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EKO•ENVIRONMENTAL

# Impact Assessment of the Diamond Recovery Operation at Jagersfontein on Surface and Groundwater Resources

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## 1.1 Background

The purpose of the assessment is to determine the risks that the Jagersfontein Developments (Pty) Ltd's ("**JD**") diamond recovery and processing operations (the "**Tailings Operation**") may have on the environment. Eko Environmental has identified that the main potential risk would be potential impacts to ground and surface water resources in the area.

The Tailings Operation entails the recovery of tailings from the old Tailing Dumps, situated on Portions 15, 16 and a portion of the Remainder of the Farm Jagersfontein 14 IS (the "**Site**"). The recovery of the diamonds from the Tailing Dumps is a wet process and produces a waste stream of fine and coarse tailings that is disposed on a Tailings Dam constructed by JD (the "**New Tailings Dam**"), which is situated on the Remainder. The New Tailings Dam was constructed by JD and has been used for the disposal of fine tailings since November 2010. (See Figure 1)

The coarse tailings are used to build the side walls of the Tailings Dam.

The Old Tailings Dam, which was used by De Beers until the early 1970's and most likely during the bulk sampling operations, is also situated on the Remainder (the "**Old Tailings Dam**"). The Old Tailings Dam is filled with tailings from the previous operations conducted before JD commenced its operations. It has never been used by JD. The New Tailings Dam is located west and adjacent to the Old Tailings Dam.

Also situated on the Site, on Portion 15, are:

An opencast pit, created during the first phase of the mining operations during the late 1800's and early 1900's (the "**Pit**"); and

a shaft that was later sunk by De Beers next to the Pit, through which the ore body was mined underground to a depth of approximately 750 m below surface (the "**Shaft**").

To meet the water demand of the operations, water is sourced from the following sources:

- Abstraction of surface water from catchment dams: Dam 10 and Loskop Dam
- Purified sewage effluent from the Kopanong Local Municipality's Sewage Treatment Plant (the " **Sewage Treatment Plant** ")
- Groundwater from the Shaft;
- Excess water recovered from the process in the Thickener Plant, which flows through the Process Dam. Top-up water is also added to the Process Dam from the Sewage Treatment Plant and the other water sources.

It was recently determined that there is a sufficient yield from two boreholes on the Site to satisfy JD's water requirements. JD has advised that it will therefore abstract water from these boreholes and only use the Shaft as a back-up until a water use licence is obtained.

For purposes of this report, the study area includes Portions 16 and 15 of the Farm Jagersfontein, as well as a section of the Remainder of the Farm Jagersfontein located on the western side of the road that enters Jagersfontein Town from Bloemfontein.

## 1.2 Methodology

A borehole census was done to determine localities, rest water levels and take samples for quality analyses. All these were existing boreholes and were drilled in a search for potential groundwater production boreholes. Temperature and conductivity profiles were taken at some of boreholes to determine preferential pathways in the aquifer and are referred to as water strikes during drilling.

Samples were taken of boreholes where access was possible. Most of the boreholes were equipped with submersible pumps.

Two boreholes were drilled and groundwater samples taken near the New and Old Tailings Dams, which, based on the projected groundwater flow, were determined to be on the downstream side of the Tailings Dams. This assessment was conducted to determine potential impact on groundwater from the Tailings Dams.

Three samples were taken of the coarse tailings and three from the fine tailings to be analysed by the Institute for Ground Water Studies for an Acid – Base Accounting **("ABA")** analyses. This is a method of determining via a set of procedures whether a particular sample has the potential for acid generation.

In most mining environments the onset of acid mine drainage ("**AMD"**) is as a result of the oxidation of sulphide minerals present. In waste rock or tailings dumps it is often these sulphides that react with water and oxygen, usually assisted by microbiological catalysis, to generate low pH waters, with high sulphates and often associated heavy metal mobilization.

## 1.3 Background: Groundwater

The geology of the Jagersfontein area consists mainly of sediments from the Karoo Supergroup. These are predominantly sandstone, shale and mudstones formations of the Dwyka-, Ecca- and Beuafort group, with intrusion of post Karoo dolerite sills and dykes along weak contact zones between different formations or faults zones.

The Karoo sediments are characterized by low permeability and groundwater movement mainly occurs along jointed and fractured zones caused by faults or on the contact zones with dolerite intrusions.

Based on the water levels around the Pit and the differences in water qualities, it is evident that there are two aquifer systems in the study area. At the top is a shallow aquifer with a rest water level (water table level) of approximately five metres below ground level (**mbgl**). At the bottom is a deeper aquifer with a current draw down water level at 338 mbgl and a rest water level at approximately 160 mbgl. The two aquifer systems are separated by an impermeable dolerite sill. This is based on early geological maps, as indicated in Figure 2 (as referenced by Bijengsi (Woodford et al., 2002)) that indicated a dolerite sill from surface to depth of approximately 300 m. In the two monitoring boreholes drilled about 2000 m south east of the Pit, dolerite was intersected from about 5 m to a depth of 70 m**.** It is most likely that the dolerite sill that was intersected in the two monitoring boreholes correlate with the sill at the Pit as indicated in the geological section by Woodford et al, 2002.

It is very likely that the dolerite sill is a major geological feature because of its thickness and that it is likely to cover a large area over the Site and plays an important role in the movement of groundwater in the study area.

The shallow aquifer will most probably be very recent water (i.e. recently recharged from rain water) and will move along the weathered zone of the dolerite sill and/or fractures along the contact with the Karoo sediments that can be associated with the dolerite sill intrusion.

The aquifer systems are to a large extent independent of each other because of the impermeable sill that separates them. There may however be some isolated zones of connectivity between the two aquifer systems.

The surrounding groundwater users in the Jagersfontein Town abstract from the shallow aquifer, as it is not feasible to drill boreholes to the depths required to abstract from the deeper aquifer. The shallow aquifer is not affected by the draw-down created in the deep aquifer. Abstraction from the deeper aquifer has therefore an insignificant impact on the water levels in the shallow aquifer.

Because of the restricted movement of groundwater between the two aquifer systems, this will also be applicable to the movement of any undesirable chemical elements that may naturally occur in the deeper aquifer or from previous mining operations. JD is not conducting underground mining and the Tailings Operations will not directly impact on the deeper aquifer. Any undesirable chemical elements in the shallow aquifer system, caused by the historical mining operations or the Tailings Operations will similarly not migrate into the deeper aquifer.

Borehole information in the study area

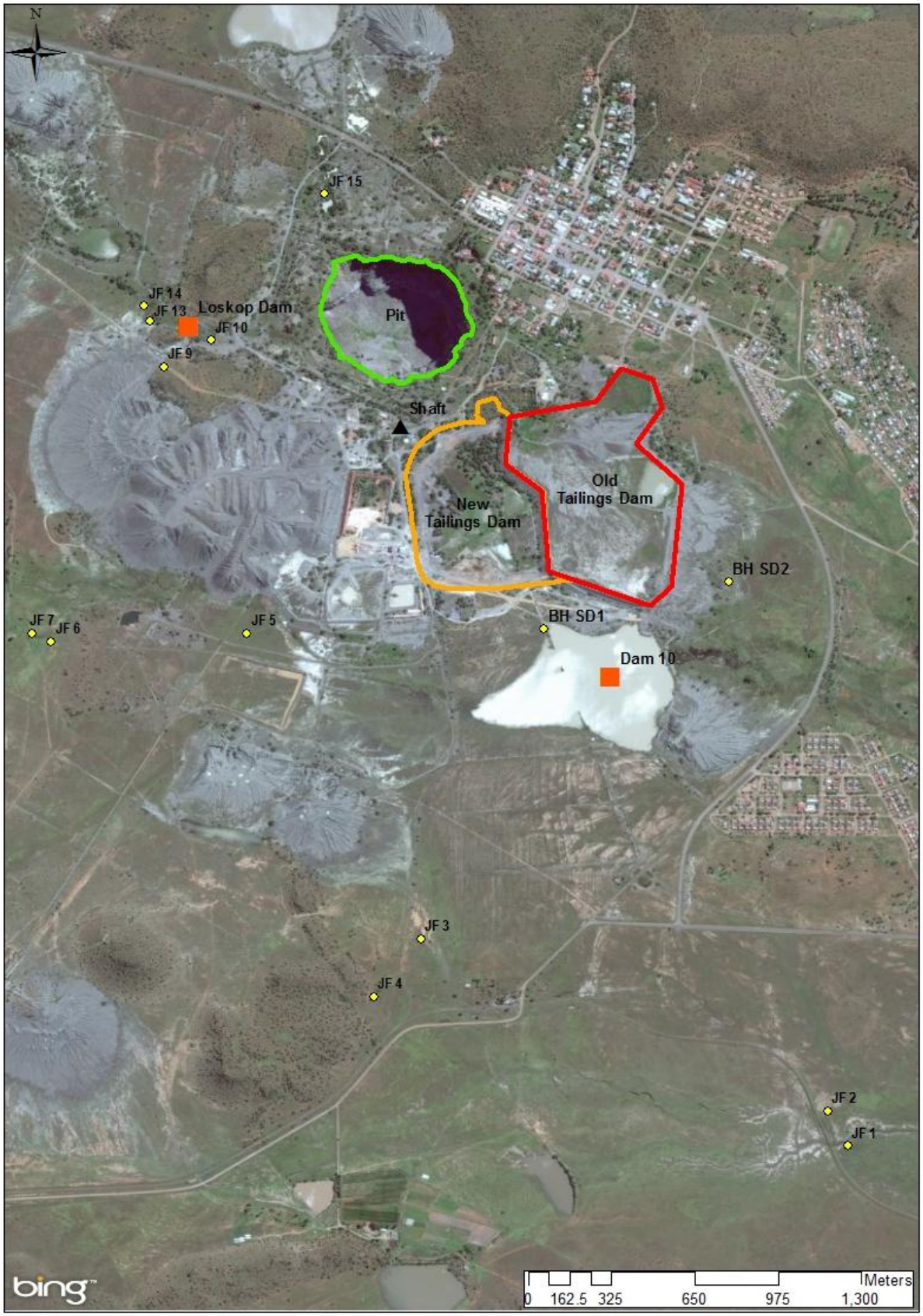
*Table 1.*

| BH ID | Latitude | Longitude | Elevation (mamsl) | Static water level (m) and comment |
|---|---|---|---|---|
| JF 1 | 29.793078 | 25.435184 | 1378 | SWL 2.680 mbch |
| JF 2 | 29.791850 | 25.434473 | 1377 | SWL - 2.295 mbch |
| JF 3 | 29.785796 | 25.420167 | 1396 | SWL - 9.960 mbch |
| JF 4 | 29.787835 | 25.418505 | 1397 | Artesian |
| JF 5 | 29.775066 | 25.414069 | 1404 | SWL - 4.515 mbch |
| JF 6 | 29.775363 | 25.407192 | 1415 | SWL - 4.800 |
| JF 7 | 29.775064 | 25.406488 | 1415 | SWL - 5.725 mbch |
| JF 9 | 29.765700 | 25.411150 | 1422 | SWL - Pumped 17.470 mbch |
| JF 13 | 29.764082 | 25.410646 | 1421 | SWL - PIC |
| JF 14 | 29.763561 | 25.410464 | 1421 | SWL - 2.400 mbch |

| | | | | |
|---|---|---|---|---|
| JF 10 | 29.764779 | 25.412813 | 1416 | SWL - 6.375 mbch |
| JF 15 | 29.759630 | 25.416805 | 1416 | SWL - 4.280 mbch |
| BH SD 1 | 29.774933 | 25.424483 | 1403 | SWL – 4.0 m |
| BH SD 2 | 29.773267 | 25.430983 | 1399 | SWL – 31.03 m |

