. A triangle of well-constructed boreholes to the north of the mine, drilled into the Dwyka, can confirm or refute this statement.

West of the mine and the Gamagara River the general complaint is that the yield of the boreholes deteriorates, despite the fact that the water levels remain relatively constant, or even rise in some places. With thin Kalahari layers in the area, recharge into the deeper lavas will be very little during seasons with below normal or normal rainfall. The recharge pulse, created when rainfall is absorbed by the ground, will only reaches and recharges the aquifer if the pulse is big enough; this is called episodic recharge. After a lot of thought and consulting with a number of the top hydrogeologists in the country, we are still in the dark why this phenomenon occurs. According to existing reports the recharge in this area is very low.

Gamagara River

All reports agree that due to the absence of major rainfall events in recent times and the absence of corresponding flow data in the river, it is not possible to state whether recent rainfall events caused, or should have caused flooding in the river or not, compared to historical floods in the Gamagara River. It will be interesting to see what happens when such a flood occurs (this should be sometime in the near future if the flood cycle is going to repeat itself). Only then any scientific conclusions can be made regarding the permanent loss of water in the aquifers, as currently stated by the river farmers, and if water levels (and the yield of the boreholes) return back to normal as was the case after the 1974 floods.

Only time will tell if a major flood will result in a rise of the Gamagara aquifer’s water level throughout the whole aquifer as there is some contention that not all the storage in the alluvial aquifer can be recharged during a flow event over the full profile depth because infiltration rates decrease rapidly shortly after surface ponding, or flooding.

Individual farms:

1. Murray 570:

According to the limited historical data available, the water levels are currently at the same level as the pre-1974 floods (as is the case on other farms in the area e.g. on the farm Bredenkamp,
illustrated in the report by Meyer 2010e). This raises the same question as mentioned in the regional part of the report:

- The farms on the lavas all indicate a decrease in yield.
- Is the aquifer being depleted due to lower recharge? The 1974 episodic recharge filled the aquifers. Do we know what the recharge was into the aquifer since 1974?
- Is the high alkalinity in the water responsible for the closure of water-bearing fractures and other structures?

Due to all the above, the distance of the farm from the mine, and the current information that indicates that the farm lies outside the dewatering cone, and also the fact that the geological structures discontinue, with the information available to us there is no evidence that the mine can be held responsible for the decrease in yield.

2. Smythe 566

Unfortunately no water level recordings of the boreholes exist between 1970 and 2000 on the farm. However, some data is available from other farms close to Smythe, which indicates that the water levels in the area are currently at the same level as the pre-1974 floods (as is the case on other farms in the area e.g. on the farm Bredenkamp, Cox, Crossley, Gamaliets), illustrated in the report by Meyer 2010c).

We have to agree with the report by Meyer (2012) that more water was held in storage after the high recharge period of 1974-1976 and due to the high extraction and lower recharge during later years, the aquifer may have been depleted. Due to all the above, the distance of the farm from the mine, and the current information that indicates that the farm lies outside the dewatering cone, and also the fact that the geological structures discontinue, with the available data no evidence can be found that the mine is to blame any decrease in yield. However, there is a definite drop in yield, and also a drop of a few meters in water levels in all the boreholes since 2002 when water levels were recorded again (Figure 23); the reason for this is still not understood.

3. Beaumont 569

A short pumping test was performed on borehole BM01, which indicated a transmissivity of 0.8 m²/d. Despite this the water level recovery indicates that the static water level trend remains sideways. This again indicates that the transmissivities changed. Only the investigation suggested in the report will indicate the reason for this; is this a recharge (and thus an over-exploitation) problem as conditions has changed in the last few years or is it a dewatering problem? No geological structures are visible on the existing maps, which exclude dewatering from the mine as a cause of the yield decrease (at such a distance from the mine). The continuous lowering of the water table, by pumping, below the fractures will definitely result in calcification (or bio-fouling) of the fractures.
4. **Gappepin 670**

According to the water level time data there was an increase in water levels after the 1974-1976 high rainfall period, but there is a definite drop since then (it was only monitored again since 2010. Available data indicates that there is a drop in water levels of some of the boreholes along this dyke since 1978 when monitoring started. However, the boreholes monitored since 2004 have a sideways water level measurement. It is not clear if this dyke will be influenced by the dewatering program of the mine; was this drop due to recovery after the high rainfall events in the mid 1970’s and subsequently influenced again by extraction? It is a must that we have to understand these structures in order to make sensible conclusions regarding their influence on the groundwater provision in the area. With the information available to us there is no evidence that the mine is to blame for the decrease in yield.

5. **Wormald 482**

According to the information from the boreholes, the area is covered with relatively thick Kalahari formations of different age, with the depth increasing up to 75 m towards the east, underlain by the lava of the Ongeluk Formation. The Budin clay (Kalahari Formation) is present at many areas on the farm, and this may decrease the recharge rate into the lava in the area. Historically the yield of the boreholes on the farm is low, with the highest yield approximately 1L/s at borehole WD04. The rest of the boreholes have a significantly lower yield (0.2-0.5 L/s). According to the water level graphs the water levels of boreholes recorded since 1955 did not change significantly over time. Not enough information currently exists on the extent of the geological structures. We suggest that a few shallow boreholes be drilled in the Kalahari Formation next to the current existing SW boreholes on the farm. These must be closely monitored during the rainy season to determine the recharge in the aquifers.

