Sasol: Report on Geohydrological Investigation as part of the EMP for the Impumelelo project

April 2016

Contact Details:
Phone: 0844091429
Fax: 0866950191
P.O. Box 448
Riversdal
6670
gcomplete@outlook.com

Compiled by: Elida Boshoff

Reviewed by: Gerhard Steenekamp
Groundwater Complete have been contracted by Clean Stream Environmental Consultants (CSEC) to conduct a specialist geohydrological investigation to update the groundwater study for the Sasol Impumelelo Mine Extension project to include the following additional reserve areas:
- Hartbeesfontein,
- Mahemsfontein,
- Paardefontein, and
- Boschmansfontein.

The project entails work done previously as updated by recent work and is applicable to the whole mining area (Impumelelo, Mahemsfontein and the current extension project).

This study will focus on the Sasol Impumelelo Mine Extension and the Impumelelo Mine itself. The baseline section of this report will include the Witnek Mine. A current mine plan is available for the Impumelelo Mine and will be updated in the numerical model and calculations since the plan has changed since 2013. Mining includes the 2 and 4 seams. The board-&-pillar mining method will be used followed by stooping.

The Impumelelo area is underlain predominantly by rocks of the Karoo Supergroup. The area is located in the Vryheid Formation which is part of the Ecca group. The Vryheid formation is made up predominantly of coal, sandstone and shale. The area is largely covered by dolerite sills. At the mining area the Vryheid formation sometimes consist of five coal seams of varying thickness. The most prominent of these are number 2 and 4 seams.

From the hydrocensus and groundwater user surveys conducted in 2009 and 2015 it followed that a significant amount of privately used boreholes occur in the area. Main groundwater uses in the area include livestock watering and water used for domestic purposes.

Groundwater levels in the Impumelelo area were measured during the hydrocensus surveys and in monitoring boreholes. Water levels recorded in all the boreholes vary mostly between 0 and 35 mbs. Several artesian boreholes were recorded in the study area during the hydrocensus.

Groundwater quality:
- Groundwater quality in the overall area is generally good with few boreholes having poor water quality.
- The groundwater is mostly fresh, clean, relatively young and has undergone some sort of ion exchange.
- Bicarbonate alkalinity dominates the anion content.
- In terms of irrigation; the salinity hazard of the groundwater is medium to high and can cause some problems if not managed properly.

The following possible impacts are expected for the Impumelelo Mine:
- Recharge to the mine will continue after closure at a much higher rate than that of pre-mining recharge.
- Water levels in the mine voids will continue to rise individually in different compartments.
- The 2 seam voids will fill first as well as lowest parts of the 4 seam that are not underlain by 2 seam workings.
- Water levels will rise until each compartment is filled and water from all compartments is interconnected.
- At Impumelelo all compartments will be filled before the decant elevation (±1560 mamsl) is reached.
- The final water level in the mine will be flat because of the high transmissive nature of the goaf material.
- Post closure, a water make of some 8 770 m$^3$/day is predicted.
- Under normal conditions, it would take around 53 years (Table 10) for the water levels in the mine to fill the 2 and 4 seam workings.
- The water level is not expected to recover to the pre-mining conditions due to the highly transmissive nature of the rock matrix above the mined areas.
- A decanting mine will derive its water from recharge that moves down into the goaf, then laterally towards the decanting position and finally through existing cracks to decant onto the surface.
- Recharged water will therefore become contaminated in the goaf before it discharges at the decant point.
- If the mine water is left undisturbed (through pumping) stratification of the water column in the mine will cause the best quality water to remain on top of the water column.
- The potential for acid rock drainage reactions has been confirmed and actions will have to be planned to manage the decant and prevent poor quality water to affect the receiving environment such as surface water, soil and downgradient aquifers.
- Downstream movement of a deeper groundwater pollution plume can occur especially in the decant area after the water level in the mine has recovered to near surface.
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LIST OF ABBREVIATIONS
Mbs - meters below surface
Mamsl - meters above mean sea level
MAP - Mean Annual Precipitation
SWL - Static Water Level
EC - Electrical Conductivity

Coordinates: WGS84 Transverse Mercator
1 INTRODUCTION

1.1 BACKGROUND

Groundwater Complete have been contracted by Clean Stream Environmental Consultants (CSEC) to conduct a specialist geohydrological investigation to update the groundwater study for the Sasol Impumelelo Mine Extension project to include the following additional reserve areas:

- Hartbeesfontein,
- Mahemsfontein,
- Paardefontein, and
- Boschmansfontein.

The project entails work done previously as updated by recent work and is applicable to the whole mining area (Impumelelo, Mahemsfontein and the current extension project).

The project includes the Impumelelo Mine, the Impumelelo Mine Extension and the Witnek Mine (Figure 1).

Groundwater Complete conducted a groundwater specialist study in 2009 for the Sasol Impumelelo Project as input to the Environmental Impact Assessment (EIA), Environmental Management Plan (EMP) and Water Use License (WUL) authorizations at the time. The authorizations have been obtained and mining commenced in 2012. Groundwater Complete have also been contracted by Clean Stream Environmental Consultants (CSEC) to conduct a specialist geohydrological investigation to update the 2009 groundwater study for the Sasol Impumelelo project to include an additional reserve area at the farm Mahemsfontein. This study was completed in 2013.

This study focuses on the Sasol Impumelelo Mine Extension and the Impumelelo Mine itself. The baseline section of this report includes the Witnek Mine. A current life-of-mine (LOM) plan is available for the Impumelelo Mine and Impumelelo Mine Extension. The focus of this study was to update the numerical model and calculations considering mine schedule layout changes and extensions since 2013. Mining includes the 2 and 4 seams. The board-&-pillar mining method will be used followed by stooping.

1.2 STUDY APPROACH

Groundwater information for the geohydrological study was obtained from different sources including:

- Groundwater information gathered and interpreted in support of the EIA for the Impumelelo mining project in 2009 and 2013,
• Groundwater information gathered and interpreted in support of the EIA for the Impumelelo Mine extension project in 2016.

• Dedicated information gathering through groundwater quality analysis and water level measurements.

For the purpose of this study, the desk top, hydrocensus and previously collected information was combined and interpreted in a holistic manner. For the purpose of compiling the specialist report the physical and chemical properties of the groundwater regime were evaluated using the following methodology:

• Topographical and geological maps and orthographic photographs was used to describe the physical properties of the groundwater domain,

• Aquifer test data from existing monitoring boreholes at the Impumelelo Mine project was evaluated to describe the geohydrological features and calculate aquifer parameters,

• Hydrocensus surveys were conducted during which groundwater users around the mining area were identified, boreholes were surveyed in terms of positions and water quality and water uses were determined,

• Existing monitoring borehole and exploration borehole logs were used to evaluate the geology and acid generating potential of the host rocks.

• Information from existing monitoring boreholes drilled at the Impumelelo project was used to determine the hydraulic properties of the saturated zone,

• Groundwater flow velocities were calculated from first principles to use as guidelines in numerical model construction,

• All the above data types were interpreted with appropriate techniques in each case and will be used to construct a conceptual and numerical model of the groundwater regime, and

• The numerical model was calibrated using groundwater levels and aquifer test information.

The locality of the Impumelelo mining area is presented in Figure 1.
The task items and terms of reference (TOR) have been developed for similar authorization studies. Virtually all aspects of groundwater are covered and the specialist study results can be used for most environmental and related authorizations, including EIA’s, EMP’s or Water Use License (WUL) applications.

The scope of work and methodology of the groundwater study are summarized below:

- Desktop study and key field data collection:

Figure 1: Locality map of the Impumelelo mining areas

1.3 PLAN OF STUDY
- Initial data collection and hydrocensus for additional mining areas,
- Measure water levels and qualities in extension areas,
- Record groundwater uses and users in extension areas,
- Use results from previous studies in 2009 and 2013.

- Site Investigation:
  - Use all information collected during the site investigations during the 2009 and 2013 studies for this study.

- Data evaluation and holistic interpretation of all data types.
- Postulation of a conceptual hydrogeological model.
- Update of numerical model.
- Flow and mass transport calculations, groundwater balance, mine water balance, stage curve development etc.
- Post-closure model.
- Evaluation and reporting.
2 Site Setting

2.1 Geography

The surface area in the vicinity of the Impumelelo Mine is gently undulating. The highest surface elevations in and around the project outline are around 1800m, while the lower elevations are at 1550m above sea level. In the Impumelelo Mine and extension area itself, the highest elevation is at approximately 1725 mamsl (Figure 2), while the lowest elevations are at 1550 mamsl. Higher run-offs can be expected from the hill slope areas than from the drier plains. The topography dips from the north of the project area at Boshmansfontein area mainly towards the south and to the south-east.

Figure 2: Topographical contour map in the Impumelelo lease area.
2.2 **Surface Water Drainage**

The water courses in the vicinity of the mining area drains in several directions. Drainage occurs as follows:

1. From Grootvley, Hartbeesfontein and Mahemfontein areas drainage occurs towards the south into the Grootspruit.
2. From Paardefontein area drainage occurs towards the south and south-east into the Waterval River.
3. From Boschmansfontein area drainage occurs towards the south-east into the Wolwespruit and east into the Kaalspruit.

The main water courses in the study area are indicated on Figure 3.

![Figure 3: Main water courses in the Impumelelo mining area.](image)

**2.3 Climate**

The Impumelelo area is located in the Highveld region where the climate is characterised as generally dry. Summers are warm to hot with an average daily temperature of approximately 20°C. Winters range from mild to cold with an average daily temperature of approximately 7.4°C, (Sasol Mining: Brandspruit Mine, Impumelelo Shaft - Scoping Report, 2009).
The Impumelelo area is situated in a summer rainfall region and thunderstorms are known to contribute a large volume of rain within a short period of time. The mean annual precipitation (MAP) varies from 550 mm to 750 mm in the areas of the closest three municipalities, (Sasol Mining: Brandspruit Mine, Impumelelo Shaft - Scoping Report, 2009).