Mamsl: meters above mean sea level, SWL: Static Water Level

*Figure 1. Location of boreholes and monitoring points at the Tailings Operations*



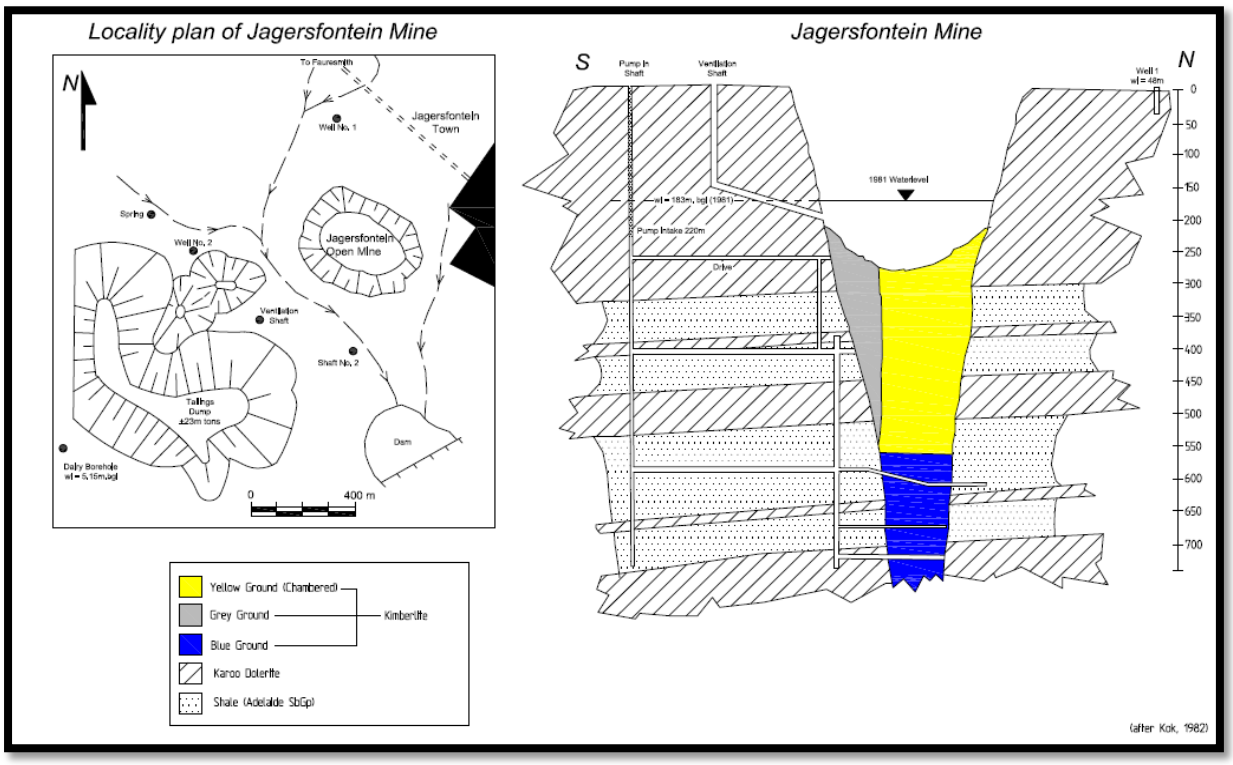



Figure 2: Geology of the Jagersfontein Kimberlite ore body (modified from Woodford et al., 2002)

## 1.4 Groundwater movement

Groundwater movement in the deeper aquifer will currently be towards the point of abstraction where a cone of depression is created with the lowest point in the Shaft. Thus any undesirable chemical elements that may naturally occur or result from previous mining operations on the Site will not migrate off the Site.

Groundwater movement in the shallow aquifer system will most likely follow the topographic gradient, unless it is also influenced by a major abstraction activity that creates a significant draw down in the shallow aquifer. There is no noticeable impact on the water level in the shallow aquifer system, irrespective of the large draw down created in the deep aquifer as a result of the abstraction from the Shaft over an extended period by the Municipality for approximately 32 years and JD for just over one year. The low rest water levels recorded in the surface boreholes is also proof that the draw-down cone that was created in the deep aquifer does not impact on the water levels in the shallow aquifer. The two aquifer systems are therefore independent.

Figure 3 and 4 indicates the expected directions of groundwater flow in the shallow aquifer system based on the topographical gradients.

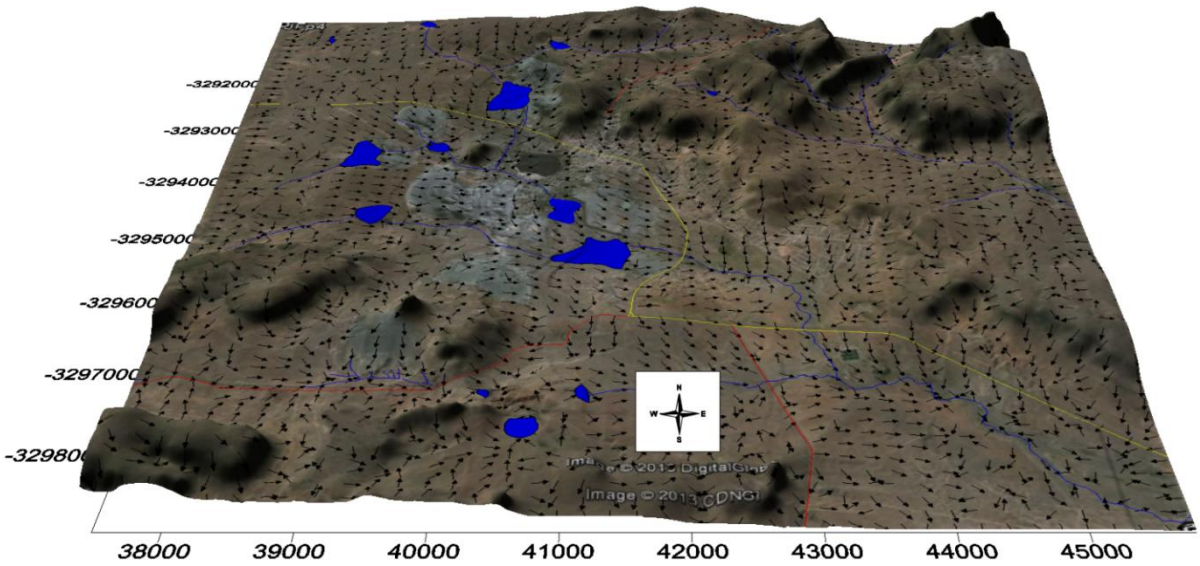



*Figure 3. 3-Dimentional representation of the Sub-Catchment and drainage regions.*

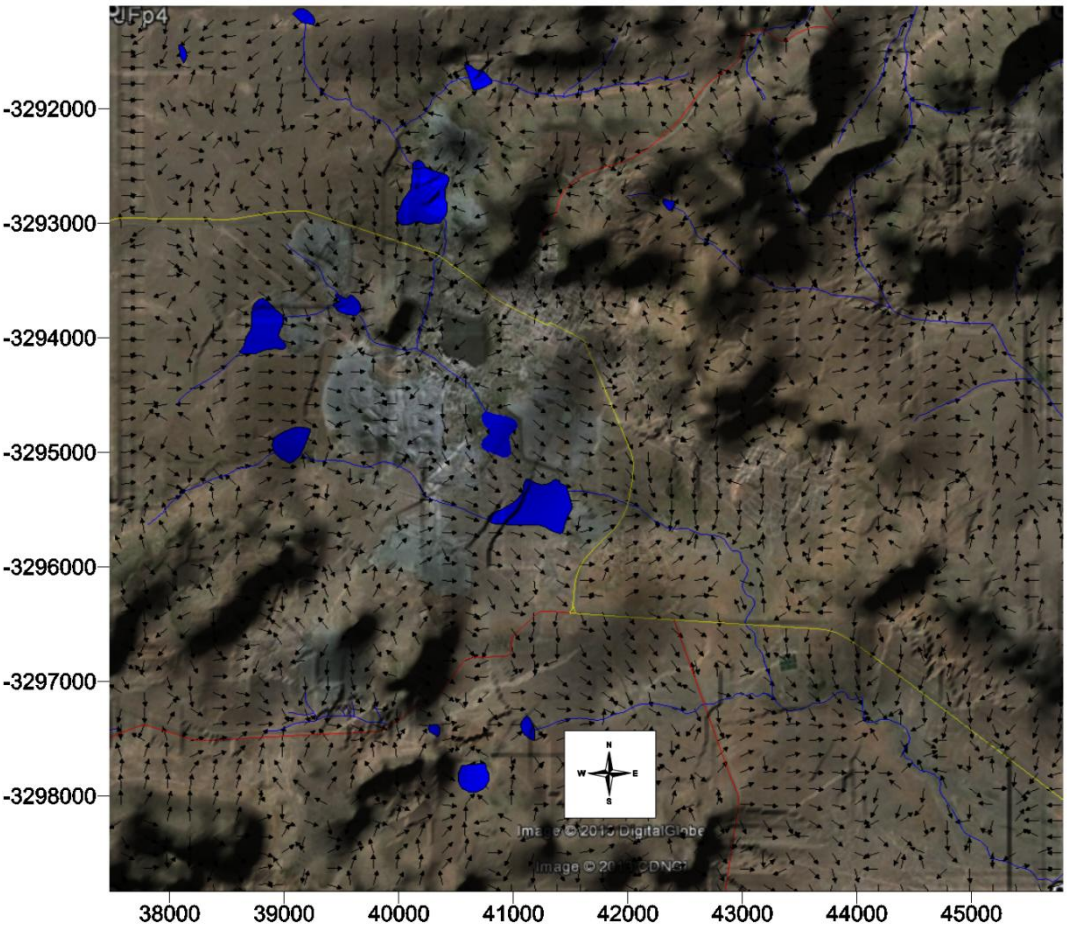



*Figure 4. Sub-Catchment and drainage regions.*

## 1.5 Groundwater Quality

### 1.5.1 Water quality in the deep aquifer

The quality of the water falls within the acceptable parameters of the SANS Standards for Drinking Water except for the As concentration. This is discussed further below.

### 1.5.2 Water quality in the shallow aquifer

The quality in the shallow aquifer is likely to be the most vulnerable against any activity that may cause elevations of undesirable chemical elements. Movement of the groundwater in the shallow aquifer will move along preferential pathways, which will most likely be in the weathered contact zone between the dolerite sill and the upper Karoo sedimentary formations.

Considering that the general direction of groundwater movement is in a south east direction, potential contamination or plume is likely to manifest in a south east direction of the Tailings Dams, which is away from the Jagersfontein Town.

The borehole at Itumeleng that is located downstream from the Tailings Operation is not impacted on by the Tailings Operation, as the water quality is very similar to groundwater from the background boreholes in the Jagersfontein Town.

Groundwater is also not extensively used in the area surrounding the Site, except for a few private boreholes in the Jagersfontein Town.

The extent of groundwater contamination is limited and is very likely to be contained to the study area, as no boreholes outside the study area downstream (Itumeleng) appear to be affected.

The disposal of slimes or fine tailings on the New and Old Tailings Dam is a wet process and therefore bears the highest risk from all the facilities on the Site to contaminate groundwater. The water in these Tailings Dams creates a piezometric or hydraulic head in the Tailings Dam (i.e. the water in these Dams is higher than the surrounding area) that can increase the potential of seepage into the upper aquifer system.

Although not as significant as a tailings dam, there is a lesser risk to also leach elements from the Tailings Dump due to water contained in the tailings during the time of disposal and aggravated by rain. There will however be much less water in the material contained in the tailings at the time of disposal than at the Tailings Dam.