**Conclusions and recommendations**

We have to commend the hydrogeological studies that have been conducted by several consultancies commissioned by the mine over time. It is of a high standard and MWC found the geohydrologists very willing to help find solutions. Unfortunately this is a very complex area geologically and therefore also hydrogeologically. Some issues are still unclear or unresolved and need to be looked into, as most of the studies were performed in isolation to each other. A lot of data has been gathered over the years, and we condensed it into one program, from that we could visualize some of the conceptual issues, but still some questions are unanswered. Currently, with the available data, it is impossible to pin liability to the mine or anyone else for the decrease in aquifer yields on the farms to the west of the Gamagara River.

- The claimed degradation in borehole yield by the farmers towards the west and south west cannot be ignored, as this is a fact. Even though most hydrogeologists consulted agreed that the decrease in transmissivity over time could be due to calcification (or bio-fouling) of some
fractures, this is just a theory and must be proven. With the currently available data it is impossible to determine the reason for the decrease in yield. A study/investigation over a far larger area is suggested to proof this, or if proof cannot be obtained to determine otherwise the cause for the decrease in yields. This study should be done on catchment scale, and should include the area up to Postmasburg, as the same problems occur in this area. The area to the east of Kathu that is underlain by lava must also be included in the study, as it is currently unaffected by mining. A hydrocensus at farms underlain by lava, but which is too far away from the mines to be affected, may provide valuable information in this regard. If the loss in yield cannot be correlated with the lavas, a very detailed study between the mine and the farms should be done to determine the cause of the decreasing yield. It is absolutely vital to understand the regional impact on the aquifers in e.g. the weathered lava before it can be determined if the mine (or any other mines operation in the area) is responsible for yield losses, as claimed. Currently no evidence can be found that the mine is responsible for the decrease in yield, and a regional study will indicate if this is a local or far wider groundwater problem.

- A detailed geophysical study should be performed over the whole area. There are too many uncertainties in all the reports regarding dykes, faults, other structures and their transmissivities. At a number of places the information currently available indicates discontinuity in the structures e.g. on Smythe where both dykes and faults breaks of on the maps, only to continue a kilometre further again; are these the same structures displaced by other geological activities or are they different structures? Anglo American has the resources to do air magnetic studies over this whole area (the Spectrum geophysical capability to rapidly assess deep and shallow fractures), and this will aid in understanding the flow zones, impact due to dewatering, and areas of no-flow. In some of the farm reports structures are indicated that are nowhere to be found in the regional structural map. This makes the regional interpretation difficult as it is unclear if these structures are connected to the dewatered area.

- When boreholes are drilled the different aquifers should be cased of (preferably pairs of boreholes should be drilled into the different aquifers) to study their respective properties and parameters e.g. water levels, pressure levels, transmissivity and storativity. Pumping tests should be done in a number of correctly constructed boreholes (also across dykes and faults) to determine the parameters transmissivity and storativity and compare it to known values from the past (if such values exist). This will make clear if the decrease in yield is due the change in transmissivity over time.

- In none of the reports a detailed recharge study has been done; in the light of the whole water balance in the area, a detailed recharge study is recommended. Water is being pumped out of the area at a rate of 11 Mm3/a (just from Sishen Iron Ore mine, and not including water use and dewatering from other mines in the area), which is much more than the estimated recharge. If pumping continues at this rate, with the same recharge values, over an extended period of time, water will be abstracted outside the current dewatering zone ultimately resulting in a large dewatering area (in some areas dewatering may take place only along the geological structures). The recharge properties and volumes into the different aquifers in depth need to be understood.
The mine (and other mines) will still function for many years, and the high extraction rate (far more than the recharge) and effect on the surrounding area must be understood and spelt out to the farming community, as it is not sustainable to dewater the area at this rate without affecting the community.

- Regarding the Gamagara aquifer, we are of the opinion that the status quo must be maintained for the time being regarding provision of water to the farmers. A river diversion around the swallet area should still be the best solution, as the river recharges the south compartment every time when a flood occurs, resulting in more dewatering to deal with in the compartment. Only a large flood, as described by Chapman, will give us an indication of the influence of the swallets on the recharge of the aquifers downstream. (A study by Jones and Wagener and AGES is underway to investigate this).

- Due to the school of thought from some of the local farmers that there is dewatering along the glacial valley to the north of the mine, and the slight drop of water levels in this area, it is suggested that a triangle of boreholes be drilled into the Dwyla as well as into the underlying lava in this area to determine the groundwater gradient and direction of groundwater movement.

- We suggest that a workshop be organised with leading hydrogeologists in the country to discuss the complexity of the area and to spell out the way forward for dewatering (and what the effect can be on the surrounding aquifers, as well as what can be done to determine this).

Report reviewed by Prof. G van Tonder
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1 Introduction

Sishen mine in the Northern Cape is in production for the last 60 years. It is one of the largest open pit mines producing iron ore in the world. To keep the 240 m deep mine dry an approximate 1 million m$^3$ of ground water is abstracted monthly. As for lately, farmers in the vicinity and especially on the western side of the mine are complaining about deteriorating yields on their boreholes. Many consultants were appointed in the past by the mine to determine the influence of the mining activity on the groundwater situation.

During 2012 Mine Water Consultants (MWC) were tasked by the Mine Manager of Sishen Iron Ore Mine to review all groundwater reports, supplied to us, produced for the mine by every consultant hired, as well as report produced by the department of water affairs, and to produce a condensed and unified answer regarding the groundwater issues with the farmers and to advise on scientific studies/investigations that still needs to be done.