Despite the significant (from a South African perspective) annual rainfall the effective recharge to the aquifer(s) is not significant and is estimated to be around 5% (or less) of MAP. This low figure is a direct result of a number of factors including most notably:

- the surface geology consisting of relatively low permeability Karoo type sediments,
- An expected high rate of evapo-transpiration that exceeds the precipitation and causes a net environmental water deficit for most of the year.

Qualified guesses from general equations and expert opinions have been made by scientists for recharge in this Karoo Supergroup geology (v. Tonder & Xu, 2001). Depending on the soil cover thickness the estimated recharge to the typical Karoo aquifers (sandstone, mudstone and siltstone) varies between 2 and 5% of the MAP (Figure 4).

Table 1: Typical recharge values for different geology (v. Tonder & Xu, 2001).

<table>
<thead>
<tr>
<th>Geology</th>
<th>% Recharge (soil cover &lt;5m)</th>
<th>%Recharge (soil cover &gt;5 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandstone, mudstone, siltstone</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>Hard Rock (granite, gneiss etc.)</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Dolomite</td>
<td>12</td>
<td>8</td>
</tr>
<tr>
<td>Calcrete</td>
<td>9</td>
<td>5</td>
</tr>
<tr>
<td>Alluvial sand</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Coastal sand</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>Alluvium</td>
<td>12</td>
<td>8</td>
</tr>
</tbody>
</table>

According to the recharge estimations by Vegter (1995), the recharge in the Impumelelo mining area can be between 3 and 5% of the MAP (Figure 5).
2.4 GEOLOGY

The Impumelelo area is underlain predominantly by rocks of the Karoo Supergroup. The area is located in the Vryheid Formation which is part of the Ecca group. The Vryheid formation is made up predominantly of coal, sandstone and shale. The area is largely covered by dolerite sills, also of Karoo age. At the mining area the Vryheid formation sometimes consist of five coal seams of varying thickness. The most prominent of these are number 2 and 4 seams.

The coal seams in the area vary in depth from 90 - 250 meter below surface (mbs) in seam 2 and 50 - 200 mbs in seam 4. A simplified geological surface map of the area is presented as Figure 5, representing geology as reproduced from the 1:250 000 scale geological map of the area. The generalized stratigraphy of the Impumelelo area is presented as a simplified geological log in Figure 6.

Floor contour sections are illustrated for the mining area in Figure 7 and the position of the section line is indicated in Figure 5. The Karoo sequence comprises of a sedimentary succession of sandstones, shales and coal measures. The coal measures are contained within the Vryheid Formation in the Ecca Group. The sedimentary succession overlies the Dwyka formation, comprising of diamicittes and tillites. The sediments consist mainly of soil, weathered sandstone, shale, mudstone and coal seams of varying thickness. The
approximate seam thickness in the area averages 2 m in the 2 seam and 2.9 m in the 4 seam.

Dolerite intrusions in the form of dykes and sills are present in the Ecca Group and sometimes result in vertical displacement of the coal seam. The dolerite dykes are important for mining purposes due to the volatilization effect these intrusions had on the coal.

From a geohydrological perspective, the intrusives are important since they will have a definite impact on the geohydrology of the mining area, either in terms of preferred pathways for flow and mass transport or horizontal flow barriers and/or confinement structures in vertical or horizontal sense. Some dolerite dyke intrusions occur in the mining areas as well as a number of displacement faults. The actual effect and hydraulic properties of the geological structures (intrusives and dykes) in the deeper aquifer have not been tested in this project.
Figure 5: Simplified geological map (1:250 000 scale) of the Impumelelo mining project
Figure 6: Generalized stratigraphical section of the Impumelelo Mine area (Sasol).
Figure 7: NW-SE vertical section through the Impumelelo lease area showing the surface and coal seams relationship.
3 HYDROCENSUS AND USER SURVEY

3.1 GROUNDWATER USE (USER SURVEY/HYDROCENSUS RESULTS)

An extensive hydrocensus and user survey was conducted in 2009 as baseline assessment to the original groundwater study. The Impumelelo Mine extension areas were not covered in the original hydrocensus and the census was expanded in the 2016 study to include these areas (Figure 9). From the hydrocensus and groundwater user surveys conducted in 2009 and 2016 it followed that a significant amount of privately used boreholes occur in the area (Figure 8). Main Groundwater uses in the area include livestock watering and water used for domestic purposes.

![Groundwater Uses Chart]

Figure 8: Chart indicating the groundwater uses in the mining area.

No direct yield information was obtained during the hydrocensus surveys. In general, borehole yields in the area are not significant and correspond to typical Karoo type aquifers in this area.

Widespread pollution or depletion of the groundwater resource will thus impact negatively not only on the resource, but also on the users depending on the source as sole source of domestic and livestock water supply.

The positions of all boreholes where some form of information was recorded during the hydrocensus survey are presented on the map in Figure 9. It is clear from the map that distribution of surrounding user boreholes is good in the area.
The potential radius of influence on the groundwater regime around a coal mine in Karoo sediments is usually accepted as 1 km. This is subjective, because the radius of influence depends strongly on geological structures such as faults and dykes (preferred groundwater flow paths), groundwater gradients, nearby mining operations and the presence of other groundwater production boreholes or dewatering from mining in the area.

3.2 Presence of Boreholes and Springs

Figure 9: Boreholes recorded during the hydrocensus surveys (2009 and 2016) in the area
Experience from other coal mines in similar Karoo-type aquifer conditions has, however, indicated that the influences of underground coal mining activities on the regional groundwater level are usually not very extensive and usually limited to less than 0.5 km.

Different types of groundwater information were obtained for a total of 428 points during the 2009 and 60 during the 2016 groundwater user surveys and hydrocensus conducted in the Impumelelo area (Figure 9 and Figure 11). No yields of the recorded boreholes were available. Yields of newly monitoring boreholes will be determined with the aid of pump tests.

A significant number of privately operated boreholes were located during the survey. Groundwater in the area is used for domestic purposes and especially livestock watering. Water levels were taken in most of the boreholes located if access was possible. These water levels were also used to aid in the calibrating the numerical model for the area.

No yields were obtained for the hydrocensus boreholes. The yields of the monitoring boreholes drilled and pump tested in the mining area compare very well with boreholes in Karoo aquifer environments and varied from 0.02 to 0.04 l/s.

In secondary, fractured rock aquifers groundwater flow through the aquifer – and thus to a successful borehole – depends directly on the presence of transmissive (permeable) fractures. The more transmissive the fracture, the higher the potential yield of the borehole will be. With mining planned to occur well below the level of the majority of the boreholes in the area, no direct impact is bound to occur on the water-yielding fractures of the shallower boreholes in the shallow aquifer.

The greatest negative impact of mining on the aquifer will be dewatering. Groundwater will seep into the mine void that is created below the static water level or piezometric head, which will result in drawdown of the water level. Initially, only the deeper aquifer will be affected but later the shallow aquifer will also be dewatered. This will happen because high extraction mining will cause breaking and partial collapse of the roof strata above the mine. Cracks will form from the mine to the surface and water from the shallow aquifer will flow through these highly transmissive cracks to the mine voids. If these areas of surface subsidence are below or close to existing boreholes, the water level will drop and the drop can be to such an extent that the boreholes will ‘dry up’ totally.

Although the transmissive fractures might still be present in the borehole, the water level drops and the borehole won’t have any yield left.

Because of the behaviour described above, borehole yields are not used as an indicator of impact but water levels are rather used.

Apart from yield testing not being practical (due to access, existing equipment, time and cost to name but a few) on a scale as the mining operation planned for the Impumelelo Mine project, it is also not the most appropriate impact assessment parameter.
The static water level distribution was measured during the hydrocensus and user surveys and will be used as indicator of impact of the mining operation. The monitoring network will be planned to include the entire active mining area as well as a buffer zone around the active mine to serve as an early warning system of dewatering impacts from the mine.

Water levels can also be measured with relative ease and at low cost over a large area in a short time and can be repeated regularly (quarterly frequency recommended) to include seasonal fluctuations. Any impacts indicated by the time-series water level measurements can then be addressed by Sasol.

Six springs were recorded during the 2009 hydrocensus in the area under investigation (Figure 10). Springs in a semi-confined or confined fractured rock aquifer usually occur where structural discontinuities in the aquifer bisect the confining layer / material and a fracture or fracture system reaches the surface. For a spring to occur, the water level or piezometric head at that point in the aquifer must be higher than the land surface. No springs were recorded during the 2016 hydrocensus survey.

Although the natural trend for the groundwater level or piezometric head is to follow the surface topography, the water level is the closest to surface in the topographically low-lying areas. For this reason, springs will mostly occur in these areas, or at least on the slopes of hills. In perched and confined aquifers however, groundwater or piezometric levels may also be high in topographical higher lying areas with subsequent spring formation.

![Figure 10: Springs recorded in the area during the 2009 hydrocensus.](image-url)
The geohydrological logs of all the groundwater monitoring boreholes are not discussed in detail because it would become somewhat exhaustive. The most important lithological intersections, yield and stratification trends and recommended sampling depths are summarized in Table 2. This geohydrological data, together with water level information is crucial for better understanding of the geohydrological regime and processes that will determine groundwater types, flow and transport velocities and aquifer parameter distribution. All information gathered from these boreholes was used, where available, in the compilation of applicable parts such as the conceptual and numerical modeling, impact and risk assessments.

Groundwater monitoring boreholes were drilled during the 2009 study, Figure 12. The groundwater monitoring boreholes in the Impumelelo Mine area have been sited mainly downgradient of the planned underground mining areas and within the hydro geographical regime that may be affected by the existing and future mining activities. All the boreholes have been drilled specifically for monitoring purposes at the mining area and were constructed accordingly.

The boreholes were mostly drilled into geological structures and intrusive features such as faults and dykes, especially on the intersection point of more than one such structure.
Drilling results indicate that most of the intersected aquifers have relative low groundwater yields. Yields vary from 0.02 to 0.04 liter per second in the new mining area with the most common groundwater intersections occurring in contact zones between Karoo Supergroup rocks such as coal and sandstone with intrusive dolerite.