Sampling on Site

The water quality in Borehole BH1SD that is about 100 m downstream of the New Tailings Dam is good. Slightly elevated levels of Ca, Mg and SO4 were recorded but are still within drinking water standards and the water quality is of similar values to background groundwater quality values in Jagersfontein Town.

Borehole BH2SD which is about 175 m downstream of De Beer's Old Tailings Dam however does appear to be impacted with elevated levels of Ca, Mg and SO4. The Old Tailings Dam is not used by JD and and these elevated levels cannot be attributed to its Tailings Operations.

Ca, Mg and SO4 also occurs naturally in groundwater. Elevated levels will have an effect on the taste of the water and increase the hardness of the water. Hard drinking water is generally not harmful to one's health but it can pose serious scaling problems to household products like geysers and kettles.

### 1.5.3 Arsenic

The boreholes in Jagersfontein Town were not sampled during this assessment and the interpretation of the groundwater quality data is based on the report and water quality data by Bijengsi, 2013. The following boreholes at localities as indicated in Figure 5 and 6 (Bijengsi, 2013), were sampled during 2011 and 2012.

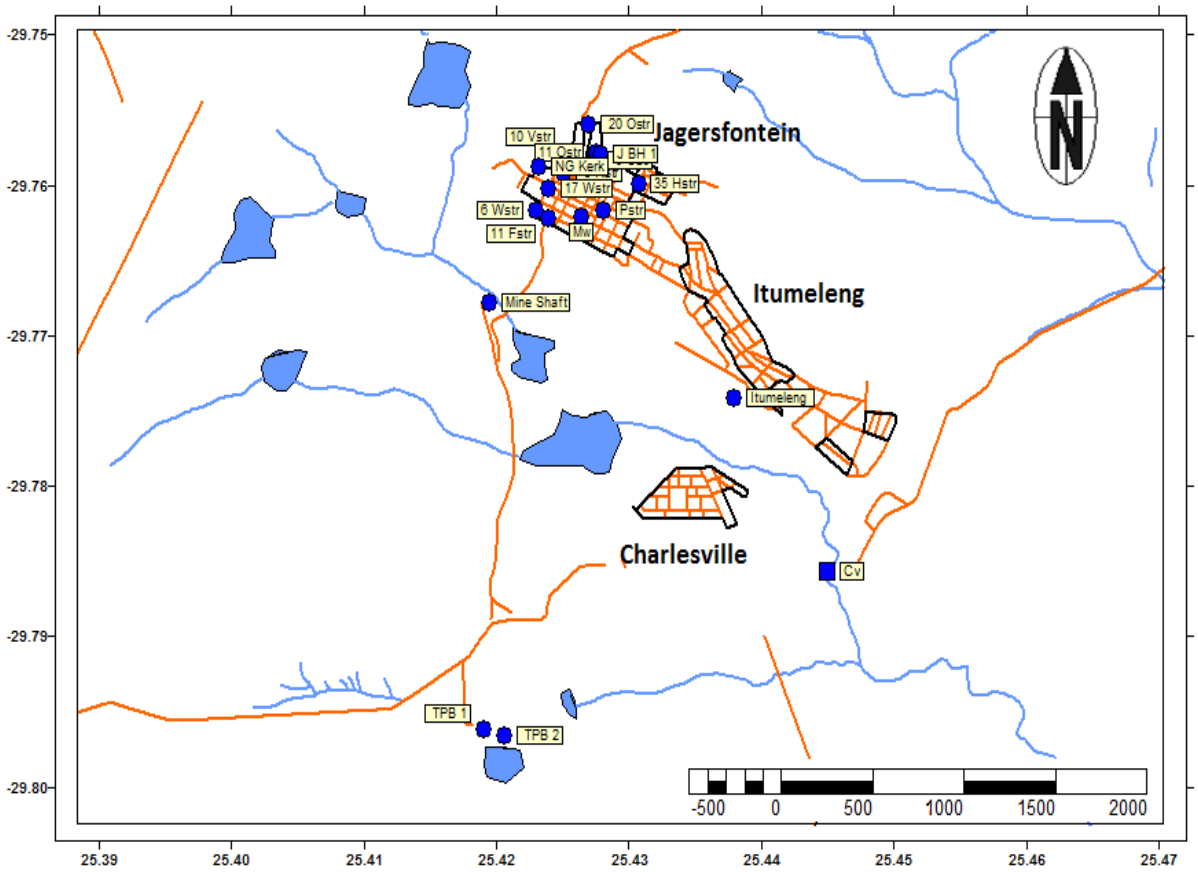



Fig 5: Location of boreholes sampled during 2011 and 2012 (Bijengsi 2013)

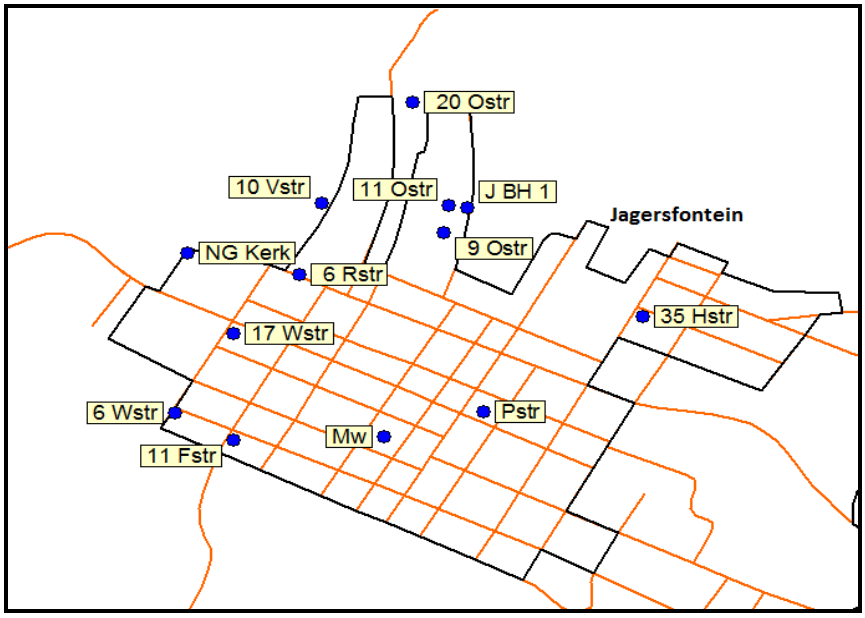



Figure 6: Distribution of boreholes in Jagersfontein sampled during 2011 and 2012 (Bijengsi 2013)

Arsenic is a metalloid (natural element whose properties are intermediate between those of metals and solid non metals) and it can be found in groundwater in an organic or inorganic form. It is an element that naturally occurs in many minerals and it's presence in groundwater may be as a result of natural or artificial processes. The presence of As in groundwater is a fairly common problem that is experienced in many places globally and the World Health Organization limit for As is 0.01 mg/l.

The average concentration for As is 0.101 mg/l in the groundwater in the Shaft is based on the 3 analyses considered since Oct'11. It was concluded in a recent study*: "A Geohydrological Assessment of Arsenic as a Contaminant in the Jagersfontein Area and Remediation Options"*, that was done as a thesis for the degree *Magister Scientea* at the Institute for Groundwater Studies, University of the Free State by Bijengsi, that As naturally occurs in the groundwater and is not caused by previous kimberlite mining operations on the Site or any reprocessing of tailings.

It is clear that the levels of arsenic in the deep aquifer system are not attributed to JD's operations, or any previous mining operation on the Site. Studies have shown that its presence in the groundwater in the lower aquifer system may be as a result of natural processes or artificial processes, such as the use of arsenic containing pesticides and herbicides.

Arsenic was present in the lower aquifer system long before JD commenced is operations. As stated above, groundwater from the lower aquifer system in the Shaft was previously abstracted by the Municipality during 1980 to 2012 for supply of water to the Jagersfontein Residents. Due to the presence of arsenic in the groundwater, a Purification Plant was built to treat the groundwater before being supplied to the Jagersfontein Residents. Water from the Shaft is presently only used as a back-up supply by the Municipality. If it is used, the water would still be treated at the Purification Plant.

Arsenic is not present in the upper aquifer system. If groundwater is abstracted by other water users it would be from the upper aquifer system, as it is not feasible to drill to the depths required to abstract groundwater from the lower aquifer system. It is reiterated that due to the underlying geological formations, the upper and lower aquifer systems are independent and not connected. Therefore arsenic present in the lower aquifer system will not migrate to the upper aquifer system.

Even in the event that arsenic was present in the upper aquifer system, due to the topography of the area the groundwater in this system flows away from the Jagersfontein Town.

The fact that arsenic is not present in the upper aquifer system is supported by studies commissioned by the Municipality in 2011 and 2012 on the quality of groundwater in the upper aquifer system in the Jagersfontein Town. The arsenic levels from borehole samples taken were within acceptable limits;

save for two sample. The reason for the level of arsenic in these sample being high was noted to be unclear but it is most unlikely that arsenic in these levels boreholes was caused by previous mining operations as a) the borehole is situated upstream of the Site and b) other boreholes in the same area had no As levels, or below detection limits.

## 1.6 Surface water:

The study area is located in quaternary drainage region C51H which covers 1 782 $km^2$ with a Maximum Annual Rainfall of 31.7 x $10^6$ $m^3$. The latter quaternary drainage region is situated in Rainfall Zone C5B with an average Mean Annual Precipitation (MAP) of between 426 mm and 452 mm, while the Mean Annual Evaporation (MAE) ranges from 1715 mm to 1 871 mm (Midgley et al.1994b).

The natural runoff from almost the entire study area drains towards "Dam 10" which is situated at the catchment outlet. The total catchment area of Dam 10 is a sizeable area of about 24 $km^2$. The main concern in terms of surface water contamination is the mobilisation of unwanted salts or elements from the Tailings Dumps and Tailings Dams into small unnamed tributaries present on the Site. The rate at which unwanted elements are transported into the tributaries is however low because of the very low average rainfall and high evaporation. Kimberlite mining and processing operations have taken place for over 100 years on the Site. It is clear that Dam 10 is the catchment area for all unwanted salts, as there is a noticeable impact on Dam 10.

Residues from kimberlite mines are generally dispersive and hence highly erodible. The sides of the Tailings Dumps in the study area were never properly sloped and rehabilitated prior to JD purchasing the Tailings Dumps. From aerial images and observations on Site it is evident that material from these Dumps has been eroded over the years to enlarge the original footprints and finer material has been transported into the tributaries and downstream to Dam 10.

Salt and fine suspended particle loads that enter Dam 10 are however trapped because the water fraction evaporates from the large surface area, leaving behind the salts and silt. Dam 10 only overflows during very high or prolonged rainfall periods because of its size. Any abstraction of water from Dam 10 to keep the levels low will cause an even lower possibility to overflow. Any impact on surface water quality from the historic and current Jagersfontein operations is therefore confined to the study area because of the buffer capacity of Dam 10.

The water quality in Dam 10 will vary according to the water level in the dam. At low levels the water quality will be poor with high levels of salt concentrations and will improve as the water level rises. This can be clearly seen in the significantly better water quality that was recorded on 24 Jul'12 in contrast

with the results of 28 May'13. Although the water quality is significantly worse in May 2013 than in July 2012 the salt load will be theoretically the same.