2 Methodology

The mine was visited on a number of occasions, and discussions were held with relevant mine personnel as well as farmers in the area that claims that their groundwater has been affected by the dewatering activities of the mine. Field trips were undertaken to these farms, as well as to areas of concern in the Gamagar riverbed.

All relevant reports were read, and data of all the boreholes in the area was consolidated in a single WISH file geohydrological program in order to set up a conceptual model of the groundwater and geology in the area of and around the mine. The consolidation of the data was a very ambitious task that took a few months to complete, but which enable us (and the mine personnel in the future) to interpret the data easier and to see early warning signs regarding water level and water chemistry changes.

Discussions were also held with the consulting companies responsible for some of the reports, as well as with some of the most well-known geohydrological experts in the country which was approached for their advice; these include Prof G van Tonder, Drs E van Wyk, S Adams, Messrs G Steenekamp, W du Toit, and A Johnstone.

No physical field work was done as this was not part of the scope of the study. However, during a visit to the farm Beaumont of Mr Gerrit Maritz a short pumping test was performed to determine the transmissivity value of the aquifer.
MWC does not claim that it has read all geohydrological reports for the Sishen area; it has merely read all the reports passed on to us. It is therefore possible that some of the suggestions made in this report may have been addressed in a report that is not part of the reviewed reports studied. A list of reviewed reports can be found in the reference list. All the conclusions reached in this report are based on the available data in the reports studied, as well as data provided to MWC by Sishen Iron Ore Mine personnel to create a conceptual model.

All maps in this report use the co-ordinate system used at the Sishen mine. i.e. Transverse Mercator Projection, Cape datum and a (+50 000, +3 000 000) offset.

3 Conceptual Model (on a regional scale)

![Figure 1: All boreholes known in the area.](image)

The development of a conceptual geohydrological model of Meyer (2009a) was reviewed, with the aid of the Environmental Impact Assessment for the Sishen Iron ore mine “sinkhole project” (CSIR/NRE/WR/ER/2006/0195) by Meyer, Impact of mining on the Gamagara River Aquifer by GCS (Ref: 4504860864), The Investigation into “sinkholes” in and adjacent to the Gamagara River and
their impact on the flow conditions in the river by PHD (2007), as well as the 1979 report “Groundwater Studies in the Gamogara Catchment” by DWA and WRC. All of these were used in the investigation and creation of a conceptual understanding.

Rainfall records were recorded on the farm Cox. The recording started in 1931 unfortunately our data set stopped in 2011. From this the high rainfall years, which will result in higher episodic recharge, can be seen.

A conceptual model was created with all the available data which were condensed into the program WISH, with all the known boreholes illustrated in Figure 1. However, not all these boreholes have data.

Figure 2: Rainfall graph of the farm Cox.
3.1 Dewatering cone:

Figure 3: All boreholes with water level data.

One of the most debated issues regarding groundwater at Sishen Iron Mine is the dewatering of the aquifers and the extent of the dewatering cone. In Figure 3 all the boreholes with water level data is illustrated. The depth of the measured water level is indicated by the size (diameter) of the point. Water levels are important in order to evaluate the dewatering cone as suggested by the conceptual model by Meyer (2009a).

Figure 4 shows two comparisons. The first one between the water levels elevations prior to 1974 and the levels in 1985 and the second one between water level elevations prior to 1974 and 2005. The cooler colours indicate a drop in water level and the warmer colours indicate a rise. The yellow area on the left of the first comparison indicates a no change in water level elevation but this is due to a lack of data. Both comparisons show a rise in water levels to the west of the mine. A boundary is indicated by the thick black line where the drop and the rise in water levels meet. The line also indicates the zero drawdown or the edge of the dewatering cone. In the area outside the polygon drop in water levels in excess of 25 m are observed. This decline is a natural drop in water level.
Using this 25 m drop as a background, a new boundary may be superimposed on the map indicating the real influence sphere of the mine (the dashed line).

Figure 4: Water level elevation differences between 1974-1985 (Left) and 1974-2005 (Right)

A detailed explanation was given regarding dykes and faults that compartmentalise the area and which results in a very specific dewatering area. It is stated that “Groundwater levels were the main criteria in defining the current boundaries of the dewatering impact, but the structural and tectonic history of the area and the impact it has on the geohydrological condition is significant”. MWC fully agree with this and, based on the water level information and the associated structures, delineated the most possible dewatering cone, illustrated in Figure 5. However, we are of the opinion that a more detailed geophysical study be done to get more detail regarding dykes and faults. This may clear any uncertainty that occurs for certain parties and individuals and can help with interpretations – see discussion later in the report.

The water levels in the figure are displayed proportionally according to size of the dots; the influence of the structures on dewatering can clearly be seen. A slightly larger area in the North-Western corner of the dewatering cone is the only difference in the author’s interpretation compared to Meyer’s dewatering cone.
3.1.1 South of mine

There are some deeper water levels outside the dewatering cone to the south of the mine, especially on the farm McCarthy, as the two deep graphs indicate in Figure 7. Unfortunately these boreholes only have data until 1986 and 1990 respectively and can thus not be used for meaningful interpretations. In Figure 5 the map with all known boreholes is illustrated on the left, and the map on the right has all boreholes with more than 3 water levels. From these graphs in is inconclusive that dewatering occurs along these structures as the graphs of the more recent data indicates a sideways trend for these boreholes. These boreholes with the deeper water levels should be monitored again as it pertains important information about the water level trends.
Figure 6: All boreholes south of the pit (left), boreholes with more than 3 values (right).