Table 2: 2009 Monitoring borehole information (yield, stratification, sampling depth, construction)

<table>
<thead>
<tr>
<th>BH ID</th>
<th>Geology</th>
<th>Sampling depth (mbs)</th>
<th>Yield (l/s)</th>
<th>Construction</th>
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<td></td>
<td></td>
<td></td>
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<td>6mm UPVC</td>
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<td>SB2-14</td>
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<tr>
<td>SB2-18s</td>
<td>SOIL, DLRT</td>
<td>15</td>
<td>0.04</td>
<td>23.2</td>
</tr>
<tr>
<td>BH ID</td>
<td>Geology</td>
<td>Sampling depth (mbs)</td>
<td>Yield (l/s)</td>
<td>Construction</td>
</tr>
<tr>
<td>--------</td>
<td>------------------</td>
<td>----------------------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td>SB2-18d</td>
<td>SOIL, DLRT, SNDS, SHLE</td>
<td>130</td>
<td>0.03</td>
<td>-</td>
</tr>
<tr>
<td>SB2-20</td>
<td>SOIL, DLRT</td>
<td>15</td>
<td>0.04</td>
<td>23.2 5.8 12</td>
</tr>
</tbody>
</table>

Note: SOIL = Soil, COAL = Coal, SNDS = Sandstone, SHLE = Shale, DLRT = Dolerite

Figure 12: Positions of 2009 monitoring boreholes.

Table 3: Positions of the existing monitoring boreholes.

<table>
<thead>
<tr>
<th>Name</th>
<th>X coordinate</th>
<th>Y coordinate</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB2-1</td>
<td>13942</td>
<td>-2943501</td>
</tr>
<tr>
<td>SB2-2d</td>
<td>10814</td>
<td>-2944170</td>
</tr>
<tr>
<td>SB2-2S</td>
<td>10814</td>
<td>-2944170</td>
</tr>
<tr>
<td>SB2-4</td>
<td>7120</td>
<td>-2946407</td>
</tr>
<tr>
<td>SB2-6s</td>
<td>9607</td>
<td>-2949043</td>
</tr>
<tr>
<td>SB2-6d</td>
<td>9618</td>
<td>-2949048</td>
</tr>
<tr>
<td>SB2-7</td>
<td>5323</td>
<td>-2950385</td>
</tr>
<tr>
<td>SB2-8s</td>
<td>1179</td>
<td>-2948060</td>
</tr>
</tbody>
</table>
In order to describe and predict the movement of water in the subsurface, a conceptual geohydrological model of the area under investigation is developed. The basis of such a model is the structural geological make-up of the study area and measurable geohydrological entities such as water levels, gradients, borehole/aquifer yields, aquifer types, depth, thickness and other characteristics. This information was obtained from the drilling results of the boreholes that were purpose-drilled for aquifer parameter testing and ongoing groundwater monitoring.

The conceptual geohydrological model for the Impumelelo area is postulated and discussed in this section.

It is concluded that the geohydrological regime in the Impumelelo area is made up of two aquifer systems. The first, the upper, semi-confined aquifer occurs in the weathered zone and on pedological discontinuities (e.g. hardpan ferricrete formations). The second, deeper aquifer is associated with fractures, fissures and joints and other discontinuities within the consolidated Karoo bedrock and associated intrusives.

### 4.1 Aquifer Classification

For the purpose of this study an aquifer is defined as a geological formation or group of formations that can yield groundwater in economically useable quantities. According to this definition of an aquifer, only the weathered-fresh interface or fractures in the hard rocks below the weathered zone could be defined as aquifers. By another definition, an aquifer is a geological formation or group of formations that can yield groundwater in economical exploitable quantities.

Distinction between aquifers is generally based on the type of porosity in the aquifer, i.e. a primary aquifer formed by primary pore porosity or secondary aquifer formed due to secondary porosity. Secondary porosity, reflecting development of open space and voids.
with potential groundwater storage and aquifer development in an otherwise impermeable rock, occurs in the presence of weathering and/or fracturing of the rock mass.

The different types of aquifer porosity are illustrated in Figure 13.

![Figure 13: Types of aquifers based on porosity.](image)

Two aquifer types were found to be present in the study area. The drilling results from the numerous boreholes completed for monitoring and testing was used to assess the groundwater regime and to postulate a conceptual groundwater model.

All significant groundwater strikes, indicating the presence of aquifers, occurred in fractures or fracture zones caused by faulting, igneous intrusion and cooling, bedding plane fracturing or small discontinuity fractures developed on hard rock / soft rock contacts.

Based on the depths of water strikes and consequent static piezometric water levels in the area, the fractured rock aquifer(s) could be regarded as semi-confined.

In spite of having relatively low blow-out yields or being dry altogether, pump tests were performed on some of the new monitoring boreholes where water was available in the boreholes, even if they did not show any significant water strike during drilling. These pump tests were performed using a low yield (± 0.3 to 0.4 l/s) pump with the main aim of determining the transmissivity and storage characteristics of the solid geological formation – the so-called aquifer matrix. These low rate pump tests are performed instead of the more commonly used slug tests because of the much improved accuracy obtained with the pump tests, resulting in much more reliable aquifer parameters calculated from the tests.

Based on the calculated aquifer parameters, yields of the aquifers in the area vary between 0.1 and 0.2 l/s. If the pump tests are analyzed to long term sustainable yields, these figures become significantly lower at less than 0.05 l/s. Borehole yields recorded during the hydrocensus and user survey were mostly in the same range but higher yields of up to 0.5 l/s were also indicated. The higher reported yields are expected to reflect short term optimum yields and have not been tested scientifically.
4.2 AQUIFER DELINEATION

Aquifer delineation is difficult to conduct to an acceptable level of confidence for a heterogeneous aquifer such as at Impumelelo, especially considering the large project area. The aquifer is intersected by numerous geological structures such as dykes. These geological structures are potential preferential flow paths for groundwater and can extent the aquifer significantly. These structures can therefore cause over- or under estimation of the delineated aquifer. For this reason aquifer delineation for the Impumelelo area will not be conducted.

The aquifer around the mining area will thus be taken as that part of the aquifer that was used or considered during simulation exercises (numerical modeling). Because the main aquifer is in all probability a fractured rock type and fractures could assume any geometry and orientation, the physical boundary or ‘end’ of the aquifer(s) is very difficult to specify or quantify. More appropriately, the aquifer boundary conditions that have been considered during numerical model simulations are described below.

Aquifer boundaries in a model are usually either no-flow boundaries (groundwater divides) or constant head boundaries. No-flow boundaries are groundwater divides (high or low areas / lines) across which no groundwater flow is possible. Constant head boundaries are positions in the model where the groundwater level is fixed at a certain elevation and cannot change.

In the regional model constructed to include the Impumelelo Mine area constant head boundaries were used as model boundaries. The constant head boundaries were not inserted as constant head nodes in the model but river nodes were rather employed on the same elevations and positions where perennial rivers occur.

The ‘river nodes’ act very much the same as constant head boundaries. Water levels in the aquifer are largely fixed at these points and the river will add water to or remove water from the aquifer if the surrounding model water levels respectively decrease below or rise above the assigned elevation of the river. Some rivers and several major streams occur in the area and are water features that are mostly perennial. These have been inserted as constant head boundaries (river nodes) in the Impumelelo Mine area.

A no-flow boundary in a numerical model is usually represented by the end / edge of the active cells of the model grid. The regional model area showing no-flow boundaries and river nodes is presented in Figure 14.
Aquifer transmissivity is defined as a measure of the amount of water that could be transmitted horizontally through a unit width of aquifer by the full-saturated thickness of the aquifer under a hydraulic gradient of 1. Transmissivity is the product of the aquifer thickness and the hydraulic conductivity of the aquifer, usually expressed as m$^2$/day (Length$^2$/Time).

The average transmissivity of the host rocks in the Impumelelo Mine area (Table 4) was calculated at around 0.2 m$^2$/d while that of the fracture zones in the Karoo aquifers are estimated at 1.6 m$^2$/day.

The transmissivity and storativity values for boreholes in the underground mining area are presented in Table 4. It should be noted that although the storage coefficient in a fractured rock aquifer cannot be calculated accurately with conventional pump test analysis methods like the Cooper-Jacob or Theis analysis algorithms, the calculated storage coefficients have been included in the table. The storage coefficients calculated by means of the low-yielding pump tests were found to be very close (slightly lower) to theoretical and calculated values for these rock types, namely in the order of 10$^{-3}$.

Because aquifer hydraulic parameters (like most geological parameters) usually display a log-normal distribution it is an accepted approach to calculate the harmonic or geometric mean in preference to the arithmetic mean. A generally accepted approach for calculating a
Representative hydraulic conductivity for an aquifer is to take the average of the harmonic and geometric means. These values have been calculated in Table 4 and it follows that the representative transmissivity of the aquifer matrix (between fracture zones) can vary between 0.1 and 0.3 with an average of \(0.2 \text{ m}^2/\text{day}\). These transmissivities calculate to representative hydraulic conductivities of between 0.01 and 0.08 m/d for the shallow aquifer in the greater Impumelelo Mine area. For the deeper aquifer the hydraulic conductivities will be at least an order of magnitude lower – in the order of 0.001 m/d.

Storativity (or the storage coefficient) is the volume of water that a permeable unit will absorb or expel from storage per unit surface area per unit change in piezometric head. Storativity (a dimensionless quantity) cannot be measured with a high degree of accuracy in slug tests or even in conventional pumping tests. It has been calculated by numerous different methods with the results published widely and a value of 0.002 to 0.01 is taken as representative for the Karoo Supergroup sediments. In the pumping tests conducted at the mining areas, the calculated storage coefficient values were exactly in that order of magnitude.