During the early stages of the operations of Jagersfontein Developments, water that was recovered from the New Tailings Dam was discharged to Dam 10 via a penstock. The Tailings Dam was originally designed with a penstock to drain water from it into Dam 10 from, where it was pumped back to the plant for re-use. The outlet was however sealed with the introduction of a Thickener Plant which was designed to recover excess water. The percentage of water in the slurry that is disposed on the New Tailings Dam was then significantly reduced and the use of the penstock to drain excess water was deemed unnecessary. Introduction of the Thickener Plant also results in less water being discharged into the New Tailings Dam, reducing the potential for seepage. The outlet of the penstock was closed as indicated in Figure 7.

Figure 7: The outlet of the penstock where the excess water that was recovered from the tailings dam was discharged in a canal that diverted the water to Dam 10.

Considering the history of the site since the 1900's, the salt loads are relatively low in Dam 10 and because of the buffer capacity in Dam 10 that trap sediments and salts, the impact on the river and downstream users are very likely to be low. The spruit downstream of Dam 10 is a perennial stream and connects with other tributaries to form the Proses Spruit. Purified sewage effluent from the Sewage Treatment Plant for Jagersfontein Town was previously discharged further downstream into the spruit and the spruit has been impacted on. Treated effluent is now being supplied from Sewage Treatment Plant to JD for the Tailings Operations, which will reduce the impact on the spruit.

## 1.7 Risk Assessment of facilities

### 1.7.1 The process water dam

The purpose of the Process Water Dam is to serve as a balancing dam. Water that is recovered in the Thickener Plant passes through the Process Water Dam for re-use in the Process Plant. The make-up of water is currently sourced from the following sources:

1. Groundwater abstracted from the Shaft.
2. Surface water abstracted from surface water catchment dams (Dam 10 and Loskop) on site, if water is available.
3. Treated sewage effluent
4. Water recovered from the Thickener Plant

As stated above, it was recently determined that there is a sufficient yield from two boreholes on the Site to satisfy JD's client water requirements. JD has advised that it will therefore abstract water from these boreholes and only use the Shaft as a back-up.

The quality of water was tested in the Process Dam. It is relatively good and within the SANS Drinking Water Standards parameters. The Dam is lined. The lining also serves as water conservation measure to prevent the loss of water through seepage.

No harmful chemicals are added in the Tailing's Operations process that would cause the water to deteriorate significantly and only a flocculent, similar to what is used in the treatment of raw water for domestic use, is used in the Thickener Plant to settle suspended solids, which are diverted to the Tailings Dam, and the clean water is recovered for re-use at the Process Plant.

A freeboard of 0.8 m is also maintained in the Process Dam. The water level in the Process Dam is managed by closing or opening the pumps from any of the sources. There is no uncontrolled inflow into the Dam and rain or flood event will not cause it to overflow.

It is therefore concluded that the Process Dam does not pose a risk to the environment or watercourses.

### 1.7.2 Tailings Dam

Acid Base Accounting ("**ABA**") analyses were done for 6 samples (3x fine tailings and 3x coarse tailing) by the Institute of Groundwater Studies (IGS). The analysis was done on the basis of an open and closed system. The Tailings Dam is considered to be a closed system, as there is no movement of $O_2$

and $CO_2$ through the Dam. The open system in contrast refers to conditions where $O_2$ and $CO_2$ are able to freely enter the system. ABA's for open systems are more onrous.

The potential for generating an acidic environment in the open and close systems is very low as indicated in Figure 3 and 4 of Annexure 1: (ABA) for Tailings at Jagersfontein Developments. The potential for AMD and the associated risk of leaching heavy metal from the waste body is therefore extremely low.

As stated above, the main risk would be higher concentrations of salt. Any seepages will however be contained in Dam 10.

## 1.8 Conclusion

**Groundwater**

The impact on the groundwater quality from the Tailings Dam and other facilities on the Site in the study area is limited to the shallow aquifer because of an impermeable sill that separates it from the deeper aquifer system. Boreholes in the Jagersfontein Town are not likely to be effected, as they are located upstream from the Site. The borehole at Itumeleng that is located downstream from the Tailings Operation appears not to be contaminated, as the water quality is very similar to groundwater from background boreholes. Groundwater is also not extensively used in the area except for a few private boreholes in the Jagersfontein Town.

Groundwater from the monitoring borehole BH 2 SD that is located about 175 m downstream of the Old Tailings Dam has elevated levels of Ca, Mg and $SO^4$ and can be attributed to the impact from the Old Tailings Dam. The water quality in borehole BH 1 SD that is located about 100 m downstream of the New Tailings Dam is good and complies with SANS drinking water standards.

The elements of concern that will impact on the quality of groundwater are Ca, Mg, and $SO^{4,}$ which also naturally occurs in the groundwater**.** Elevated levels will have an effect on the taste of the water and increase the hardness of the water. Hard drinking water is generally not harmful to one's health but it can pose serious scaling problems to household products like geysers and kettles.

The extent of impacts to groundwater is limited and is very likely to be contained to the study area, as no boreholes outside the study area downstream (Itumeleng) appear to be affected. Because of the alkaline environment and the extremely low potential for acid generation by the tailings no heavy metals are mobilized and leached into the groundwater regime.

The New Tailings Dam has a relative insignificant impact on groundwater because of the very low potential to generate AMD, the impermeable dolerite sill in the area and the low level of groundwater contamination since the construction of the Dam. It can be concluded that the facility does not warrant a liner.

Arsenic is a concern in the groundwater and mainly occurs in the deep aquifer. Water abstracted from the deep aquifer from the Shaft was treated at the Purification Plant before supply to the Residents. The Municipality has recently (November 2012) completed the installation of infrastructure to import water from Kalkfontein Dam and water from the Shaft will only be used as backup water in the event that there is a failure in the Kalkfontein supply network.

Studies undertaken of boreholes in the Jagersfontein Town confirmed that the As levels were within acceptable parameters. The two boreholes in the Jagersfontein Town that were identified with elevated As levels cannot be attributed to the operations of JD, as these boreholes are upstream of the general groundwater flow direction and the presence of other boreholes in the same area with no As levels, or below detection limits.

**Surface water**

It is possible that silt and certain the salts present in the water that is disposed with the tailings may be mobilized into the tributaries. The rates at which these elements are mobilized are relative low because of the low average rainfall in the area.

The establishment of the sand piles within the 1:100 flood line and approximately 1000 m upstream of Dam 10, may increase the discharge of silt and salts into the stream and eventually in Dam 10.

Dam 10 however acts as a pollution control dam. All run-off from the study area is captured in Dam 10 and because of the size of the dam and the high rate of evaporation (1 800 mm/annum, s-pan) there is a build-up of silt and salts in Dam 10 where it is trapped. In the unlikely event that Dam 10 will overflow, the quality in the water will be most likely diluted to a point that the impact on downstream users will be insignificant.

**General**

The impact from the mining activities over the past 100 years which included the establishment and operation of tailings facilities in the study area did not cause irreparable harm to the water environment and it is therefore unlikely that existing operations of Jagersfontein Developments will cause a significant impact on ground- or surface water in the area.

## 1.9 References


- Geohydrological Assessment of Arsenic as a Contaminant in the Jagersfontein Area and Remediation Options, April 2013, FFI Bijengsi
- Ninham Shand, Water Supply to Jagersfontein for New Mining Operations, Oct 2002
- South African Water Quality Guidelines, Volume 1: Domestic use, Second Edition, 1998
- Surface Water Resources of South Africa. User's Manual. WRC Report No. 298/1/94. Water Research Water Research Commission, Pretoria, RSA, Midgley, DC, Pitman, WV and Middleton, BJ.
- Surface Water Resources Assessment for the operations of Jagersfontein Developments, OJ Gericke, June2013

ANNEXURE 1

# 1 ACID BASE ACCOUNTING (ABA) FOR TAILINGS AT JAGERSFONTEIN DEVELOPMENTS

## 1.1 Theory

In most mining environments the onset of acid mine drainage (AMD) is as a result of the oxidation of sulphide minerals present. In waste rock dumps it is often these sulphides that react with water and oxygen, usually assisted by microbiological catalysis, to generate low pH waters, with high sulphates and often associated heavy metal mobilization.

The reactions involved are usually written with pyrite regarded as the sulphide of interest. Pyrite (FeS) is a common mineral often occurring as a gangue mineral associated with deposits of interest. The principal reactions involved are the following:

$FeS2 + 7/2\ O2 + H2O \Rightarrow Fe\ 2+ + 2SO42- + 2H+$ (1)

$Fe2+ + 1/4O2 + H+ \Rightarrow Fe3+ + 1/2\ H2O$ (rate limiting step) (2)

$Fe3+ + 3H2O \Rightarrow Fe(OH)3$ (yellow boy) $+ 3H+$ (3)

$FeS2 + 14Fe3+ + 8H2O \Rightarrow 15Fe2+ + 2SO42- + 16H+$ (4)

Reaction 1 shows oxidation of the disulphide, thus releasing ferrous iron (Fe2+) and two protons. In Reaction 2 the ferrous iron is oxidised to ferric iron (Fe3+) which hydrolyses to form ferric hydroxide (an insoluble compound at pH greater than 3.5) and in the process as shown in Reaction 3, three more protons are released. Thus for every mole op pyrite five protons are released. However, since one proton is consumed for the oxidation of ferrous to ferric, only four protons are actually produced. Upon initiation of pyrite oxidation, the ferric iron can be reduced by the pyrite itself as shown in Reaction 4.

Acid-Base Accounting (ABA) usually refers to the so-called static methods that provide no information on the speed (or kinetic rate) with which acid generation or neutralisation will proceed, but simply determine the acid-neutralising potential (assets) and acid-generating potential (liabilities) of rock samples, and calculates the difference or net neutralising potential (equity). The net neutralising potential (NNP), and/or the ratio of neutralising potential to acid-generation potential (the neutralising potential ratio, NPR), is compared with a predetermined value, or set of values, to divide samples into categories that either require, or do not require, further determinative acid potential generation test work.

The potential for a given rock to generate and neutralize acid is determined by its mineralogical composition. This includes not only the quantitative mineralogical composition, but also individual

mineral grain size, shape, texture and spatial relationship with other mineral grains. The term "potential" is used because even the most detailed mineralogical analysis, when combined with ABA, can give only a "worst case" value for potential acid production and, depending upon the NP procedure used, a "worst case", "most likely case" or "best case" value for potential neutralisation capability. The field generation and neutralisation of AMD represents the degree to which these potential values are realised in practice.

Neutralisation potential measures the sum total of carbonates, alkaline earths, and bases available to neutralize acidity and represents the most favourable condition. Calculations of maximum potential acidity and neutralisation potential are structured to equate the two measurements to a common basis for comparison. The resulting values, expressed as calcium carbonate equivalent, are compared to compute a net acid-producing or neutralising potential. Material exhibiting a net acid production potential of 5 tons/1000 tons of overburden material or more as calcium carbonate equivalent are classed as toxic or potentially toxic.

In its simplest form, Acid-Base Accounting is a way of determining via a set of procedures whether a particular sample has the potential for acid generation. Just as different methods of accounting present different sets of books to an auditor, so different methods of conducting ABA test work will generate different sets of sample data for evaluation. Three methods commonly used to interpret ABA data are described below:

### 1.2 pH

A sample from the waste rock is subjected to ultra-oxidizing conditions by the addition of a strong oxidizing agent, such as hydrogen peroxide. This agent oxidizes all the sulphides in the sample to sulphates, liberating protons in the process. This test therefore gives a worst-case end member that could arise from oxidation. The criteria used to assess acid-generation potential are:

Final pH > 5.5, sample is considered to be non acid-generating,

3.5 < Final pH < 5.5, sample has a low risk of acid generation,

Final pH < 3.5, sample has a high acid generation risk.

### 1.3 Net neutralising potential (NNP)

The NNP is simply the difference between the neutralising potential (NP) and the acid-generation potential (AP). The following criteria are used to evaluate the potential of the sample to generate acid:

If NNP = NP – AP < 0, the sample has the potential to generate acid,

If NNP = NP – AP >0, the sample has the potential to neutralise acid produced.