Figure 7: Time graphs of the water levels of the filtered boreholes.
3.1.2 North of mine

A Dwyka glacial valley is present to the north of the dewatering cone. Some of the farmers suggested that dewatering will take place along this valley resulting in lower ground water yields for some of the farms to the west of the mine.

![Image of boreholes and water levels](image)

**Figure 8**: All known boreholes in the glacial valley north of the pit (left); Boreholes with more than 3 values displayed on the right proportionally scales according to water level depth.

The data in Figure 8 (left) suggests shallower water levels north of the mine compared to the other areas, however when we zoom in (right) and create a time dependent graph of the water levels (Figure 10), it seems as though there is a slight drop in water levels.

It is suggested that a triangle of boreholes be drilled into the Dwyka as well as into the underlying lava in this area to determine the groundwater gradient and direction of groundwater movement. However, a few investigations were done with the “Groundwater Flow” software. Three deep boreholes at Wiscanton indicate flow away from the mine; however, the construction of these boreholes is unknown. At the farms Lanham and Bishops Wood triangles of boreholes into the Dwyka are also available and gives identical flow direction as on Wincanton. This implicates that dewatering along the paleo-channel does not occur; no reverse gradient exists. A triangle of well-constructed boreholes to the north of the mine, drilled into the Dwyka, can confirm or refute this statement.
3.1.3 West and south of the mine

West of the mine and the Gamagara River the general complaint is that the yield of the boreholes deteriorates, despite the fact that the water levels remain relatively constant, or even rise in some places. Interesting is the fact that this phenomenon only occurs in the lava areas, and the same seem to happen on the lavas in the Postmasburg area. According to the geological map (Figure 11) most of the area to the west of the mine is underlain by lava of the Ongeluk Formation, with Kalahari deposits on top of it. It outcrops over large areas south and south west of the mine. The Kalahari sands are quite thin in this area, and thicken towards the north (mostly the clays that thickens), as illustrated in the thickness contour map of the Kalahari group in Figure 12. These contours were
created from data provided by DWA. The DWA report states that “to the south the Kalahari cover becomes thin and patchy, and large area of bedrock are exposed in the vicinity of the southern watershed”. It also states that after the 1974 floods “the most consistent rises have occurred on the rock exposures south of Sishen with an average of 15.5 m being recorded”. This indicates that there is a very direct response in the aquifer due to rainfall, which can either be positive or negative.

This was discussed and illustrated to the investigation team by the relevant farmers during a field visit. A short pumping test performed on the farm Beaumont of Mr Gerrit Maritz confirmed this. The pumping test results indicated that the current transmissivity is only 0.8 m²/d.

After a lot of thought and consulting with a number of the top hydrogeologists in the country, we are still in the dark why this phenomenon occurs. The only reasonable explanation is that the transmissivities of the boreholes decrease. We therefore propose a study on another area underlain by lava unaffected by mining e.g. to the east of Kathu.
According to Darcy’s law $Q = K \cdot i \cdot A$ (or $Q = T \cdot i \cdot L$) the only feasible solution is that $Q$ (yield) can only decrease if $T$ (transmissivity) or $K$ (hydraulic conductivity) decreases, as the gradient ($i$) and the area ($A$) are constants that cannot change because the water levels remain constant.
In Figure 13 a contour map of the surface is displayed, with a cross section below, indicating borehole depths in the area. The Langeberge to the west can clearly be seen on this map. From this it is clear that most boreholes to the west are approximately the same depth, with a few exceptions.

According to the chloride method recharge at Beaumont is about 1.2%, or even less. (Vegter, 1995; Wiegmans, 2006). This is supported by the 1979 DWA report that recharge in the Kalahari sands is relatively low. Isotope observations by Dziembowski in 1979 found that the Kalahari sediments
provide a limited contribution to the regional groundwater recharge in the Sishen area and that the main regional recharge is provided by the dolomite outcrop area(s).

Figure 13: Topographic map with a cross section below. The borehole depths can be seen in the cross section.

With thin Kalahari layers in the area, recharge into the deeper lavas will be very little during seasons with below normal or normal rainfall. The recharge pulse, created when rainfall is absorbed by the ground, will only reaches and recharges the aquifer if the pulse is big enough; this is called episodic
recharge (Figure 14). Very clear pulses can be seen in 1974 and 1988. Unfortunately not all these pulses are displayed in the graph (Figure 14), as data lacks during 1990-2002. Smaller pulses will stay in the ground as saturated and/or unsaturated zones. This water is being used by plants or is lost through evaporation. It is possible that due to the smaller recharge, and while the same pumping equipment still installed in the boreholes, the water levels are drawn down below the water bearing fractures, resulting in oxygen ingress, and the consequent formation of calcium deposits in the fractures resulting in a lower borehole yield.

![Figure 14: Water levels compared to rainfall events.](image)

It is currently very improbable that the decrease in yield is due to mine dewatering, for the following reasons:

- These farms are a distance away from the mine, with large geological structures in between that compartmentalize the area and prohibit direct flow from the farms to the mine.
- If the dewatering takes place in the deeper weathered lava layer, the water level in the unconfined Kalahari aquifer on top has to decline as well because boreholes are normally only cased off for the unconsolidated top layer enabling water to flow from the Kalahari aquifer into the lower lava aquifer.
To stop the on-going debate about the loss in borehole yield it is recommended that a detailed study must be performed on the lavas to determine the reason for the decrease in yield – is this a local or regional phenomenon? Part of the solution will be to drill boreholes into the different aquifers, and case them off properly. This will allow the researchers to study the water and pressure levels.