**Table 4: Summary of pump test data in the Impumelelo Mine area**

<table>
<thead>
<tr>
<th>Borehole Number</th>
<th>Tf (m²/day)</th>
<th>Tm (m²/day)</th>
<th>Sf</th>
<th>Sm</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB2-BH01</td>
<td>3.0</td>
<td>0.1</td>
<td>9.0E-03</td>
<td>9.0E-03</td>
</tr>
<tr>
<td>SB2-BH02s</td>
<td>0.9</td>
<td>0.2</td>
<td>5.0E-03</td>
<td>4.0E-03</td>
</tr>
<tr>
<td>SB2-BH06s</td>
<td>5.0</td>
<td>0.2</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SB2-BH07</td>
<td>1.9</td>
<td>0.2</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SB2-BH08s</td>
<td>3.0</td>
<td>0.2</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SB2-BH08d</td>
<td>3.0</td>
<td>0.3</td>
<td>8.0E-03</td>
<td>9.0E-03</td>
</tr>
<tr>
<td>SB2-BH11</td>
<td>2.0</td>
<td>0.2</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SB2-BH13s</td>
<td>2.0</td>
<td>0.2</td>
<td>NA</td>
<td>6.0E-03</td>
</tr>
<tr>
<td>SB2-BH13d</td>
<td>1.0</td>
<td>0.2</td>
<td>4.0E-03</td>
<td>6.0E-03</td>
</tr>
<tr>
<td>SB2-BH14</td>
<td>1.3</td>
<td>0.2</td>
<td>3.0E-03</td>
<td>4.0E-03</td>
</tr>
<tr>
<td>SB2-BH16</td>
<td>1.2</td>
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<td>2.0E-03</td>
<td>4.0E-03</td>
</tr>
<tr>
<td>SB2-BH17</td>
<td>3.0</td>
<td>0.2</td>
<td>7.0E-03</td>
<td>NA</td>
</tr>
<tr>
<td>SB2-BH18s</td>
<td>1.0</td>
<td>0.3</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SB2-BH18d</td>
<td>1.0</td>
<td>0.2</td>
<td>2.0E-03</td>
<td>2.0E-03</td>
</tr>
<tr>
<td>SB2-BH20</td>
<td>1.0</td>
<td>0.3</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Geometric mean</td>
<td>1.7</td>
<td>0.2</td>
<td>4.3E-03</td>
<td>5.0E-03</td>
</tr>
<tr>
<td>Harmonic mean</td>
<td>1.5</td>
<td>0.2</td>
<td>3.7E-03</td>
<td>4.4E-03</td>
</tr>
<tr>
<td>Mean of Geo and Harmonic</td>
<td>1.6</td>
<td>0.2</td>
<td>4.0E-03</td>
<td>4.7E-03</td>
</tr>
</tbody>
</table>

**Note:**

Tf – Transmissivity at the start of the test, usually fracture dominated flow.

Tm – Transmissivity at the end of the test, usually matrix dominated flow.
4.4 AQUIFER RECHARGE AND DISCHARGE RATES

Effective recharge in the project area is estimated to be between 2 and 5% (Section 2.3) of MAP. Based on this estimate the average recharge to the entire Impumelelo Mine area (MAP = 750 mm) can vary between approximately 11 700 m$^3$/d (4 300 000 m$^3$/y) to 29 300 m$^3$/day (10 700 000 m$^3$/y). The average recharge to the entire Witnek Mine area (MAP = 750 mm) can vary between approximately 7 900 m$^3$/d (2 900 000 m$^3$/y) to 19 700 m$^3$/day (7 200 000 m$^3$/y).

The recharge figures will be used in the calculation of the groundwater component of the environmental water balance and the effect of the mining on the natural water balance.

4.5 DEPTH TO WATER LEVEL

Groundwater levels in the Impumelelo area were measured during the hydrocensus surveys and in monitoring boreholes. Water levels recorded in all the boreholes vary mostly between 0 and 35 mbs (Figure 15). Several artesian boreholes were recorded in the study area during the hydrocensus.

The groundwater levels measured during the hydrocensus surveys and in monitoring boreholes will be used as calibration points for the numerical groundwater model to verify the conceptual model and construction thereof.

The boreholes where water level information is available are too many to display clearly on a single thematic map. A map of static water level contours was created to display the water level distribution as contours and is presented in Figure 15. From the contour map it is clear that the water levels mostly vary between zero (artesian) and 35 mbs. Pumping occurs at numerous boreholes and in some cases the water levels are significantly impacted by pumping.

The deepest water levels normally occur in the topographically higher lying areas while water levels are shallower near the valley bottoms. The boreholes were used to construct a groundwater level iso-surface map and this map is presented in Figure 16. The highest measured static water level elevations are approximately 1 785 mamsl and are also situated on the highest topographical regions.

The groundwater levels in the mining areas together with levels measured during the hydrocensus surveys were used as calibration points for the regional and site-specific numerical groundwater model of the Impumelelo mining area to verify the conceptual model and construction thereof. Seen in the light of water level differences because of pumping
and recharge effects, filtering and processing of water levels are conducted to remove water levels considered anomalous high or low. The final interpolated potentiometric surface of the water levels is thus bound to contain local over- or under estimations of the actual water levels but it will be representative of the general regional trend of the static groundwater level.

The natural steady state water levels as determined by Bayes interpolation are presented in Figure 16.

Figure 15: Water level depth contour map for the Impumelelo mining area.
Figure 16: Bayesian water levels in the Impumelelo mining area.

4.6 Flow Rates, Pathways and Gradients in Potentially Impacted Areas

4.6.1 Groundwater Gradients

Contours of the static water level or piezometric heads in and around the Impumelelo mining rights area have been shown in Figure 15 and 16. Path lines or flow lines of groundwater particles are lines perpendicular to the contours. Flow occurs faster where contours are closer together and gradients are thus steeper.

On the relatively steeper sloping hillocks where groundwater gradients are higher, groundwater seepage rates are correspondingly higher. Seepage rates on the other hand are much lower in the flat plateaus and valley bottoms.
It follows from the groundwater contours (Figure 16) that groundwater flow can occur locally in numerous different directions. Numerous groundwater flow gradients can thus also be calculated for the large area and this would not really serve a useful purpose. Just as an indication, an average groundwater gradient was calculated from the water level elevation data for the entire mine block. Based on the groundwater elevations the average gradient in the area will be from the north-west to the south-east and is in the order of 0.008 (0.8%).

4.6.2 **Direction and rate of groundwater movement in potentially impacted areas**

The pre-mining groundwater contours have been presented in Figure 16. These contours represent steady state conditions without impacts from sources or actions other than natural conditions like rivers, natural spring discharges, pans or wetland recharge areas.

A large number of manmade actions could impact on the groundwater regime; including the aquifer structure, flow paths and directions, storage, discharges and recharge. Possible impacts relevant to the project will be discussed briefly:

During active mining and thereafter, the voids created by mining (underground) will impact on the natural groundwater movement. Mine voids destroy the in situ aquifer structures and could be compared to areas of very high (even infinitely high) transmissivity and also high storativity. Because groundwater will follow the route of least resistance, groundwater will prefer to move through the mined-out areas. Although subsidence is expected to occur after stooping and mine closure, the transmissivity and storativity remain higher than the pre-mining natural aquifer(s). Because the Karoo rocks where mining will take place have relatively low transmissivity values, impacts on the natural flow pattern in the region are expected to be only noticeable in the immediate vicinity of the operations. The extent of the impact depends mostly on the transmissivity of the *in situ* aquifer material. Karoo type formations in the coal mining environment generally do not have very high *in situ* transmissivities, as could be seen from the pumping test analyses.

4.7 **Aquifer discharge**

A mining and processing operation may impact significantly on the discharge of an aquifer in different ways. If mining occurs and mine dewatering is required, the natural aquifer discharge will decrease by the volume of groundwater removed by dewatering. Aquifer discharge may also increase with the use of return water dams, slurry and other dams through leakage of water to the subsurface, especially if water is imported to the project from other sources. Other factors that may decrease the aquifer discharge are compacted surfaces, haul roads and concrete surfaces that prevent infiltration to the aquifer and decrease groundwater discharge, although increasing surface runoff.

After mine closure, however, recharge is usually higher to the mine void than to the pre-mining aquifer and after filling up, the discharge is usually higher than before the disruption by mining.
4.8 **AQUIFER RECHARGE**

All the aspects mentioned under aquifer discharge apply to aquifer recharge. Surface water features like dams (tailings, slurry, process water, storm water, return water etc.) will also usually increase the recharge to the aquifer but compacted or concrete surfaces and roads will decrease the recharge.

The underground mining operation itself will have the most significant effect on aquifer recharge, especially with stooping planned for the largest portion of the coal reserves. Surface subsidence can be expected to occur, at least to some degree, and this will result in recharge to the workings increasing significantly through the cracks and broken strata above the workings.

The abovementioned aspects will be discussed and quantified in more detail in Section 5 where calculations and modeling for the groundwater impact assessment are conducted.
4.9 **GROUNDWATER QUALITY EVALUATION**

4.9.1 **HYDROCENSUS BOREHOLES**

A hydrocensus survey was conducted in 2009 for the Impumelelo Mine area and the Witnek Mine area. A follow up hydrocensus was conducted in 2016 to include the Impumelelo Mine Extension areas. The hydrocensus boreholes will therefore be discussed as follows:

- Impumelelo Mine Hydrocensus
- Witnek Hydrocensus
- Impumelelo Mine Extension Hydrocensus

The groundwater quality data of the hydrocensus points was interpreted with the aid of diagnostic chemical diagrams and by comparing the inorganic concentrations with the South African Drinking Water Guidelines for Domestic Use.

The first step in the water quality interpretation was to classify the groundwater quality. The classification was based on the following:

- the spatial distribution of the monitoring points, and
- the proximity of the monitoring points to certain known pollution sources that are expected to impact on the groundwater and/or surface water in the downstream flow direction.

The four main factors usually influencing groundwater quality are:

- **annual recharge** to the groundwater system,
- **type of bedrock** where ion exchange may impact on the hydrogeochemistry,
- **flow dynamics** within the aquifer(s), determining the water age and
- **source(s) of pollution** with their associated leachates or contaminant streams.

Where no specific **source of groundwater pollution** is present upstream of the borehole, only the other three factors play a role.

Water qualities will be compared to the SANS241:2011 standards for drinking water.