More specifically, any sample with an NNP < -20 is potentially acid generating, while any sample with NNP >20 is likely not to generate acid. The acid generation potential of samples with NNP values between –20 and 20 is usually considered as uncertain and other static and/or kinematic tests are performed to obtain more certainty.

### 1.4 Neutralising potential ratio (NPR)

The NPR is calculated from NP/AP. The following criteria are used to evaluate the potential for Acid Mine Drainage (AMD):

NPR <1, likely AMD generating,

1 < NPR < 2, possibly AMD generating if NP is sufficiently reactive or is depleted at a faster rate than sulphides,

2 < NPR < 4, not potentially AMD generating, unless significant preferential exposure of sulphides along fracture planes, or extremely reactive sulphides in combination with insufficiently reactive NP,

NPR > 4, high neutralising potential, AMD very unlikely.

### 1.5 ABA Results

The samples (1 – 6) taken from the operations at Jagersfontein Developments were submitted to the laboratory of the Institute for Groundwater Studies (UFS) for Acid-Base Accounting (ABA).

To interpret the results of the analyses, the analysed chemical variables (pH, Acid Potential, Neutralisation Potential) were entered into the spreadsheet ABACUS, Acid Base Accounting Cumulative Screening, developed by Dr Brent Usher. This spreadsheet makes use of various accepted approaches to interpret ABA data and allows a comparison of the results from each approach. These approaches include assessments made on the basis of pH values, Net Neutralising Potential (NNP) values and Neutralising Potential Ratios (NPR) for both open and closed systems. In open systems O2 and CO2 are able to freely enter and leave the solution. However, in closed systems, such as positions below the water table, no gas phase is present to supply CO2 to the system. This reduces the solubility of calcite/calcrete causing the system to have an overall higher acid potential. The sample and comparative interpretations of the ABA data for the discards is presented in Table 1.

Table 1.Sample interpretation of the Acid/Base Accounting (ABA) results.

| Acid Generating Potential | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample nr | pH | | | NNP open system | | NNP closed system | | NPR open system | | NPR closed system | |
| | Initial pH | Final pH | Interpretation | Value | Interpretation | Value | Interpretation | Value | Interpretation | Value | Interpretation |
| 1 | 9.3 | 9.55 | Lower Acid Risk | 115.43 | Probably Excess Neutralising Minerals | 114.26 | Probably Excess Neutralising Minerals | 99.74 | No Acid Potential | 49.87 | No Acid Potential |
| 2 | 9.54 | 9.39 | Lower Acid Risk | 127.43 | Probably Excess Neutralising Minerlas | 126.30 | Probably Excess Neutralising Minerlas | 113.77 | No Acid Potential | 56.88 | No Acid Potential |
| 3 | 9.51 | 9.39 | Lower Acid Risk | 123.63 | Probably Excess Neutralising Minerlas | 122.43 | Probably Excess Neutralising Minerlas | 103.69 | No Acid Potential | 51.84 | No Acid Potential |
| 4 | 9.49 | 9.1 | Lower Acid Risk | 113.90 | Probably Excess Neutralising Minerlas | 113.56 | Probably Excess Neutralising Minerlas | 335.99 | No Acid Potential | 167.99 | No Acid Potential |
| 5 | 9.74 | 9.53 | Lower Acid Risk | 117.09 | Probably Excess Neutralising Minerlas | 116.74 | Probably Excess Neutralising Minerlas | 339.40 | No Acid Potential | 169.70 | No Acid Potential |
| 6 | 9.82 | 9.4 | Lower Acid Risk | 115.23 | Probably Excess Neutralising Minerlas | 114.90 | Probably Excess Neutralising Minerlas | 351.24 | No Acid Potential | 175.62 | No Acid Potential |

Table 2. Sample interpretation of the Acid/Base Accounting (ABA) results for the samples.

| Sample nr | pH values | Net Neutralising Potential | NPR (Open System) | NPR (Closed System) | %S and NPR Method(Soregali and Lawrence,1997) | ABA INDEX | ABA INDEX | VERDICT |
|---|---|---|---|---|---|---|---|---|
| 1 | Lower Acid Risk | Probably Excess Neutralising Minerals | No Acid Potential | No Acid Potential | Too little S to create sustained acididty | 0.03482 | -15 | Very Low Risk |
| 2 | Lower Acid Risk | Probably Excess Neutralising Minerlas | No Acid Potential | No Acid Potential | Too little S to create sustained acididty | 0.03597 | -14 | Very Low Risk |
| 3 | Lower Acid Risk | Probably Excess Neutralising Minerlas | No Acid Potential | No Acid Potential | Too little S to create sustained acididty | 0.03370 | -15 | Very Low Risk |
| 4 | Lower Acid Risk | Probably Excess Neutralising Minerlas | No Acid Potential | No Acid Potential | Too little S to create sustained acididty | 0.07325 | -11 | Very Low Risk |
| 5 | Lower Acid Risk | Probably Excess Neutralising Minerlas | No Acid Potential | No Acid Potential | Too little S to create sustained acididty | 0.07285 | -11 | Very Low Risk |
| 6 | Lower Acid Risk | Probably Excess Neutralising Minerlas | No Acid Potential | No Acid Potential | Too little S to create sustained acididty | 0 | -11 | Very Low Risk |

Table 2 and Figure 1 and Figure 2 are graphs of the initial and final pH values of the tailings and it's plotted against the NNP values calculated for an open and closed system, respectively. It can be seen

that all the final pH values are all above the 9 and are likely to not be acid generating in both the open and closed systems.

Figure 1. Initial and final pH values plotted versus NNP values (open system) for the samples.

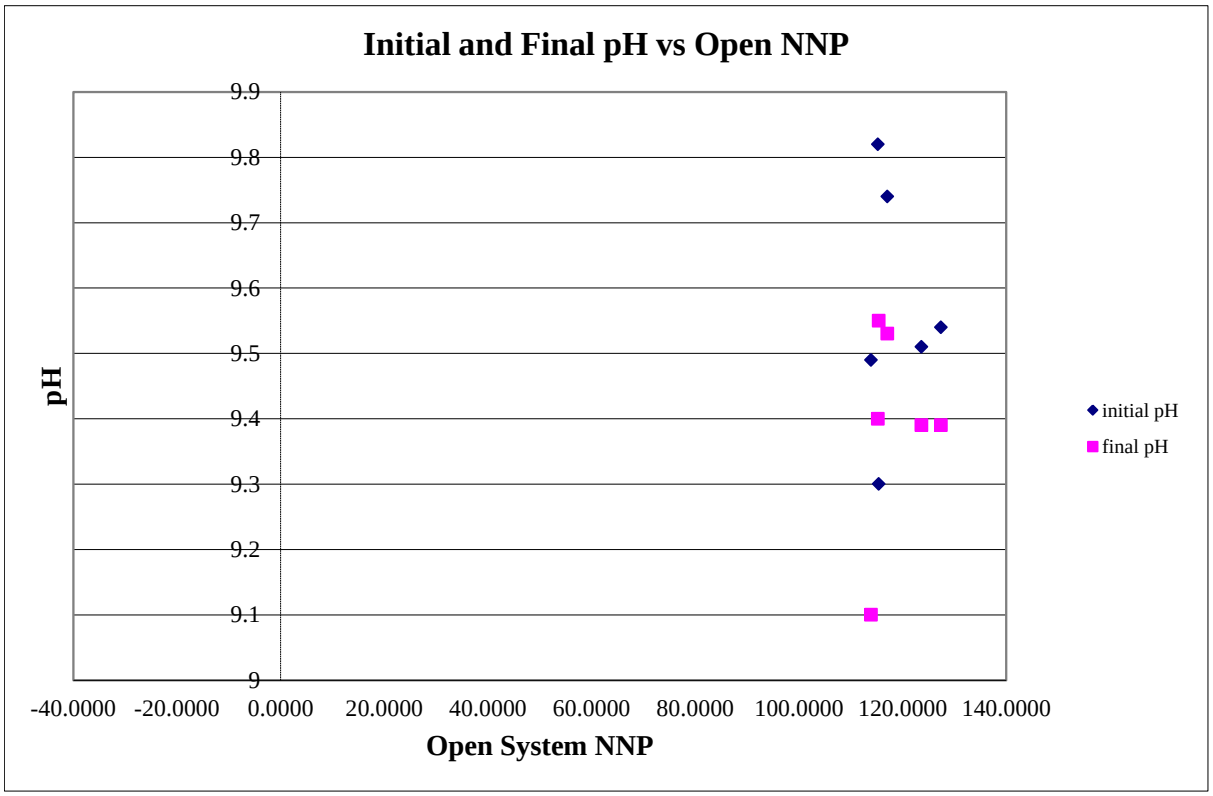


Figure 2. Initial and final pH values plotted versus NNP values (closed system).

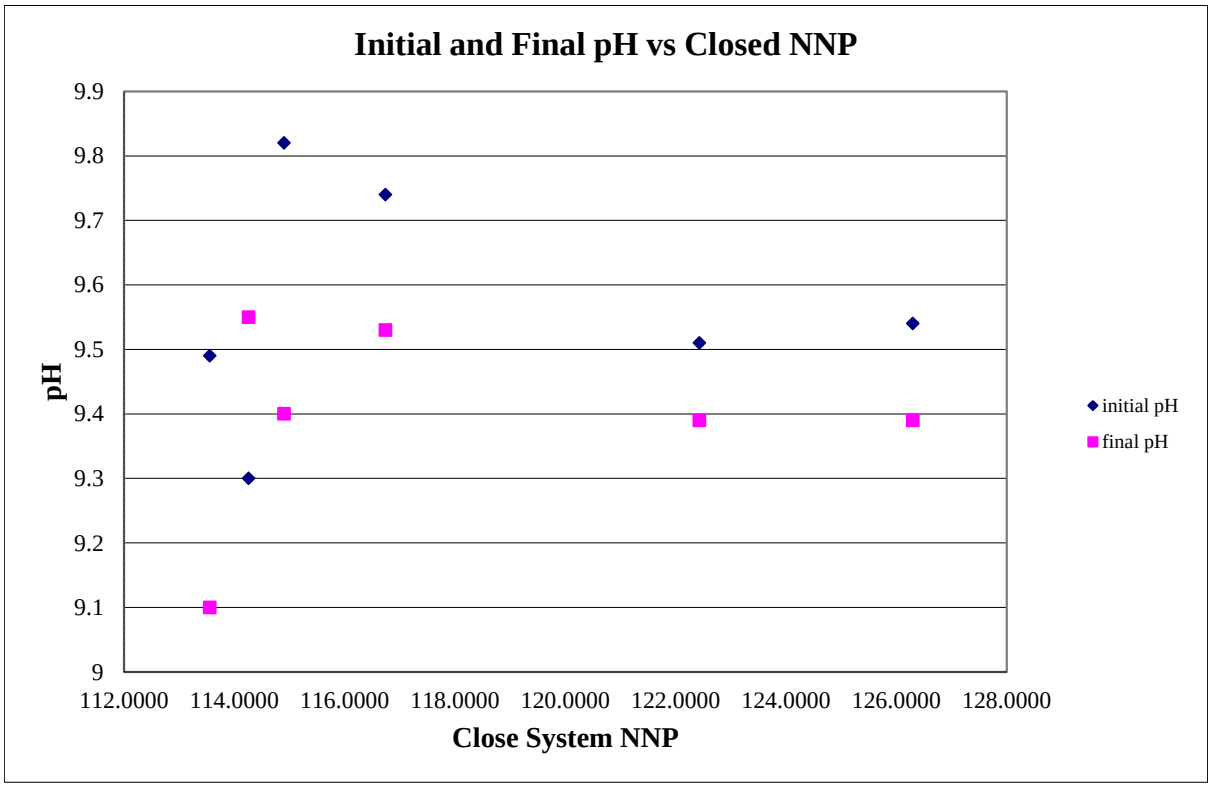



Figure 3 is a graph of the acid potential (AP) plotted against neutralising potential (NP) for samples for both open and closed systems. All the samples plot below the 4:1 line (blue line) and are therefore unlikely to be acid generating. This observation holds true for both the open and closed systems.