4 Gamagara River

All the reports and investigations agree that water will be lost through the swallets when the Gamagara River is in flood, affecting downstream users. **For this reason the mine provides all farmers adjacent to the river with water, a practice that should be continued.** However, there are a few different interpretations on the consequences of the water loss downstream.

The report by GCS (2011) states that the impact on the river (because of the water loss into the swallets) is likely to be permanent over the whole distance of the river down to Dibeng. This is disputable as local rainfall events result in flow in different sections below the swallets (according to the flow table in the CSIR report (Meyer, 2007) – e.g. as reported by Mr P Kruger that the river flowed up to Dibeng in 1999 due to local flow). This will result in flood recharge over sections of the river.

GCS also state that:

.........Two recharge mechanisms of the Gamagara River alluvial aquifer can be deduced, viz recharge from surrounding aquifers (currently only outside the dewatered zone) and recharge from flow/flood events in the Gamagara River. Recharge from the surrounding aquifer outside the dewatered zone is likely to be minor. Major recharge of the Gamagara River alluvial aquifer is dominated by flow events in the River. It is likely that if no flow events are found in the Gamagara River, then the water level in the Gamagara River alluvial aquifer will be similar (or in equilibrium) to the surrounding fractured and karst rock aquifers......

A critical error in this statement is the negligence of recharge from rainfall, as this will also be an important part of the recharge – GCS do however mention the influence of rainfall recharge later in the report. Recharge into these alluvium aquifers is a lot higher that for the rest of the area; Van Tonder (1993) calculated rainfall recharge in the area as between 7 and 10%.

According to GCS (2011) a general decreasing trend of water levels occurred in the Gamagara aquifer. To determine if this is correct MWC delineated a zone across the river and looked at all the
boreholes with three or more data readings below the swallets (since 1990). These boreholes are illustrated in Figure 15.

All reports agree that due to the absence of major rainfall events in recent times and the absence of corresponding flow data in the river, it is not possible to state whether recent rainfall events caused, or should have caused flooding in the river or not, compared to historical floods in the Gamagara River. Calculations by Chapman (2006) indicate that the river will flow past the swallets up to the farm Wright 538 (or further) when a flood of $15 \times 10^6 \text{ m}^3$ occurs. Such events only happen every 10-15 years, and have not occurred since the start of this study. It will be interesting to see what happens when such a flood occurs (this should be sometime in the near future if the cycle is going to repeat itself). Only then any scientific conclusions can be made regarding the permanent loss of water in the aquifers, as currently stated by the river farmers, and if water levels (and the yield of the boreholes) return back to normal as was the case after the 1974 floods.
The following three figures show water level depths for boreholes close to the Gamagara River. The first one (Figure 16) depicts the sites with water levels for the time period from 1970 to 1984. The second one (Figure 17) shows the boreholes with data for 1970 to 2013 and the last figure shows the boreholes with data from 2007 till 2013 (Figure 18). There is an apparent general drop in the water levels since 1970 but it seems as though most water levels remained unchanged since 2008 when measuring took place on a regular basis. The few boreholes that were measured throughout (1970-2013) indicate a drop in water levels since 1970 with elevated spikes during the major rainfall events e.g. 1974. Only time will tell if a major flood will result in a rise of the Gamagara aquifer’s water level throughout the whole aquifer as there is some contention that not all the storage in the alluvial aquifer can be recharged during a flow event over the full profile depth because infiltration rates decrease rapidly shortly after surface ponding, or flooding. According to CSIR, (Pulles, Howard & de Lange Inc, 2007) “the ponding water traps air in the pore spaces, while suspended particles in the water also block these soil pores spaces, resulting in resistance to further infiltration. As the flood propagates downstream in response to the natural slope of the land, water in the channel does not stand long enough in one place to take up the storage”. The DWA report of 1979 also mentions this fact.

Figure 16: Borehole water levels close to the Gamagara River 1970-1984
Figure 17: Borehole water levels close to the Gamagara River 1970-2013

Figure 18: Borehole water levels close to the Gamagara River 2007-2013
With the lack of flow in the Gamagara River the following question arises “What is the effect of the non-flow of the Gamagara River really on the aquifer downstream from the swallets?” According to GCS (2011) “the decline in recharge to the Gamagara alluvial aquifer (downstream of Demaneng) from surface flow in the river is due to the river bed losses across the dewatered area and the swallet”. The variation of the natural shallow water level in the Gamagara alluvial aquifer due to recharge as a result of rainfall is still unsure. GCS (2011) also mention the fact that the aquifer shows responses to rainfall related recharge. This is in contradiction to some of the other statements in the GCS report, mentioned earlier in this section. A water balance study in this aquifer will be interesting (if it has been done, MWC did not have the opportunity to review it).