**Table 5:** South African National Standard for drinking water (SANS241:2011)

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Risk</th>
<th>Unit</th>
<th>Standard limits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical and aesthetic determinants</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free chlorine</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 5</td>
</tr>
<tr>
<td>Monochloramine</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 3</td>
</tr>
<tr>
<td>Colour</td>
<td>Aesthetic</td>
<td>mg/L Pt-Co</td>
<td>≤ 15</td>
</tr>
<tr>
<td>Conductivity at 25 °C</td>
<td>Aesthetic</td>
<td>mS/m</td>
<td>≤ 170</td>
</tr>
<tr>
<td>Odour or taste</td>
<td>Aesthetic</td>
<td>–</td>
<td>Inoffensive</td>
</tr>
<tr>
<td>Total dissolved solids (TDS)</td>
<td>Aesthetic</td>
<td>mg/L</td>
<td>≤ 1 200</td>
</tr>
<tr>
<td>Turbidity</td>
<td>Operational</td>
<td>NTU</td>
<td>≤ 1</td>
</tr>
<tr>
<td></td>
<td>Aesthetic</td>
<td>NTU</td>
<td>≤ 5</td>
</tr>
<tr>
<td>Determinant</td>
<td>Risk</td>
<td>Unit</td>
<td>Standard limits</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>-------------------</td>
<td>-----------</td>
<td>-----------------</td>
</tr>
<tr>
<td>pH at 25 C</td>
<td>Operational</td>
<td>pH units</td>
<td>≥ 5 to ≤ 9.7</td>
</tr>
</tbody>
</table>

**Chemical determinants - macro-determinants**

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Risk</th>
<th>Unit</th>
<th>Standard limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrate as N</td>
<td>Acute health – 1</td>
<td>mg/L</td>
<td>≤ 11</td>
</tr>
<tr>
<td>Nitrite as N</td>
<td>Acute health – 1</td>
<td>mg/L</td>
<td>≤ 0.9</td>
</tr>
<tr>
<td>Sulfate as SO₄²⁻</td>
<td>Acute health – 1</td>
<td>mg/L</td>
<td>≤ 500</td>
</tr>
<tr>
<td>Fluoride as F⁻</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 1.5</td>
</tr>
<tr>
<td>Ammonia as N</td>
<td>Aesthetic</td>
<td>mg/L</td>
<td>≤ 1.5</td>
</tr>
<tr>
<td>Chloride as Cl⁻</td>
<td>Aesthetic</td>
<td>mg/L</td>
<td>≤ 300</td>
</tr>
<tr>
<td>Sodium as Na</td>
<td>Aesthetic</td>
<td>mg/L</td>
<td>≤ 200</td>
</tr>
<tr>
<td>Zinc as Zn</td>
<td>Aesthetic</td>
<td>mg/L</td>
<td>≤ 5</td>
</tr>
</tbody>
</table>

**Chemical determinants - micro-determinants**

<table>
<thead>
<tr>
<th>Determinant</th>
<th>Risk</th>
<th>Unit</th>
<th>Standard limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium as Al</td>
<td>Operational</td>
<td>mg/L</td>
<td>≤ 0.3</td>
</tr>
<tr>
<td>Antimony as Sb</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.02</td>
</tr>
<tr>
<td>Arsenic as As</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.01</td>
</tr>
<tr>
<td>Cadmium as Cd</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.003</td>
</tr>
<tr>
<td>Total chromium as Cr</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.05</td>
</tr>
<tr>
<td>Cobalt as Co</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.5</td>
</tr>
<tr>
<td>Copper as Cu</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 2</td>
</tr>
<tr>
<td>Cyanide (recoverable) as CN⁻</td>
<td>Acute health – 1</td>
<td>mg/L</td>
<td>≤ 0.07</td>
</tr>
<tr>
<td>Iron as Fe</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 2</td>
</tr>
<tr>
<td>Lead as Pb</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.3</td>
</tr>
<tr>
<td>Manganese as Mn</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.1</td>
</tr>
<tr>
<td>Mercur as Hg</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.006</td>
</tr>
<tr>
<td>Nickel as Ni</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.07</td>
</tr>
<tr>
<td>Selenium as Se</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.01</td>
</tr>
<tr>
<td>Uranium as U</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.015</td>
</tr>
<tr>
<td>Vanadium as V</td>
<td>Chronic health</td>
<td>mg/L</td>
<td>≤ 0.2</td>
</tr>
</tbody>
</table>

One of the most appropriate ways to interpret the type of water at a sampling point is to assess the plot position of the water quality on different analytical diagrams like a Piper, expanded Durov and Stiff diagrams. Of these three types, the expanded Durov Diagram probably gives the most holistic water quality signature. The characteristics of the different fields are discussed briefly in Figure 17.
Another way of presenting the signature or water type distribution in an area is by means of Stiff diagrams. These diagrams plot the equivalent concentrations of the major cations and anions on a horizontal scale on opposite sides of a vertical axis. The plot point on each parameter is linked to the adjacent one resulting in a polygon around the cation and anion axes. The result is a small figure/diagram of which the geometry typifies the groundwater composition at the point. Groundwater with similar major ion ratios will show the same geometry. Ambient groundwater qualities in the same aquifer type and water polluted by the same source will for example display similar geometries.

The typical impacts on groundwater quality caused by coal mining operations include different chemical reactions such as ion exchanges, mobilization and precipitation of ions and / or groups of ions. Sulphate (SO$_4$) related chemical reaction is one of the most important reactions in this regard and is a fair representation of pollution in coal mines. SO$_4$ related reactions take place when it enters the groundwater system through oxidation of pyrite through chemical weathering, mining, washing or percolation through stockpiles of the host material, coal.
An example of a reaction is:

\[ 2\text{FeS}_2 + 7\text{O}_2 = 2\text{FeSO}_4 + 2\text{H}_2\text{SO}_4 \]

pyrite + oxygen = iron sulphate + sulphuric acid

Iron sulphate forms, as well as sulphuric acid (H\(_2\text{SO}_4\)), causing decreases in the pH and mobilization of metal ions (that are usually more soluble at a low pH), the reactions collectively referred to as “acid mine drainage”.

As seen from the reaction equation, oxygen is required for the oxidation and consequent acidification to take place. At the pre-mining environment of Impumelelo, coal reserves and associated pyrite occur below the static groundwater level and under anaerobic conditions, causing a reducing chemical environment and none of the acid mine drainage reactions to occur.

4.9.2 IMPUMELELO MINE HYDROCENSUS 2009

During the hydrocensus in 2009, 200 samples were collected from the boreholes that were located. The ambient qualities discussed in this part of the document are the same as in the 2009 Brandspruit Mine, Impumelelo Shaft EMP. A map indicating the distribution of the borehole positions where groundwater quality information is available is presented in Figure 18.

![Figure 18: Distribution of Impumelelo Mine hydrocensus sampling points within the 2km buffer area](image)
In the Impumelelo Mine area, most of the boreholes of surrounding users display good to marginal groundwater quality. Groundwater in the area is used for domestic purposes and livestock watering and will therefore be compared with drinking water standards.

The electrical conductivities in the groundwater vary between 10 and 320 mS/m, which range between good and marginal with respect to human consumption.

The ambient groundwater levels are relatively shallow with rest water levels mostly between 0 and 35 meters below surface. The average rainfall is in the order of 750 mm per year but the effective recharge percentage is considered to be very low due to dolerite sills covering much of the surface areas.

**Aquifer flow dynamics**, in spite of the relatively low matrix transmissivities, do appear to be sufficient to facilitate the existence of fresh groundwater in the area. The hydraulic conductivities of the bedrock in the vicinity of the boreholes are usually in the order of $10^{-3}$ to $10^{-2}$ m/d. Such conductivities should facilitate a sufficient flow rate to prevent stagnant groundwater conditions, especially where groundwater gradients are higher such as along the sloping topography.

A factor that can however cause stagnant groundwater hydraulics is the occurrence of numerous dykes and faults that compartmentalize the aquifer(s) in the horizontal dimension. These compartments could cause much longer residence times of groundwater in the aquifer to result in long time for ion exchange and high salinities of ambient groundwater.

The majority of the sampled points are grouped in field 2 and 3 of the expanded Durov diagram (Figure 19), which represents fresh, clean, relatively young groundwater that has undergone some ion exchange. Bicarbonate alkalinity dominates the anion content and magnesium and sodium the cation content. Boreholes plotting in fields 4 to 9 have various elements that are already higher before impacts from mining. The groundwater in these boreholes does however still display good groundwater quality.
Stiff diagrams of some regional groundwater qualities around the Impumelelo mining area are presented in Figure 20. The geometries of the Stiff diagrams confirm the general dominance of the anion content by bicarbonate alkalinity. The figure is only used as an illustration and displays 20 sample diagrams of the 200 samples that were analyzed.

In terms of suitability of the groundwater for agricultural use (irrigation) the SAR diagram (Sodium Adsorption Ratio) is a handy tool to assess the suitability of the water. Sodium enrichment with respect to calcium and magnesium in groundwater will present a risk of sodium accumulation in soils (especially when clayey) and cause deterioration in soil structure and increase erodability because of dispersion reactions in the soil. Soils will form surface crusts, compaction rates will increase which will in turn cause poorer infiltration, higher runoff and more erosion.

From the SAR diagram in Figure 21 it follows that most of the regional water types present a low sodium hazard but a medium to high salinity hazard towards soil and vegetation if used for irrigation. A few boreholes indicate very high sodium hazards. The water from these boreholes will thus definitely not be suitable for irrigation except for specially controlled instances.
Summary:

- Groundwater quality in the overall area is generally good with few boreholes having marginal water quality.
- The groundwater is mostly fresh, clean, relatively young and has undergone some sort of ion exchange.
- Bicarbonate alkalinity dominates the anion content and the magnesium and sodium the cation content.
- In terms of irrigation; the salinity hazard of the groundwater is medium to high and can cause some problems if not managed properly.

The discussion in this section was only a very broad overview.
Figure 20: Stiff diagrams of Impumelelo Mine ambient groundwater qualities
During the same hydrocensus in 2009, a significant amount of boreholes were located. A map indicating the distribution of the borehole positions where groundwater quality information is available is presented in Figure 22.

The electrical conductivities in the groundwater vary between 19 and 315 mS/m, which range between good and poor with respect to human consumption. The permissible limits for drinking water in terms of EC have been exceeded in five boreholes.