Figure 3. Acid potential (AP) plotted versus neutralising potential (NP).

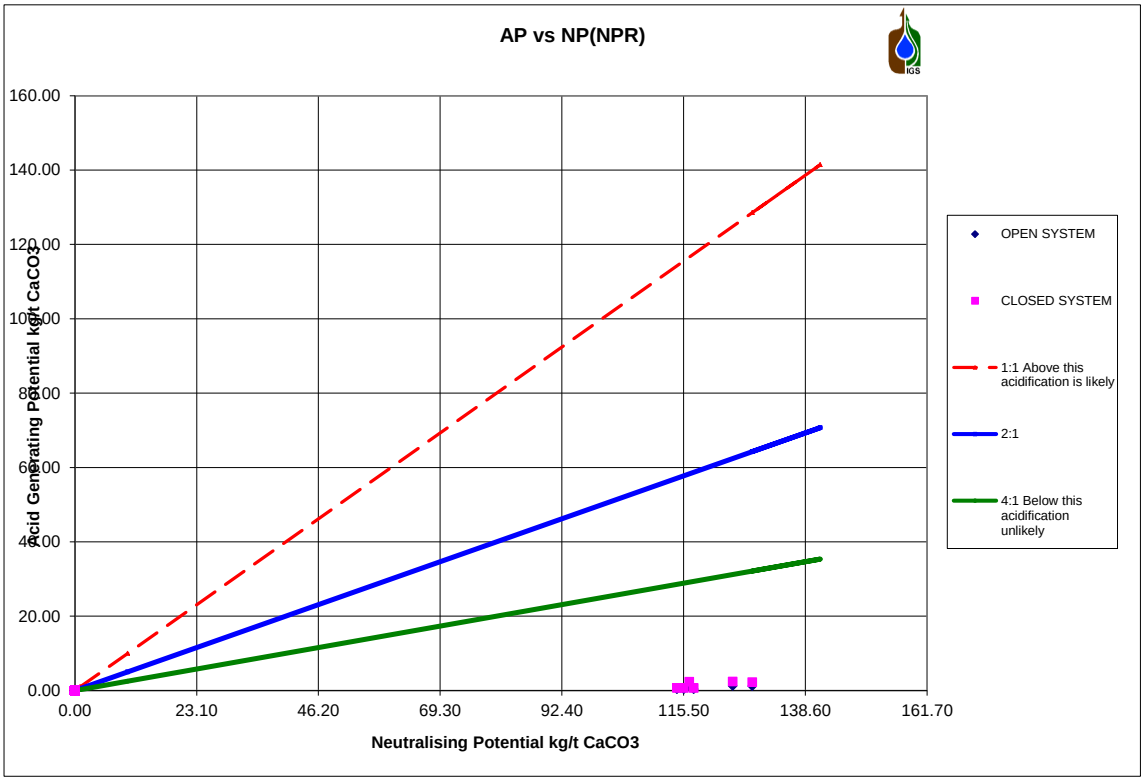
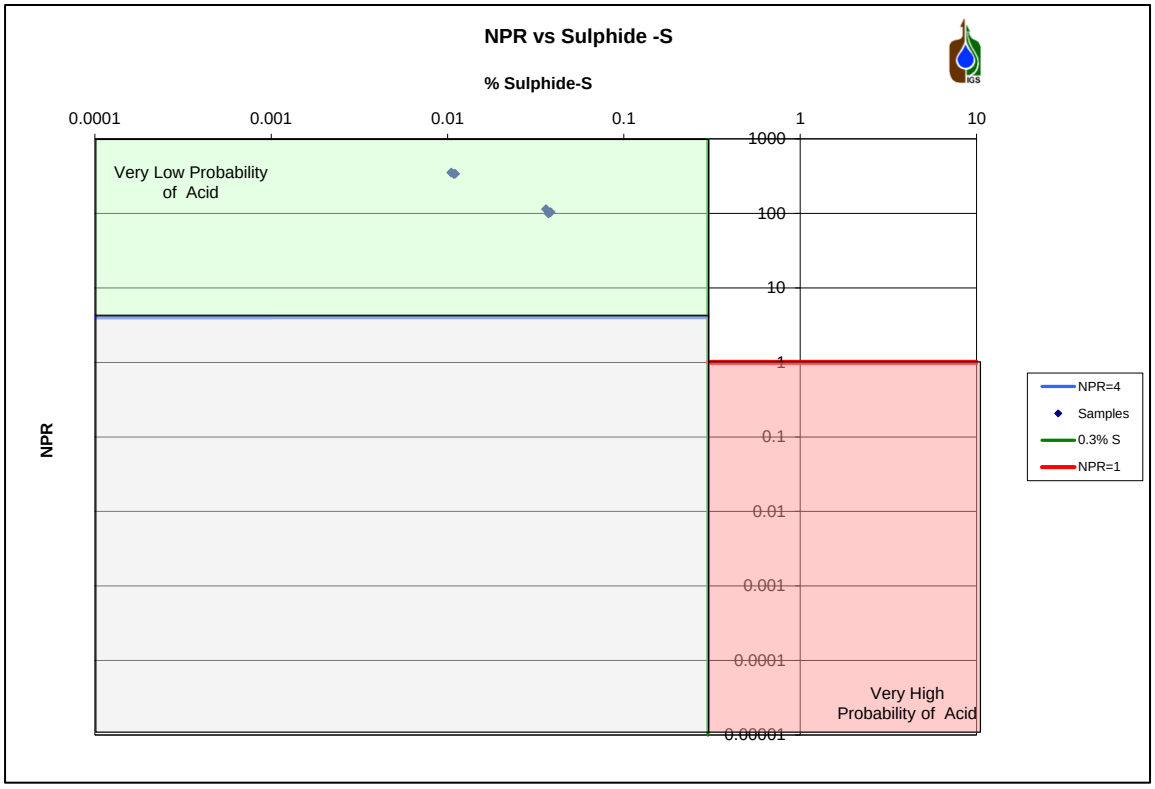



Figure 4. Neutralising Potential Ratios (NPR) plotted versus % S



Annexure 2: Water quality and ABA data

STATIC ACID-BASE ACCOUNTING

| Date | Source of samples |
|---|---|
| Junie 2013 | Jagersfontein - Gys Hoon |

Table 1. Water soluble constituents in kg/t

| Samples | Lab numbe | Initial pH | Ag | Al | As | Ba | Be | Ca | Cd | Cr | Co | Cu | Fe | K | Mg | Mn | Mo | Na | Ni | Sb | Se | Sn | Sr | Pb | V | Zn | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 9.30 | 0.00000 | 0.01130 | 0.00000 | 0.00025 | 0.00000 | 0.03768 | 0.00000 | 0.00018 | 0.00000 | 0.00001 | 0.02384 | 0.24513 | 0.11460 | 0.00019 | 0.00023 | 1.08971 | 0.00027 | 0.00362 | 0.00032 | 0.15521 | 0.00066 | 0.00000 | 0.00006 | 0.00020 | 0.85617 |
| 2 | 2 | 9.54 | 0.00000 | 0.00917 | 0.00000 | 0.00040 | 0.00000 | 0.03910 | 0.00000 | 0.00012 | 0.00000 | 0.00000 | 0.02267 | 0.29409 | 0.11709 | 0.00011 | 0.00017 | 1.35776 | 0.00018 | 0.00576 | 0.00025 | 0.16023 | 0.00105 | 0.00000 | 0.00005 | 0.00018 | 1.03131 |
| 3 | 3 | 9.51 | 0.00000 | 0.00000 | 0.00000 | 0.00021 | 0.00000 | 0.02751 | 0.00000 | 0.00013 | 0.00000 | 0.00000 | 0.00353 | 0.25093 | 0.01283 | 0.00002 | 0.00027 | 1.16018 | 0.00000 | 0.00539 | 0.00023 | 0.13734 | 0.00054 | 0.00000 | 0.00005 | 0.00016 | 1.00395 |
| 4 | 4 | 9.49 | 0.00000 | 0.00000 | 0.00000 | 0.00032 | 0.00000 | 0.01271 | 0.00000 | 0.00006 | 0.00000 | 0.00000 | 0.00260 | 0.30295 | 0.00288 | 0.00001 | 0.00006 | 1.10149 | 0.00000 | 0.00289 | 0.00028 | 0.14955 | 0.00016 | 0.00000 | 0.00007 | 0.00014 | 0.40926 |
| 5 | 5 | 9.74 | 0.00000 | 0.00208 | 0.00000 | 0.00041 | 0.00000 | 0.01932 | 0.00000 | 0.00009 | 0.00000 | 0.00000 | 0.00825 | 0.25345 | 0.02921 | 0.00006 | 0.00008 | 0.89741 | 0.00001 | 0.00339 | 0.00024 | 0.14581 | 0.00020 | 0.00000 | 0.00010 | 0.00016 | 0.42319 |
| 6 | 6 | 9.82 | 0.00000 | 0.00152 | 0.00014 | 0.00025 | 0.00000 | 0.03038 | 0.00000 | 0.00010 | 0.00000 | 0.00002 | 0.00786 | 0.24193 | 0.02725 | 0.00010 | 0.00034 | 0.86522 | 0.00004 | 0.00455 | 0.00017 | 0.17904 | 0.00025 | 0.00000 | 0.00020 | 0.00018 | 0.33817 |

Table 2. Constituents released during complete oxidation in kg/t

| Samples | Lab numbe | Final pH | Ag | Al | As | Ba | Be | Ca | Cd | Cr | Co | Cu | Fe | K | Mg | Mn | Mo | Na | Ni | Sb | Se | Sn | Sr | Pb | V | Zn | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 9.55 | 0.00000 | 0.21506 | 0.00079 | 0.01774 | 0.00000 | 2.62889 | 0.00045 | 0.00769 | 0.00147 | 0.00052 | 0.30368 | 1.46819 | 2.65885 | 0.01757 | 0.00064 | 3.87546 | 0.02890 | 0.00525 | 0.00353 | 0.65229 | 0.06433 | 0.00438 | 0.00165 | 0.00333 | 1.12211 |
| 2 | 2 | 9.39 | 0.00000 | 0.13537 | 0.00060 | 0.01299 | 0.00000 | 2.35114 | 0.00045 | 0.00747 | 0.00136 | 0.00052 | 0.18772 | 1.48311 | 1.86822 | 0.01657 | 0.00082 | 3.89818 | 0.02702 | 0.00350 | 0.00190 | 0.57275 | 0.05726 | 0.00465 | 0.00244 | 0.00319 | 1.08479 |
| 3 | 3 | 9.39 | 0.00000 | 0.13906 | 0.00047 | 0.01402 | 0.00000 | 2.42899 | 0.00044 | 0.00773 | 0.00115 | 0.00040 | 0.18164 | 1.52884 | 1.90826 | 0.01447 | 0.00063 | 3.84079 | 0.02337 | 0.00303 | 0.00145 | 0.52045 | 0.06041 | 0.00489 | 0.00195 | 0.00305 | 1.15557 |
| 4 | 4 | 9.10 | 0.00000 | 0.00000 | 0.00068 | 0.00031 | 0.00000 | 0.33888 | 0.00045 | 0.00690 | 0.00000 | 0.00018 | 0.00494 | 1.10084 | 0.08728 | 0.00018 | 0.00033 | 2.36322 | 0.00000 | 0.00204 | 0.00170 | 0.25717 | 0.00460 | 0.00429 | 0.00234 | 0.00203 | 0.32623 |
| 5 | 5 | 9.53 | 0.00000 | 0.27278 | 0.00000 | 0.02092 | 0.00000 | 3.23704 | 0.00045 | 0.00580 | 0.00076 | 0.00137 | 0.25239 | 1.53996 | 1.93198 | 0.01848 | 0.00000 | 2.64698 | 0.01604 | 0.00248 | 0.00155 | 0.99779 | 0.05396 | 0.00490 | 0.00218 | 0.00388 | 0.33237 |
| 6 | 6 | 9.40 | 0.00000 | 0.21521 | 0.00000 | 0.01680 | 0.00000 | 3.00243 | 0.00046 | 0.00515 | 0.00059 | 0.00123 | 0.10737 | 1.45827 | 1.41043 | 0.02382 | 0.00057 | 2.75175 | 0.01294 | 0.00210 | 0.00164 | 1.04502 | 0.05082 | 0.00456 | 0.00207 | 0.00356 | 0.31592 |