5 Conclusions and recommendations

This part of the review addressed the groundwater issues from a regional perspective; specific farms and their borehole issues are not addressed, as some boreholes show decreases in yield (even to the point of a complete dry-up) that may be due to a number of reasons which ranges from fractures that calcifies, to over-exploitation and mismanagement, to changes in the aquifer due to dewatering or lower recharge.
We have to commend the hydrogeological studies that have been conducted by several consultancies commissioned by the mine over time. It is of a high standard and MWC found the geohydrologists very willing to help find solutions. Unfortunately this is a very complex area geologically and therefore also hydrogeologically. Some issues are still unclear or unresolved and need to be looked into, as most of the studies were performed in isolation to each other. A lot of data has been gathered over the years, and we condensed it into one program, from that we could visualize some of the conceptual issues, but still some questions are unanswered. Currently, with the available data, it is impossible to pin liability to the mine or anyone else for the decrease in aquifer yields on the farms to the west of the Gamagara River.

The claimed degradation in borehole yield by the farmers towards the west and south west cannot be ignored, as this is a fact. Even though most hydrogeologists consulted agreed that the decrease in transmissivity over time could be due to calcification (or bio-fouling) of some fractures, this is just a theory and must be proven. A study/investigation over a far larger area is suggested to proof this, or if proof cannot be obtained to determine otherwise the cause for the decrease in yields. This study should be done on catchment scale, and should include the area up to Postmasburg, as the same problems occur in this area. The area to the east of Kathu underlain by lava must also be included. It is absolutely vital to understand the regional impact on the aquifers in e.g. the weathered lava before it can be determined if the mine (or any other mines operation in the area) is responsible for yield losses, as claimed. Currently no evidence can be found that the mine is responsible for the decrease in yield, and a regional study will indicate if this is a local or far wider groundwater problem.

- A detailed geophysical study should be performed over the whole area. There are too many uncertainties in all the reports regarding dykes, faults, other structures and their transmissivities. At a number of places the information currently available indicates discontinuity in the structures e.g. on Smythe where both dykes and faults breaks of on the maps, only to continue a kilometre further again; are these the same structures displaced by other geological activities or are they different structures? Anglo American has the resources to do air magnetic studies over this whole area (the Spectrum geophysical capability to rapidly assess deep and shallow fractures), and this will aid in understanding the flow zones, impact due to dewatering, and areas of no-flow. In some of the farm reports structures are indicated that are nowhere to be found in the regional structural map. This makes the regional interpretation difficult as it is unclear if these structures are connected to the dewatered area.

- The different aquifers should be cased of (preferably pairs of boreholes should be drilled into the different aquifers) to study their respective properties and parameters e.g. water levels, pressure levels, transmissivity and storativity. Pumping tests should be done in a number of boreholes (also across dykes and faults) to determine the parameters transmissivity and storativity and compare it to known values from the past (if such values exist).
In none of the reports a detailed recharge study has been done; only figures from other studies have been mentioned (which varies between 3.3 Mm\(^3\)/a by Vegter in 1995 and GRAII in 2006 and 4.5 Mm\(^3\)/a by Wiegmans in 2006), but in the light of the whole water balance in the area, a detailed recharge study is recommended. Water is being pumped out of the area at a rate of 11 Mm\(^3\)/a (just from Sishen Iron Ore mine, and not including water use and dewatering from other mines in the area), which is much more than the estimated recharge. If pumping continues at this rate, with the same recharge values, over an extended period of time, water will be abstracted outside the current dewatering zone ultimately resulting in a large dewatering area (in some areas dewatering may take place only along the geological structures). The recharge properties and volumes into the different aquifers in depth need to be understood. The mine will still function for many years, and the high extraction rate (far more than the recharge) and effect on the surrounding area must be understood and spelt out to the farming community, as it is not sustainable to dewater the area at this rate without affecting the community.

Regarding the Gamagara aquifer, we are of the opinion that the status quo must be maintained for the time being regarding provision of water to the farmers. A river diversion around the swallet area should still be the best solution, as the river recharges the south compartment every time when a flood occurs, resulting in more dewatering to deal with in the compartment. Only a large flood, as described by Chapman, will give us an indication of the influence of the swallets on the recharge of the aquifers downstream. (A study by Jones and Wagener and AGES is underway to investigate this).

Due to the school of thought from some of the local farmers that there is dewatering along the glacial valley to the north of the mine, and the slight drop of water levels in this area, it is suggested that a triangle of boreholes be drilled into the Dwyka as well as into the underlying lava in this area to determine the groundwater gradient and direction of groundwater movement.

We suggest that a workshop be organised with leading hydrogeologists in the country to discuss the complexity of the area and to spell out the way forward for dewatering (and what the effect can be on the surrounding aquifers, as well as what can be done to determine this).
6 Individual Farm Reports review (on a local scale)

6.1 Murray 570

The farm Murray was not visited physically during our previous visit, but we had a meeting with the owner Mr van der Linde. He mentioned to us that although he does not have water problems currently, the yield of some of his boreholes has decreased.

Figure 20: The farm Murray with the geological formations illustrated.

![Geological Formations](image)

Figure 21: Water level time graph of boreholes at Murray East.

![Water Level Depth vs Time](image)
The farm is underlain by the lava of the Ongeluk Group (the bluish green colour in Figure 20), with a thin cover of unconsolidated wind-blown sands. The dykes (in green) and the faults (in red) are discontinuous on the farm Smythe, and should thus according to current information, not be influenced by any mine dewatering activities. The lavas aquifer, in which most of the boreholes are drilled, is a low-yielding aquifer. According to meetings with other farmers in the area, the branch of the Olifantsloop closest to the farm last flowed in 1974.