Fluoride in two of the boreholes sampled during the hydrocensus displayed concentrations exceeding permissible limits. At the concentrations present in these boreholes mottling and tooth damage can occur in most continuous users. One of these boreholes was not in use and the other one was used for livestock watering.

Nitrate concentrations in the area are often very high and often exceed permissible limits for drinking water. Since the area is situated in a highly agricultural area, the high nitrate could be an effect of soil fertilizers used by the farmers.

Parameters concentrations such as calcium, chloride, iron, magnesium and sodium exceed the ideal limits for drinking water in some of the boreholes in the area.
Figure 22: Distribution of Witnek Mine hydrocensus sampling points within the 2km buffer area

The majority of the points are grouped in field 2 and 3 of the diagram (Figure 23), which represents fresh, clean, relatively young groundwater that has undergone some ion exchange. Bicarbonate alkalinity dominates the anion content and magnesium and sodium the cation content. Boreholes plotting in the other fields (fields 4 to 9) have various elements that are already higher before impacts from mining.
Stiff diagrams of a few of the regional groundwater qualities around the Witnek mining areas are presented in Figure 24. The geometries of the Stiff diagrams confirm the general dominance of the anion content by alkalinity. The figure is only used as an illustration and displays 20 sample diagrams of the approximately 121 samples that were analyzed.
Figure 24: Stiff diagrams of Witnek Mine ambient groundwater qualities
From the SAR diagram in Figure 25 it follows that most of the regional water types present a low sodium hazard but a medium to high salinity hazard towards soil and vegetation if used for irrigation. One borehole indicates a very high sodium hazard and two boreholes indicate a very high salinity hazard. The water from these boreholes will thus definitely not be suitable for irrigation except for specially controlled instances.

![SAR diagram of Witnek Mine ambient groundwater qualities](image)

**Figure 25: SAR diagram of Witnek Mine ambient groundwater qualities**

**Summary:**
- Groundwater quality in the overall area is generally good with few boreholes having poor water quality.
- The groundwater is mostly fresh, clean, relatively young and has undergone some sort of ion exchange.
- Bicarbonate alkalinity dominates the anion content.
- In terms of irrigation; the salinity hazard of the groundwater is medium to high and can cause some problems if not managed properly.

**4.9.4 IMPUMELELO MINE EXTENSION HYDROCENSUS 2016**

During the follow up hydrocensus in 2016, 60 boreholes were located. Thirty of these boreholes were selected based on their use and location for quality evaluation. Firstly boreholes used for domestic purpose and secondly to get a good distribution of qualities. A
The electrical conductivities in the groundwater vary between 25 and 110 mS/m, which is good with respect to human consumption. Fluoride in one of the boreholes (JCO4) sampled during the hydrocensus displayed concentrations exceeding permissible limits for domestic use. At the concentrations present in this borehole, mottling and tooth damage can occur in most continuous users.

Nitrate concentrations in the area often exceed permissible limits for drinking water. Since the area is situated in a highly cultivated area, the high nitrate could be an effect of soil fertilizers used in the long-term farming activities.
The majority of the points are grouped in field 2 and 3 of the diagram (Figure 27), which represents fresh, clean, relatively young groundwater that has undergone some ion exchange. Bicarbonate alkalinity dominates the anion content and magnesium and sodium the cation content. Boreholes plotting in the other fields (fields 5, 7 and 8) have various elements that are already higher before impacts from mining.

**Figure 27: Expanded Durov diagram of Impumemelo extension ambient groundwater qualities**

**Stiff diagrams** of groundwater qualities in the Impumelelo extension areas are presented in Figure 28. The geometries of the Stiff diagrams confirm the general dominance of the anion content by alkalinity. The dominance of nitrate in several boreholes is clear.
Figure 28: Stiff diagrams of Impumelelo extension ambient groundwater qualities
Figure 27 (Continue): Stiff diagrams of Impumelelo extension ambient groundwater qualities
From the SAR diagram in Figure 29 it follows that most of the regional water types present a low sodium hazard but a medium to high salinity hazard towards soil and vegetation if used for irrigation. One borehole (JC04) indicates a very high sodium hazard. The water from this borehole will thus definitely not be suitable for irrigation except for specially controlled instances.

Summary:
- Groundwater quality in the overall area is generally good with few boreholes having poor water quality.
- The groundwater is mostly fresh, clean, relatively young and has undergone some sort of ion exchange.
- Bicarbonate alkalinity dominates the anion content.
- In terms of irrigation; the salinity hazard of the groundwater is medium to high and can cause some problems if not managed properly.

Figure 29: SAR diagram of Impumelelo extension ambient groundwater qualities

For a more detailed description of the groundwater qualities of the Impumelelo extension project area, refer to the hydrocensus report in Appendix A.
4.9.5 **Groundwater quality in the existing Impumelelo Mine monitoring boreholes.**

Groundwater monitoring in the purpose-drilled monitoring boreholes of the Impumelelo Mine has been conducted since October 2012. The qualities obtained during these sampling runs can therefore indicate impacts from mining or any changes in the groundwater quality.

Figure 30: Location of the site specific monitoring boreholes at Impumelelo Mine.
Table 6: Average parameter concentrations in the mine monitoring boreholes from 2012 to the present.

<table>
<thead>
<tr>
<th>Borehole</th>
<th>pH</th>
<th>EC mS/m</th>
<th>TDS mg/l</th>
<th>Ca mg/l</th>
<th>Mg mg/l</th>
<th>Na mg/l</th>
<th>K mg/l</th>
<th>Cl mg/l</th>
<th>SO4 mg/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB2-1</td>
<td>7.9</td>
<td>66</td>
<td>427</td>
<td>37</td>
<td>24</td>
<td>44</td>
<td>0.9</td>
<td>14</td>
<td>70</td>
</tr>
<tr>
<td>SB2-10</td>
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<td>58</td>
<td>21</td>
<td>24</td>
<td>4.0</td>
<td>25</td>
<td>47</td>
</tr>
<tr>
<td>SB2-11</td>
<td>7.1</td>
<td>24</td>
<td>154</td>
<td>26</td>
<td>9.2</td>
<td>6.6</td>
<td>3.8</td>
<td>16</td>
<td>36</td>
</tr>
<tr>
<td>SB2-13d</td>
<td>7.5</td>
<td>102</td>
<td>666</td>
<td>62</td>
<td>31</td>
<td>52</td>
<td>1.2</td>
<td>99</td>
<td>140</td>
</tr>
<tr>
<td>SB2-13s</td>
<td>7.6</td>
<td>152</td>
<td>988</td>
<td>126</td>
<td>66</td>
<td>69</td>
<td>2.0</td>
<td>147</td>
<td>281</td>
</tr>
<tr>
<td>SB2-14</td>
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<td>116</td>
<td>757</td>
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<td>103</td>
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<tr>
<td>SB2-17</td>
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<td>724</td>
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<td>724</td>
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<td>180</td>
<td>1.4</td>
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<td>66</td>
<td>429</td>
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<td>0.8</td>
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<td>365</td>
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<td>56</td>
<td>47</td>
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<td>SB2-2d</td>
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<td>421</td>
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<td>1.8</td>
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<td>SB2-2s</td>
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<td>0.9</td>
<td>17</td>
<td>69</td>
</tr>
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<td>9.7</td>
<td>53</td>
<td>345</td>
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<td>0.8</td>
<td>105</td>
<td>0.6</td>
<td>38</td>
<td>20</td>
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<tr>
<td>SB2-6s</td>
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<td>372</td>
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<td>1.4</td>
<td>16</td>
<td>130</td>
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<td>7.5</td>
<td>77</td>
<td>499</td>
<td>51</td>
<td>31</td>
<td>45</td>
<td>3.1</td>
<td>13</td>
<td>101</td>
</tr>
<tr>
<td>SB2-9</td>
<td>7.5</td>
<td>128</td>
<td>835</td>
<td>94</td>
<td>42</td>
<td>69</td>
<td>7.6</td>
<td>83</td>
<td>113</td>
</tr>
</tbody>
</table>

*Note

Exceed aesthetic limits
Exceed chronic/acute health limits
The EC in the majority of the monitoring boreholes were below the permissible limits for drinking water. The exceptions are SB2-13s and SB2-13d which fluctuated and often exceeded the permissible limits since monitoring started in 2012 (Figure 32). This was also the case with the sulphate concentrations where these 2 boreholes often exceeded the aesthetic limits for drinking water. The average EC varied between ±20 and 150 mS/m which were within permissible limits for drinking water. The average sulphate concentrations varied between ±20 and 280 mg/l.

The average fluoride concentrations in SB2-1, SB2-6d, SB2-17, SB2-18s and SB2-18d exceeded the maximum permissible concentration for drinking water. Fluoride at these levels can cause severe tooth damage and cause Skeletal Fluorosis when consumed for long periods. A significant increasing concentration trend was observed in SB2-16d and SB2-18D over the monitoring period, (Figure 33).

Nitrate concentrations in two boreholes (SB2-9 and SB2-13s) exceeded the permissible limits for drinking water. Since the Impumelelo Mine area is situated in an agricultural area, higher nitrate concentrations could be expected as a result of farming activities (fertilisers, feedlot etc.) The nitrate concentrations mostly fluctuated over the monitoring history but clear overall decreasing concentrations were observed in SB2-9 and SB2-14 (Figure 33).

The majority of the new monitoring boreholes plot in fields 2 and 5 of the expanded Durov diagram indicating domination of the magnesium cation. Bi-carbonate alkalinity dominates in field 1, 2 and 3 and sulphate in field 5 and 6. The plot positions in field 5 could also be as a result of elevated nitrate concentrations. The stiff diagrams in Figure 34 indicate that the composition of the groundwater over the area varies. Bicarbonate alkalinity does however dominate the anion content in most of the boreholes.

Figure 31: Expanded Durov diagram of the groundwater quality from the monitoring boreholes.
Figure 32: EC and sulphate Time-series graph of the Impumelelo Mine monitoring boreholes.
Figure 33: Fluoride and nitrate time-series graph of the Impumelelo Mine monitoring boreholes.
Figure 34: Stiff diagrams of groundwater qualities from the monitoring boreholes.
Summary:
Groundwater in the monitoring boreholes is:

- Mostly of good quality.
- Mostly clean, fresh and recently recharged,
- Bicarbonate alkalinity dominated, and
- So far unaffected by the Impumelelo mining activities.