Table 3: Acid (H2SO4) soluble constituents in kg/t

| Samples | Lab numbe | Final pH | Ag | Al | As | Ba | Be | Ca | Cd | Cr | Co | Cu | Fe | K | Mg | Mn | Mo | Na | Ni | Sb | Se | Sn | Sr | Pb | V | Zn | SO4 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | | 0.00000 | 2.92196 | 0.00000 | 0.00085 | 0.00000 | 5.46830 | 0.00000 | 0.00006 | 0.02939 | 0.00000 | 5.21542 | 2.44343 | 29.29588 | 0.22933 | 0.00000 | 3.85309 | 0.48524 | 0.05583 | 0.00000 | 2.40181 | 0.21150 | 0.00423 | 0.00001 | 0.01507 | 0.00000 |
| 2 | 2 | | 0.00000 | 2.67521 | 0.00000 | 0.00082 | 0.00000 | 5.73810 | 0.00000 | 0.00004 | 0.02784 | 0.00000 | 6.65562 | 2.46702 | 27.83681 | 0.22720 | 0.00000 | 3.92429 | 0.46855 | 0.05535 | 0.00000 | 2.42675 | 0.20729 | 0.00454 | 0.00000 | 0.01435 | 0.00000 |
| 3 | 3 | | 0.00000 | 2.95323 | 0.00000 | 0.00103 | 0.00000 | 5.80200 | 0.00000 | 0.00007 | 0.00682 | 0.00002 | 6.82483 | 2.47105 | 28.17298 | 0.22376 | 0.00000 | 3.78917 | 0.45643 | 0.05572 | 0.00000 | 2.41724 | 0.21294 | 0.00121 | 0.00000 | 0.01440 | 0.00000 |
| 4 | 4 | | 0.00000 | 4.04870 | 0.00000 | 0.00102 | 0.00000 | 6.13150 | 0.00007 | 0.00006 | 0.01443 | 0.00000 | 8.32729 | 3.34218 | 19.73526 | 0.22473 | 0.00000 | 5.26892 | 0.24161 | 0.05524 | 0.00000 | 6.89895 | 0.21077 | 0.00693 | 0.00002 | 0.01505 | 0.00000 |
| 5 | 5 | | 0.00000 | 2.97735 | 0.00000 | 0.00097 | 0.00000 | 5.92343 | 0.00015 | 0.00006 | 0.01247 | 0.00000 | 6.68115 | 2.99648 | 15.75634 | 0.21683 | 0.00000 | 4.29522 | 0.19556 | 0.05129 | 0.00000 | 5.71355 | 0.21790 | 0.00551 | 0.00001 | 0.01259 | 0.00000 |
| 6 | 6 | | 0.00000 | 3.42028 | 0.00000 | 0.00109 | 0.00000 | 5.74042 | 0.00011 | 0.00006 | 0.01293 | 0.00000 | 7.09108 | 2.77786 | 16.44855 | 0.25624 | 0.00000 | 4.76170 | 0.23073 | 0.05132 | 0.00000 | 6.64442 | 0.21139 | 0.00539 | 0.00002 | 0.01328 | 0.00000 |

Table 4. Acid/base calculations (kg/t CaCO3 where applicable)

| Samples | Lab numbe | Initial pH | Final pH | Acid (Oper | Acid (Close | Base | NNP (Open | NNP (Close | Initial pH | Final pH |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 9.3 | 9.55 | 1.169 | 2.338 | 116.596 | 115.427 | 114.258 | 9.30 | 9.55 |
| 2 | 2 | 9.54 | 9.39 | 1.130 | 2.260 | 128.558 | 127.428 | 126.298 | 9.54 | 9.39 |
| 3 | 3 | 9.51 | 9.39 | 1.204 | 2.407 | 124.838 | 123.635 | 122.431 | 9.51 | 9.39 |
| 4 | 4 | 9.49 | 9.1 | 0.340 | 0.680 | 114.236 | 113.897 | 113.557 | 9.49 | 9.10 |
| 5 | 5 | 9.74 | 9.53 | 0.346 | 0.692 | 117.434 | 117.088 | 116.742 | 9.74 | 9.53 |
| 6 | 6 | 9.82 | 9.4 | 0.329 | 0.658 | 115.557 | 115.228 | 114.899 | 9.82 | 9.40 |

What is below?

| Determinand | | Dam 10 | Dam10 | Loskop | Process Water Dam | Prosess Water Dam | Penstock Slimes Dam | Shaft | Shaft | Shaft | JF4 | JF-5(30) | JF-5(60) | JF7 | JE 9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 24-Jul-12 | 28-May-13 | 28-May-13 | 24-Jul-12 | 14-Feb-13 | 24-Jul-12 | 20-Oct-11 | 21-Apr-12 | 28-May-13 | 14-Feb-13 | 14-Feb-13 | 14-Feb-13 | 24-Jun-13 | 28-May-13 |
| **Chemical report** | **Units** | **Value** | **Value** | **Value** | **Value** | **Value** | **Value** | **Value** | **Value** | **Value** | **Value** | **Value** | **Value** | **Value** | **Value** |
| pH | | 8.81 | 9.01 | 8.19 | 9.18 | 8.95 | 8.83 | 7.56 | 8.66 | 8.23 | 8.61 | 6.94 | 6.98 | 7.43 | 7.82 |
| Electrical conductivity | mS/m | 213 | 698 | 72.1 | 293 | 142 | 291 | 106 | 95.3 | 112 | 38 | 172 | 187 | 67.9 | 75 |
| Calcium as Ca | mg/L | 19 | 40.1 | 57.4 | 11.2 | 10.2 | 11.7 | 24.7 | 22.62 | 33.3 | 3.47 | 155 | 174 | 66.5 | 78.5 |
| Magnesium as Mg | mg/L | 11 | 61.7 | 51.5 | 0.5 | 7.23 | 0.6 | 10.6 | 9.77 | 15.6 | 0.16 | 81.06 | 85.89 | 33.9 | 47.1 |
| Sodium as Na | mg/L | 416 | 1598 | 45.0 | 575 | 256 | 580 | 177.2 | 173.7 | 203.3 | 81 | 117 | 120 | 39.6 | 25.1 |
| Potassium as K | mg/L | 43.7 | 174.0 | 3.7 | 68.2 | 42.18 | 71.7 | 6.1 | 5.86 | 7.0 | 0.36 | 7.30 | 7.20 | 3.37 | 2.4 |
| P-Alkalinity | mg/L | 16.2 | 37.8 | 0 | 27.4 | 0 | 11.1 | 3.08 | 5.56 | 0 | 6.99 | 0 | 0 | 0 | 0 |
| M-Alkalinity | mg/L | 238 | 332 | 261 | 167 | 227 | 131 | 197 | 201 | 200 | 138 | 239 | 269 | 298 | 300 |
| Fluoride as F | mg/L | 0.55 | 0.33 | 0.13 | 0.48 | 0.21 | 0.39 | 0.93 | 1.57 | 1.84 | 0.04 | 0.12 | -0.10 | 0.38 | 0.12 |
| Chloride as Cl | mg/L | 108.8 | 446.4 | 16.6 | 220.0 | 29.9 | 208.0 | 36.6 | 41.5 | 47.2 | 13.9 | 62.1 | 70.5 | 24 | 17.0 |
| Bromide as Br | mg/L | <0.4 | 1.32 | 0.22 | <0.4 | <0.4 | <0.4 | -0.4 | 0.2 | <0.4 | 0.21 | 0.95 | 0.62 | 0.19 | 0.18 |
| Nitrate as N | mg/L | 0.56 | <1 | 0.1084 | 4.59 | 1.96 | 2.32 | | | <0.5 | 0.15 | <0.5 | <0.5 | <0.05 | 0.5516 |
| Phosphate as $PO_4$ | mg/L | <1 | <2 | <0.1 | <1 | <1 | <1 | -1 | -0.1 | <1 | <0.1 | < | <1 | <0.1 | <0.1 |
| Sulphate as $SO_4$ | mg/L | 650 | 2818 | 132 | 922 | 437.8 | 959 | 272 | 248 | 315 | 38.3 | 681.0 | 759.0 | 55 | 106 |
| Calcium Hardness | mg/L | 47.5 | 100.3 | 143.4 | 28 | 25.4 | 29.25 | | | 83.3 | 8.7 | 387.8 | 434.2 | 166 | 196.3 |
| Magnesium Hardness | mg/L | 45.1 | 252.8 | 211.1 | 2.05 | 29.6 | 2.46 | | | 63.9 | 0.7 | 332.4 | 352.2 | 139 | 193.2 |
| Total Hardness as $CaCO_3$ | mg/L | 92.6 | 353.1 | 354.5 | 30.05 | 55.0 | 31.71 | | | 147.1 | 9.3 | 720.2 | 786.3 | 305 | 389.6 |
| Total Dissolved Solids | mg/L | 1488 | 5464 | 568 | 1983 | 1017 | 1972 | | | 819 | 276 | 1340 | 1482 | 520 | 579 |
| Aluminium as Al | mg/L | 0.503 | 0.361 | 0.014 | 0.959 | 1.046 | 0.933 | | 0.008 | 0.010 | 0.061 | 0.002 | 0.000 | 0.007 | <0.004 |
| Arsenic as As | mg/L | <0.006 | 0.026 | <0.006 | <0.006 | <0.006 | <0.006 | 0.153 | 0.087 | 0.064 | <0.006 | <0.006 | <0.006 | <0.006 | <0.006 |
| Chromium as Cr | mg/L | <0.006 | 0.006 | <0.006 | <0.006 | <0.005 | <0.006 | | | <0.006 | <0.005 | <0.005 | <0.005 | <0.006 | <0.006 |
| Copper as Cu | mg/L | 0.003 | 0.025 | 0.006 | 0.004 | 0.010 | 0.004 | | 0.009 | 0.006 | 0.004 | 0.003 | 0.003 | 0.008 | 0.010 |
| Iron as Fe | mg/L | 0.546 | 0.474 | 0.018 | 0.825 | 1.185 | 0.883 | | 0.013 | 0.067 | 0.069 | 0.027 | 0.067 | 0.476 | 0.004 |
| Manganese as Mn | mg/L | 0.005 | 0.022 | 0.014 | 0.009 | 0.022 | 0.009 | | 0.018 | 0.029 | 0.003 | 0.126 | 0.137 | 0.104 | 0.008 |
| Molybdenum as Mo | mg/L | 0.131 | 1.703 | 0.036 | 0.238 | 0.191 | 0.290 | | 0.137 | 0.151 | 0.004 | <0.002 | <0.002 | <0.002 | 0.029 |
| Lead as Pb | mg/L | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | | | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 | <0.010 |
| Zinc as Zn | mg/L | <0.004 | 0.016 | 0.014 | <0.004 | 0.012 | <0.004 | | 0.015 | 0.015 | 0.005 | 0.007 | 0.007 | 0.014 | 0.014 |
| Vandium as V | mg/L | | 0.010 | 0.023 | | | | | | 0.006 | | | | <0.006 | 0.023 |
| Sodium Adsorption Ratio(SAR) | | | | | | | | | | | | | | | |
| Water Type | | | | | | | | | | | | | | | |
| Boron as B | mg/L | | | | | | | | | | | | | | |
| NO2-N | mg/L | | | | | | | -0.1 | 0 | | | | | | |
| NO3-N | mg/L | | | | | | | -0.5 | 0 | | | | | | |
| Si | mg/L | | | | | | | 10.8 | 11.269 | | | | | | |
| Ba | | | | | | | | | 0.01 | | | | | | |
| | | | | | | | | | | | | | | | |