According to the limited historical data available (Figure 21), the water levels are currently at the same level as the pre-1974 floods (as is the case on other farms in the area e.g. on the farm Bredenkamp, illustrated in the report by Meyer 2010e). This raises the same question as mentioned in the regional part of the report:

- The farms on the lavas all indicate a decrease in yield.
- Is the aquifer being depleted due to lower recharge? The 1974 episodic recharge filled the aquifers. Do we know what the recharge was into the aquifer since 1974?
- Is the high alkalinity in the water responsible for the closure of water-bearing fractures and other structures?

Due to all the above, the distance of the farm from the mine, and the current information that indicates that the farm lies outside the dewatering cone, and also the fact that the geological structures discontinue, with the information available to us there is no evidence that the mine is to blame for the decrease in yield.

These questions and uncertainties may be answered if the studies recommended on a more regional scale, be performed on the area underlain by lava.
6.2 Smythe 566

The farm Smythe was visited physically during our previous visit, and we had a meeting with the owner Mr JP Steenkamp. According to him the yield of the boreholes on his farm, with which 50 ha was irrigated previously (Figure 22), decreased drastically. He thus wants the mine to help him with water from the Gamagara pipeline. Apparently 7-8 ha was irrigated at any given time with 38 sprayers, but the irrigation practice already ceased in 1994. The boreholes started to decrease in yield since 2004. The boreholes used for irrigation were SME-01, 03 & 07.

![Figure 22: Topographic map of Smythe, illustrating the irrigation area.](image)

As with the farm Murray the farm Smythe is underlain by the lava of the Ongeluk Group (the bluish green colour in Figure 23), with large areas covered by a few meters thick unconsolidated wind-blown sands. The dykes (in green) and the faults (in red) are discontinuous on the farm Smythe, and should thus according to current information, not be influenced by any mine dewatering activities; not enough is known regarding these structures. The lava, into which most of the boreholes are drilled, is a low-yielding aquifer.

![Figure 23: The farm Smythe with the geological formations illustrated.](image)
Unfortunately no water level recordings of the boreholes exist between 1970 and 2000 on the farm. However, some data is available from other farms close to Smythe, which indicates that the water levels in the area are currently at the same level as the pre-1974 floods (as is the case on other farms in the area e.g. on the farm Bredenkamp, Cox, Crossley, Gamaliets), illustrated in the report by Meyer 2010c).

We have to agree with the report by Meyer (2012) that more water was held in storage after the high recharge period of 1974-1976 and due to the high extraction and lower recharge during later years, the aquifer may have been depleted. Due to all the above, the distance of the farm from the mine, and the current information that indicates that the farm lies outside the dewatering cone, and also the fact that the geological structures discontinue, with the available data no evidence can be found that the mine is to blame any decrease in yield. However, there is a definite drop in yield, and also a drop of a few meters in water levels in all the boreholes since 2002 when water levels were recorded again (Figure 24); the reason for this is still not understood.

![Figure 24: Water level time graph of boreholes at Smythe.](image)

This raises the same question as mentioned in the regional part of the report, as well as for the farm Murray:

- The farms on the lavas all indicate a decrease in yield.
- Is the aquifer being depleted due to less recharge? The 1974 episodic recharge filled the aquifers. Do we know what the recharge was into the aquifer since 1974?
6.3 Beaumont 569 and Gappepin Reserve 670

6.3.1 Beaumont

The farm Beaumont was visited physically during our previous visit, and we had a meeting with the owner Mr GMJ Maritz. The problems on the farm Gappepin were also discussed. As with the other farms investigated, both farms are underlain by the lava of the Ongeluk Group, with large areas covered by a few meters thick unconsolidated wind-blown sands of the Gordonia Formation of the Kalahari Group.

According to Mr Maritz borehole BM 04 does not really has a problem; it is interesting that this borehole is situated in the quartzite of the Voëlwater Formation (pink areas in Figure 25). He also mentioned that the adjacent farm Spence historically had trouble with water. The trouble is more to the south, and borehole BM03 is having problems since 1998.

![Figure 25: Borehole positions and geological formations on the farm Beaumont.](image)

A short pumping test was performed on borehole BM01, which indicated a transmissivity of 0.8 m²/d. This borehole only receives water from the fracture at 43.8 m, and the yield is a lot less than previously, despite the fact that the water levels did not drop since 2010 when water level monitoring started (Figure 26).
The borehole at BM02 has virtually no yield any more, and the wind pump drops the water to the foot valve level within minutes after pumping commences. Despite this the water level recovery indicates that the static water level trend remains sideways (Figure 26). This again indicates that the transmissivities changed. Only the investigation suggested in the report will indicate the reason for this; is this a recharge (and thus an over-exploitation) problem as conditions has changed in the last few years or is it a dewatering problem? No geological structures are visible on the existing maps, which exclude dewatering from the mine as a cause of the yield decrease (at such a distance from the mine). The continuous lowering of the water table below the fractures will definitely result in calcification (or bio-fouling) of the fractures, but this may be only the result of another bigger hydrogeological issue.

### 6.3.2 Gappepin

According to Mr Maritz borehole GP02 (Figure 27), which he used to irrigate potatoes with in 1984, ran into trouble since 1992.