Nitrate and fluoride concentrations are often elevated and exceed permissible limits for drinking water in several boreholes.
4.10 GROUNDWATER IMPACT DISCUSSION BASED ON THE CONCEPTUAL MODEL

4.10.1 BACKGROUND TO IMPACT ASSESSMENT

For a negative groundwater quality impact to be registered the following three aspects must be present:

- **Source** to generate and emit contamination
- **Pathway** along which contamination is transported
- **Receptor** to receive contamination

We define a source as a facility or an area in which groundwater contamination is generated or released from as seepage or leachate.

Source areas are subdivided into two main groups:

- **Point source**
  The contamination can easily be traced back to a specific source and typically includes mining infrastructure such as tailings dams, discard dumps, pollution control dams, etc.

- **Diffuse source**
  The source is very diffuse or occurs over a large area or the exact source/s of the contamination is unknown.

In order for contamination to reach and eventually affect groundwater users, it needs to travel along a preferred pathway. Aquifer transmissivity and storage coefficient (Section 4.3) are important parameters used to characterize the pathway. These values indicate whether the aquifer host rock of the area is a poor or good pathway for flow and mass transport.

Groundwater flow and contaminant transport within the aquifer also depend directly on the hydraulic gradient. The groundwater hydraulic gradient (Sections 4.5-4.7) is therefore another very important parameter in determining the effectiveness of the aquifer as a pathway for contamination.

For an impact to occur there must be a receptor that can be adversely affected. Receptors refer to all groundwater users or other receptors within the immediate vicinity of the mining area. Two potential receptors are recognized in the Impumelelo lease area, namely:

- **Direct users** (humans that utilize groundwater through boreholes as a source of water for domestic (including potable) use, livestock supply, irrigation etc. – Section
3), and to a lesser extent plants that may use groundwater in shallow water table areas or in the riparian zones along water courses; and
- The receiving **surface water environment** that can receive groundwater through base flow to rivers and streams.

The impact assessment (flow, transport, modelling) will show the expected radius of influence from sources and sinks. Should these calculations indicate that users will be affected by mine dewatering or groundwater quality impacts, management or mitigation actions will be recommended to compensate for or replace losses.

For groundwater to contribute to surface drainage or base flow to streams, the static water level of the aquifer needs to be at the same elevation or higher than the base of the stream. The measured static water levels in the Impumelelo mining area vary mostly between 0 and 35mbs (Figure 15). Therefore, base flow to the streams in the area may occur but is mostly expected for short periods after rainfall events.

Emphasis should be on:
- Eliminating sources of pollution as far as possible,
- Prevention of poor quality surface water discharge because discharge into the natural drainage extends the sources of groundwater pollution, and
- Optimization of groundwater recycling and reuse.
- Treatment should be the last option if no alternative management action is viable.

The groundwater study for the Impumelelo Project will have a holistic approach and consider where practically possible other environmental disciplines during the study. Outputs from our study will also be provided as input to e.g. the surface water study and mine water balance compilation.

### 4.10.2 Conceptual Impact Discussion

Mining at the Impumelelo Project will occur in the deep aquifer and well below the shallow, weathered zone aquifer. The high extraction mining will be by far the most significant determinant of groundwater impact. The high extraction mining will cause roof collapse and the formation of cracks above the mining horizon that extends all the way to surface. The collapsed material above the mine panels will result in progressive surface depressions (goafs) over nearly the entire area above the planned underground workings.

The cracks will result in:

- Localised ‘dewatering’ of the shallow aquifer with water flowing down to the mine workings;
- Dewatering of the deeper aquifer above the mine workings; and
- Significant increase in effective recharge from surface to the underground workings (deep aquifer).
Large volumes of water flowing from the shallow and/or deeper aquifer may sometimes be experienced after goafing behind the stooping/longwall face. The effective recharge to the mine horizon (deep aquifer) can increase from around 2% of MAP to more than 5% due to the goafing. Higher effective recharge was used for the Impumelelo Shaft calculations because of two seams earmarked for mining and seam thickness in excess of 2 meters each.

The quality of groundwater in the upper aquifer can be expected to remain unaffected as the water has not been in contact with shales carbonaceous material. The quality of the water in the lower aquifers will be affected due to the contact with carbonaceous sedimentary strata, specifically coal. These strata are chemically alterable and can cause significant mineralization. The deeper aquifer will change from confined or semi-confined to unconfined as a result of the cracks forming and some oxygen will be available which will promote the chemical reactions. These reactions are collectively referred to as acid rock drainage (ARD) and are discussed in more detail in Section 5.4.

The rate of influx of water into the underground workings will be such that mining will not be able to progress unhindered without dewatering. With all else being equal the ingress will increase progressively as the undermined area and associated roof collapse and surface subsidence area increases. Possibilities for permanent or temporary use or disposal of mine water are:

- Disposal into surface water.
- Storage in underground compartments where mining has been completed. The storage capacity of these compartments may be enhanced by creating artificial hydraulic seals. Storage volumes for the Impumelelo project are estimated in Section 5.2.
- Treatment of the water and use for potable water, irrigation or other applications.
- The water can also be used as process make-up water in other nearby mining operations of Sasol.

Of the different options, the latter will probably be the preferred one during the operational phase since it will be the most cost-effective. Disposal on surface will most probably not be allowed by legislation due to the expected inferior water quality in the mine.

The depth of mining will range between 50 and 250 m below surface. The average depth at which farmers extract groundwater is between 20 and 50 meters. Cracks above the high extraction mining areas will interconnect the coal seam and upper shallow aquifer, causing dewatering. Water will have to be supplied to affected farmers to meet their daily requirements.

A typical schematic section through the Impumelelo mining area is shown in Figure 35 to illustrate water level reaction to subsidence and associated dewatering.
Figure 35: A simplified schematic section through the Impumelelo Shaft mining area to illustrate water level reaction to subsidence and associated dewatering.
5 GROUNDWATER IMPACT ASSESSMENT: CALCULATIONS AND NUMERICAL MODELLING

For the purpose of water balance and excess (ground) water management planning (seepage, storage etc) during the operational phase, recharge rates and storage volumes were calculated based on the mine layout plan and extraction schedule as received from Sasol for the Impumelelo Mine. The methodology and results of the recharge/volumes/storage calculations are provided in the remainder of this section.

The majority of information used in this section was obtained from numerous reports and case studies conducted by Prof. Frank Hodgson who is recognized as a leader in mine water flow and management in South Africa. Prof. Hodgson studied influx of water into underground high extraction mining in numerous South African collieries and made the following conclusions:

- Influx into high extraction panels happens after the first collapse of the overhanging strata has occurred.
- Depending on the direction of the slope of the coal floor, this influx may or may not be problematic. Water in the goaf could accumulate for months before being noticed.
- Where longwall methods are employed, influx rates are initially in the range of 500 – 3,000 m$^3$/d. During the development of adjacent panels, the total influx increases by about 10% for each successive panel mined.
- Undermining of surface water bodies often leads to an increase in the influx rate. Streams where rock outcrop would typically dry up. Stream water, as well as groundwater that normally emanates in the stream, drain into the cracks and into goafed areas.
- Where large areas have been undermined by high extraction methods, influx into the mine can usually be expressed as a percentage of the rainfall. Values of between 6 – 11% are suggested, based on observations at various collieries.

5.1 ESTIMATION OF GROUNDWATER SEEPAGE RATES TO UNDERGROUND WORKINGS

Effective natural recharge to the aquifer(s) in the Impumelelo Mine area to the relatively deep (up to 250 mbs) underground workings is estimated to be very low - in the order of 1 to 3% of MAP. With high extraction mining however, roof collapse and surface subsidence is expected to occur above the mined areas. Cracks can extend from the underground mining areas to surface and these cracks can cause a significant increase in recharge to the mine voids.

The increased recharge depends on a number of factors such as:
- the surface area that has been under-mined,
- The depth of mining under the surface,
- The rock strength and consistency of the rock strata above the mine horizon,
- The type and thickness of soil cover at surface above the mined area, and
- The free-draining nature of the surface area after subsidence has occurred.

Some of these factors can be calculated directly and others can be estimated with a fair degree of accuracy based on long observation records at comparative case studies in the same mining conditions. Other factors such as rainfall intensity also play a role, but all cannot be calculated or predicted to a high level of confidence.

**It should be noted that no stooping will occur below streams and wetlands.**

For the Impumelelo Mine, the **surface area** of the mine blocks and the **surface cover material** have been used as an estimate for recharge during the LOM.

The surface area was calculated by using the combined horizontal surface area of the planned 2 seam and 4 seam workings on a year-by-year and later a 6-year basis as received in the LOM schedule and layout plan. Layouts of the annual and later 6-yearly schedule are indicated in Figure 36 (4 seam workings) and Figure 37 (2 seam workings).

![Figure 36: Future LOM for the 4 seam.](image-url)
For the surface cover material there was only distinguished between areas with normal soil cover, surface areas where boulder outcrop was identified and areas where direct rock outcrop occur. The outlines of these outcrop areas were calculated and provided by Jones & Wagener Consulting and Civil Engineers.

The 3 types of surface area were used to apply different recharge rates. The most probable effective recharge rates were applied as follows:
- The normal soil cover area - 5%
- Boulder outcrop area - 7.5%
- Rock outcrop area - 10%

The rates above were applied as the most probable scenario. A lower recharge scenario (2% lower) for all three types was calculated as well as a higher recharge scenario (2% higher) for a sensitivity analysis.

The relative areas of the three types of surface cover are provided in Table 7 below.