| BH1 SD | BH2 SD | J BH 1 | J BH 1 | 17 Wstr | 17 Wstr | 11 Fstr | 11 Fstr | Pstr | Pstr | Itumeleng | Itumeleng | Cv | Cv | 6 Wstr | 35 Hstr | 35 Hstr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 24-Jun-13 | 24-Jun-13 | 20-Oct-11 | 20-Apr-12 | 20-Oct-11 | 30-Apr-12 | 20-Oct-11 | 18-Apr-12 | 20-Oct-11 | 24-Apr-12 | 20-Oct-11 | 28-Apr-12 | 20-Oct-11 | 17-Apr-12 | 26-Oct-11 | 26-Oct-11 | 19-Apr-12 |
| Value | Value | Value | Value | Value | Value | Value | Value | Value | Value | Value | Value | Value | Value | Value | Value | Value |
| 7.54 | 7.32 | 8.21 | 7.92 | 7.19 | 7.12 | 7.05 | 7.35 | 7.31 | 7.35 | 7.2 | 7.25 | 8.32 | 8.81 | 7.18 | 7.23 | 7.52 |
| 119 | 233 | 124 | 93.7 | 194 | 186 | 247 | 161 | 239 | 287 | 196 | 198 | 265 | 123 | 176 | 176 | 165 |
| 117.0 | 235.4 | 110.3 | 77.78 | 194.9 | 206.49 | 226.8 | 151.07 | 182.9 | 267.39 | 158.3 | 178.86 | 106.7 | 54.12 | 169.4 | 193.1 | 187.05 |
| 74.2 | 175.7 | 40.5 | 28.72 | 135.1 | 142.17 | 115.7 | 79.76 | 127.7 | 193.07 | 119 | 134.68 | 199.9 | 95.62 | 108.6 | 116.7 | 115.56 |
| 94.9 | 130.7 | 93.7 | 93.19 | 49.4 | 55.44 | 159.7 | 121.96 | 148 | 169.27 | 93.2 | 99.14 | 175.2 | 91.28 | 84.7 | 66.8 | 62.34 |
| 9.85 | 9.89 | 1.5 | 1.32 | 1.8 | 1.67 | 3.2 | 2.38 | 2.1 | 2.36 | 2.3 | 1.96 | 7.9 | 6.06 | 3.013 | 1.736 | 1.38 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6.46 | 0 | 0 | 0 |
| 298 | 479 | 365 | 298 | 410 | 261 | 453 | 354 | 430 | 414 | 426 | 420 | 404 | 199 | 386 | 427 | 463 |
| 1.44 | 0.11 | -0.1 | 0.15 | 0.1 | 0.16 | 0.16 | -0.1 | 0.09 | 0.1 | -0.1 | -0.1 | -0.1 | 0.21 | -0.1 | -0.1 | 0.1 |
| 53 | 80 | 55.5 | 48 | 118.2 | 109.1 | 173.2 | 107 | 227.8 | 413.3 | 132.3 | 158.8 | 348 | 128.3 | 99.39 | 95.26 | 104.3 |
| 0.33 | 0.64 | -0.4 | 0.2 | -0.4 | -0.4 | -0.4 | -0.4 | -0.4 | 0.9 | -0.4 | -0.4 | -0.4 | -0.4 | 0.95 | -0.4 | -0.4 |
| 4.32 | 2.38 | | | | | | | | | | | | | | | |
| <1 | <1 | -1 | -0.1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | 1.6 | 1 | -1 | -1 | -1 |
| 358 | 898 | 241 | 168.7 | 530 | 653 | 709 | 432.2 | 533 | 798 | 411 | 447 | 675 | 322.1 | 556 | 565 | 474.2 |
| 292 | 589 | | | | | | | | | | | | | | | |
| 304 | 721 | | | | | | | | | | | | | | | |
| 597 | 1309 | | | | | | | | | | | | | | | |
| 1024 | 2019 | | | | | | | | | | | | | | | |
| 0.147 | 0.053 | | 0.004 | | 0.004 | | 0.004 | | 0.004 | | 0.004 | | 0.009 | | | 0.004 |
| <0.006 | <0.006 | 0.015 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 |
| <0.006 | <0.006 | | | | | | | | | | | | | | | |
| 0.014 | 0.010 | | 0.008 | | 0.009 | | 0.007 | | 0.012 | | 0.01 | | 0.01 | | | 0.006 |
| 0.184 | 0.171 | | 0.025 | | 0.011 | | 0.01 | | 0.027 | | 0.011 | | 0.016 | | | 0.013 |
| 0.050 | 0.107 | | 0.011 | | 0.009 | | 0.007 | | 0.249 | | 0.011 | | 0.014 | | | 0.024 |
| 0.006 | 0.010 | | 0.014 | | 0.026 | | 0.013 | | 0.02 | | 0.021 | | 0.024 | | | 0 |
| <0.010 | <0.010 | | | | | | | | | | | | | | | |
| 0.082 | 0.034 | | 0.04 | | 0.031 | | 0.014 | | 3.552 | | 0.015 | | 0.012 | | | 0.142 |
| <0.006 | 0.013 | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | -0.1 | 0 | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 |
| | | 2.99 | 2.9 | 12.87 | 8.4 | 9.86 | 12.4 | 3.84 | 13 | 34.26 | 41.2 | 1.46 | 5.8 | 10.65 | 3.19 | 3.1 |
| | | 14.2 | 12.389 | 24.1 | 25.504 | 26.2 | 27.914 | 14.7 | 12.078 | 21.8 | 22.545 | 5.7 | 2.077 | 26.1 | 23.4 | 20.332 |
| | | | 0.01 | | 0.006 | | 0.006 | | 0.019 | | 0.019 | | 0.029 | | | 0.005 |
| | | | | | | | | | | | | | | | | |

| NG Kerk | 9 Ostr | 11OStr | 20 Ostr | 20 Ostr | 6 Rstr | 6 Rstr | TPB 1 | TPB 1 | TPB 2 | TPB 2 | 10 Vstr | 10 Vstr | Mw |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26-Oct-11 | 26-Oct-11 | 26-Oct-11 | 26-Oct-11 | 23-Apr-12 | 26-Oct-11 | 25-Apr-12 | 26-Oct-11 | 26-Apr-12 | 26-Oct-11 | 27-Apr-12 | 26-Oct-11 | 29-Apr-12 | 22-Apr-12 |
| Value | Value | Value | Value | Value | Value | Value | Value | Value | Value | Value | Value | Value | Value |
| 8.3 | 7.3 | 7.05 | 7.41 | 7.43 | 7.73 | 7.73 | 7.23 | 7.39 | 7.49 | 7.39 | 7.56 | 7.4 | 8.22 |
| 99.9 | 173 | 146 | 75.9 | 77.9 | 87.1 | 82 | 62.9 | 57.9 | 46 | 53.5 | 137 | 119 | 96.2 |
| 21.7 | 148.5 | 138.9 | 67.5 | 79.07 | 58.9 | 54.76 | 59.6 | 49.95 | 36.3 | 49.97 | 142.8 | 135.86 | 22.34 |
| 10.8 | 98.9 | 84.2 | 39.5 | 44.75 | 17.4 | 14.31 | 31.7 | 21.66 | 23.9 | 31.89 | 61.3 | 58.53 | 9.73 |
| 171.8 | 120.9 | 89.9 | 36.5 | 36.23 | 110.7 | 101.22 | 36.6 | 49.92 | 25.4 | 25.49 | 67.8 | 60.24 | 171.91 |
| 6.136 | 1.891 | 1.532 | 1.155 | 0.87 | 1.01 | 1.12 | 1.61 | 0.99 | 1.41 | 1.13 | 1.1511 | 1.33 | 5.83 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1.58 |
| 182 | 408 | 464 | 302 | 314 | 218 | 206 | 295 | 276 | 245 | 281 | 346 | 355 | 194 |
| 1.519 | -0.1 | -0.1 | 0.1981 | 0.22 | 0.1727 | 0.16 | 0.2532 | 0.29 | 0.2118 | 0.18 | -0.1 | -0.1 | 1.64 |
| 52.11 | 108.97 | 63.96 | 21.92 | 22.3 | 66.05 | 63.3 | 15.38 | 14.6 | 5.73 | 7.9 | 92.46 | 77.6 | 49.2 |
| -0.4 | -0.4 | -0.4 | 0.11 | 0.2 | 0.23 | 0.3 | 0.09 | 0.1 | 0.06 | 0 | -0.4 | -0.4 | 0 |
| | | | | | | | | | | | | | |
| -0.1 | -1 | -1 | -0.1 | -0.1 | -0.1 | -1 | -0.1 | -0.1 | -0.1 | -0.1 | -1 | -1 | -0.1 |
| 271 | 493 | 338 | 113 | 117.7 | 161 | 798 | 41 | 33 | 14 | 24.7 | 307 | 244.8 | 249 |
| | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| | | | | 0.004 | | 0.004 | | 0.004 | | 0.006 | | 0.004 | 0.012 |
| 0.058 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.07 |
| | | | | | | | | | | | | | |
| | | | | 0.007 | | 0.012 | | 0.047 | | 0.01 | | 0.007 | 0.011 |
| | | | | 0.013 | | 0.027 | | 0.011 | | 0.014 | | 0.009 | 0.034 |
| | | | | 0.01 | | 0.249 | | 0.023 | | 0.012 | | 0.01 | 0.013 |
| | | | | 0.004 | | 0.02 | | 0.006 | | 0.002 | | 0.005 | 0.159 |
| | | | | | | | | | | | | | |
| | | | | 0.033 | | 3.552 | | 0.194 | | 0.018 | | 0.011 | 0.033 |
| | | | | | | | | | | | | | |
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| | | | | | | | | | | | | | |
| | | | | | | | | | | | | | |
| -0.01 | -0.1 | -0.1 | -0.01 | 0 | -0.01 | 0 | -0.01 | 0 | -0.01 | | -0.1 | -0.1 | |
| -0.05 | 4.6 | 0.54 | 0.86 | 0.8 | 2.2 | 1.1 | 2.29 | 1.3 | 0.21 | | 5.89 | 5 | |
| 10.7 | 21.8 | 22.1 | 16.6 | 16.766 | 7.7 | 7.609 | 15.2 | 13.591 | 19.7 | | 14 | 14.503 | |
| | | | | 0.015 | | 0.012 | | 0.005 | | | | 0.005 | |
| | | | | | | | | | | | | | |