A detailed investigation was performed by Meyer (2010c), with a follow-up report in 2011 (Meyer, R 2011b). This was due to wrong interpretations of water levels. A number of cut-off dykes are present on this farm, on which two boreholes were drilled by the mine. Both were successful, with SW752 having a recommended yield of 1.5 L/s. If these dykes were affected by dewatering from the mine, these boreholes would have been dry. It is interesting to note that water was struck in the fresh lava deeper down at 96 m and 147 m respectively in the two boreholes. The higher yielding borehole SW752 also struck water in the weathered lava. Monitoring of these boreholes over time should give valuable information regarding the weathered as well as the fresh lava aquifer. According to the
water level time graph in Figure 28 there was an increase in water levels after the 1974-1976 high rainfall period, but there is a definite drop since then (it was only monitored again since 2010.

![Water Level Time Graph](image)

**Figure 27:** Position of boreholes and geological structures at Gappepin.

![Position of Boreholes](image)

**Figure 28:** Water level time graph at Gappepin.

Detailed geophysics was done across the geological structures (to site the boreholes), but the influence of the extended major dyke which extend in the direction of the mine (through the dewatering cone), as illustrated in Figure 29, indicates that there is a drop in water levels of some of the boreholes along this dyke since 1978 when monitoring started. However, the boreholes
monitored since 2004 have a sideways water level measurement. It is not clear if this dyke will be influenced by the dewatering program of the mine; was this drop due to recovery after the high rainfall events in the mid 1970’s and subsequently influenced again by extraction?

Figure 29: Boreholes along the major dyke extending towards the mine, with the water level graph of these boreholes.

It is a must that we have to understand these structures in order to make sensible conclusions regarding their influence on the groundwater provision in the area. With the information available to us there is no evidence that the mine is to blame for the decrease in yield.
6.4 Wormald 482

Mr Willie Cornelissen asked a number of questions which were addressed by Meyer (2010b). I agree fully with the outcome of the report that no primary aquifer is present, as the water strikes historically are deeper (mostly 60+ m) than the Kalahari deposits.

Mr Cornelissen also made a comment during our meeting that the water may drain along the Dwyka paleo-channel back towards the mine. According to the regional water level elevation map (Figure 30) it seems as though the water drains towards the north (as the arrow indicates), but there is a definite lowering of water levels along the paleo-channel. This has to be investigated, as earlier suggested in the report. Locally the water drains from Tamplin towards Wormald.

![Figure 30: Water level elevation contour map of the farms to the west and north of the mine.](image)

According to the information from the boreholes, the area is covered with relatively thick Kalahari formations of different age, with the depth increasing up to 75 m towards the east (Figure 31), underlain by the lava of the Ongeluk Formation. The Budin clay (Kalahari Formation) is present at many areas on the farm, and this may decrease the recharge rate into the lava in the area.
Historically the yield of the boreholes on the farm is low, with the highest yield approximately 1L/s at borehole WD04. The rest of the boreholes have a significantly lower yield (0.2-0.5 L/s). According to the water level graphs the water levels of boreholes recorded since 1955 did not change significantly over time. The time graph since 2010 in Figure 32 also indicates this, with variations probably due to abstraction.
The sudden spike in March 2012 is very peculiar as it is for three boreholes (SW756, SW757 and SW759) measured on the same day (and only these three were measured). It is presumed that these are incorrect readings. According to the information on the boreholes in the report it seems as if a number of boreholes decrease in yield, e.g. WD01, WD03 and WD04. From the table it is clear that the water level drops below some of the fractures during abstraction, which may result in calcification of the fractures. WD04 was 137 m deep in 1967, and is currently only 59 m; this will obviously result in a decrease in yield, as the deeper fractures will now be sealed off. Therefore it is understandable that the yield decreased from 1200 L/hr to 800 L/hr.

A huge drawback is the lack of detailed regional geophysical information. In the report by Meyer (2010) a number of dykes and faults are indicated, but this information is seen in isolation from the bigger area. Subsequently it is not possible to see if there is any link with other structures that are connected to areas of dewatering.

In conclusion, we have to agree with the Meyer (2010) report page 28 that a hydraulic connection with the mine cannot be ruled out, but that it is highly unlikely over such a distance from the mine; not enough information currently exists on the extent of the geological structures as mentioned earlier in the report. We suggest that a few shallow boreholes be drilled in the Kalahari Formation next to the current existing SW boreholes on the farm. These must be closely monitored during the rainy season to determine the recharge in the aquifers. I also suggest that a thorough recharge study be done, as the Budin clay may have a major influence on the recharge into the lavas. The area should be included in the study suggested earlier in the report to determine the regional recharge into the lavas, as the yield of the boreholes decrease despite the fact that the water levels on this farm also remain constant.

6.5 Conclusion and recommendations

It is clear that all the farmers to the west of the mine have the same problem, i.e. that the yield of the boreholes decreases despite the fact that the water levels remain constant. With the currently available data it is impossible to determine the reason for the decrease in yield. It is expected (but this is not a proven fact) that there is a transmissivity problem in the lavas, which may result in over-abstraction, which in turn results in fractures closing thereby deteriorating the yield again. This problem is probably encountered over a larger area of the lavas and should be investigated on a regional scale. A hydrocensus at farms underlain by lava, but which is too far away from the mines to be affected, may provide valuable information in this regard. If this is not the case, a very detailed study between the mine and the farms should be done to determine the cause of the decreasing yield.
It is suggested that a small number of boreholes (correctly constructed) are selected for pumping tests and aquifer parameter analysis on an annual basis. This will make clear if the decrease in yield is due the change in transmissivity over time.
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