**Table 7: Surface areas for recharge and estimated inflow volumes during the LOM at Impumelelo Shaft workings**

<table>
<thead>
<tr>
<th>Year</th>
<th>Total Area (m²)</th>
<th>Boulder outcrop area (m²)</th>
<th>Rock Outcrop area (m²)</th>
<th>No outcrop area (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>411060</td>
<td>41120</td>
<td>112270</td>
<td>257670</td>
</tr>
<tr>
<td>2016</td>
<td>875520</td>
<td>259160</td>
<td>162060</td>
<td>454300</td>
</tr>
<tr>
<td>2017</td>
<td>2870190</td>
<td>1249620</td>
<td>204040</td>
<td>1416530</td>
</tr>
<tr>
<td>Year</td>
<td>Total Area (m²)</td>
<td>Boulder outcrop area (m²)</td>
<td>Rock Outcrop area (m²)</td>
<td>No outcrop area (m²)</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------</td>
<td>---------------------------</td>
<td>------------------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>2018</td>
<td>5359650</td>
<td>2668540</td>
<td>319660</td>
<td>2371450</td>
</tr>
<tr>
<td>2019</td>
<td>8356020</td>
<td>4111520</td>
<td>777290</td>
<td>3467210</td>
</tr>
<tr>
<td>2020</td>
<td>11949940</td>
<td>511560</td>
<td>1095420</td>
<td>5739060</td>
</tr>
<tr>
<td>2021</td>
<td>15166370</td>
<td>6349730</td>
<td>1658850</td>
<td>7157790</td>
</tr>
<tr>
<td>2022</td>
<td>18257900</td>
<td>7058290</td>
<td>2099110</td>
<td>9100500</td>
</tr>
<tr>
<td>2023</td>
<td>21823640</td>
<td>7875370</td>
<td>2758070</td>
<td>11190200</td>
</tr>
<tr>
<td>2024</td>
<td>25155920</td>
<td>8507410</td>
<td>3555360</td>
<td>13093150</td>
</tr>
<tr>
<td>2025</td>
<td>28492660</td>
<td>9011850</td>
<td>4259750</td>
<td>15221060</td>
</tr>
<tr>
<td>2026</td>
<td>31294610</td>
<td>9619710</td>
<td>4479270</td>
<td>17195630</td>
</tr>
<tr>
<td>2027</td>
<td>34089660</td>
<td>9912570</td>
<td>4820150</td>
<td>19356940</td>
</tr>
<tr>
<td>2028</td>
<td>36544350</td>
<td>10121270</td>
<td>5067850</td>
<td>21355230</td>
</tr>
<tr>
<td>2029-2034</td>
<td>50126510</td>
<td>11822470</td>
<td>7624510</td>
<td>30679530</td>
</tr>
<tr>
<td>2035-2040</td>
<td>65204620</td>
<td>13740330</td>
<td>9420890</td>
<td>42043400</td>
</tr>
<tr>
<td>2041-2046</td>
<td>78937270</td>
<td>14854340</td>
<td>10904660</td>
<td>53178270</td>
</tr>
<tr>
<td>2047-2052</td>
<td>91245030</td>
<td>15952260</td>
<td>11168370</td>
<td>64124400</td>
</tr>
<tr>
<td>2053-2058</td>
<td>92871030</td>
<td>16161320</td>
<td>11168370</td>
<td>65541340</td>
</tr>
</tbody>
</table>

The estimated groundwater recharge rates based on 3 scenarios are provided in Table 8. Please note that direct surface water ingress volumes in areas where drainage lines cross surface subsidence areas were not taken into account in the estimation.

Table 8: Recharge and estimated inflow volumes per annum during the LOM at Impumelelo Shaft workings (m³/day)

<table>
<thead>
<tr>
<th>Year</th>
<th>Low recharge</th>
<th>Most probable recharge</th>
<th>High recharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mined</td>
<td>14420</td>
<td>20668</td>
<td>26916</td>
</tr>
<tr>
<td>2016</td>
<td>31044</td>
<td>44352</td>
<td>57660</td>
</tr>
<tr>
<td>2017</td>
<td>96937</td>
<td>140564</td>
<td>184190</td>
</tr>
<tr>
<td>2018</td>
<td>185049</td>
<td>266516</td>
<td>347983</td>
</tr>
<tr>
<td>2019</td>
<td>298173</td>
<td>425185</td>
<td>552196</td>
</tr>
<tr>
<td>2020</td>
<td>411278</td>
<td>592917</td>
<td>774557</td>
</tr>
<tr>
<td>2021</td>
<td>529474</td>
<td>760003</td>
<td>990532</td>
</tr>
<tr>
<td>2022</td>
<td>630154</td>
<td>907674</td>
<td>1185194</td>
</tr>
<tr>
<td>2023</td>
<td>752018</td>
<td>1083737</td>
<td>1415456</td>
</tr>
<tr>
<td>2024</td>
<td>870299</td>
<td>1252669</td>
<td>1635039</td>
</tr>
<tr>
<td>2025</td>
<td>982728</td>
<td>1415817</td>
<td>1848905</td>
</tr>
<tr>
<td>2026</td>
<td>1066504</td>
<td>1542182</td>
<td>2017860</td>
</tr>
<tr>
<td>2027</td>
<td>1148749</td>
<td>1666912</td>
<td>2185074</td>
</tr>
<tr>
<td>2028</td>
<td>1218094</td>
<td>1773568</td>
<td>2329042</td>
</tr>
<tr>
<td>2029</td>
<td>1291285</td>
<td>1881167</td>
<td>2471050</td>
</tr>
<tr>
<td>2030</td>
<td>1364477</td>
<td>1988767</td>
<td>2613057</td>
</tr>
<tr>
<td>2031</td>
<td>1437668</td>
<td>2096367</td>
<td>2755065</td>
</tr>
<tr>
<td>2032</td>
<td>1510860</td>
<td>2203966</td>
<td>2897073</td>
</tr>
<tr>
<td>2033</td>
<td>1584051</td>
<td>2311566</td>
<td>3039081</td>
</tr>
<tr>
<td>2034</td>
<td>1657243</td>
<td>2419166</td>
<td>3181089</td>
</tr>
<tr>
<td>2035</td>
<td>1731990</td>
<td>2532111</td>
<td>3332232</td>
</tr>
</tbody>
</table>
5.2 Estimation of Available Underground Storage Space

The amount of subsidence/roof collapse above high extraction panels is expected to be in the order of 50% or less of the coal seam thickness. The amount of void space that will be available for water to accumulate will therefore be variable throughout the mine, depending on the mining height. On average, the seam thickness at Impumelelo Mine is in the order of 2.9 m for the 4 seam and 2 m for the 2 seam.

The life of mine plan has been used to estimate storage space for mine water during the planned mine sequence. The available space for each compartment was calculated only for total extraction methods and on a time-series basis only for the deeper 2 seam workings. The volume in each compartment was calculated according to the life of mine plan/schedule.

During the mining phase, compartments can only be filled to the levels at which they decant into adjacent areas. Depending on the locality and elevation of the lowest entrance into a compartment, some compartments may hold significant amounts of water, while others cannot be flooded. The total volumes and constraints of flooding adjacent compartments will be shown with the volume and storage calculations.

Expected progressive recharge seepage rate to the underground workings is indicated in Table 8.
The following aspects should be noted when using the storage calculations:

- Only the void volumes of the 2S workings were used in the storage calculations.
- Six areas were identified (Figure 38) where 2 seam mining will take place. The connectivity between these areas and the connectivity between the six areas and 4 seam is unknown. Therefore the entire void space of each block was assumed to be available for storage space. The areas should be sealed off (hydraulic seals) in the case of connectivity between the areas and between the 4 seam.
- Local variations in the floor and roof contours are bound to occur and the calculations can only be used as a first order indication of volumes and elevations at this stage.
- Effective storage has been assumed to be **50% of the total seam volume** to be extracted during mining. Although storage might initially be 100% of the extracted seam, subsidence will occur and the seam ‘porosity’ is expected to decrease to approximately 50% of the total volume.

The storage space of each block and the time it would be available for storage are presented in the table below.

**Table 9: Storage space and time when available for storage.**

<table>
<thead>
<tr>
<th>Area</th>
<th>50% of Total void space (m³)</th>
<th>Time available (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Block 1</td>
<td>9183900</td>
<td>2046</td>
</tr>
<tr>
<td>Block 2</td>
<td>7348350</td>
<td>2034</td>
</tr>
<tr>
<td>Block 3</td>
<td>5220700</td>
<td>2040</td>
</tr>
<tr>
<td>Block 4</td>
<td>10980250</td>
<td>2052</td>
</tr>
<tr>
<td>Block 5</td>
<td>5311400</td>
<td>2058</td>
</tr>
<tr>
<td>Block 6</td>
<td>3449650</td>
<td>2058</td>
</tr>
</tbody>
</table>

The 2S floor contours and the main areas with potential for storage are indicated on **Figure 38.**
Figure 38: Storage areas (2 Seam) during LOM with seam 2 contours.

A graph is provided in Figure 39 that depicts the water make (low, most probable and high recharge) compared to the storage volume available in the entire 2S over the LOM.

It follows from Figure 39 that up to 2034 no storage will be available for excess water. Storage in the 2 seam will be a problem throughout the entire mining period. At no stage does the storage space exceed the cumulative recharge.

Figure 39: Groundwater make compared to storage volume through the LOM
It is concluded that there will be excess mine water to manage in other ways than underground storage during the entire operational life of the project.

5.3 Time-to-fill and Decant Estimations

From the numerical modeling exercise (Section 5.6 and 5.7) and volume/recharge calculations (Sections 5.1-5.3) it is concluded that the water level will never recover fully post-closure due to the very transmissive nature of the fractured rock as a result of stooping.

Decanting will occur at the lowest elevation in the mined out area. At the Impumelelo Mine area the decant elevation is in the order of 1560 mamsl, which is approximately 40 meters higher than the highest elevation of the coal floor of the 4 seam. This means that the entire underground workings will fill with water before any decant could occur. This is positive from a water quality perspective since ARD reactions will decrease in an anaerobic environment (Section 5.5)

The total volume of groundwater that will fill up the mine is estimated at approximately 168 million cubic meters. This volume includes the 2 and 4 seam workings.

Based on different variables such as recharge, goafing and storage during the life of mine, the time to fill the mine voids is estimated to be in the order of 53 years after closure.

Table 10: Time to fill estimations.

<table>
<thead>
<tr>
<th></th>
<th>Total underground</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Rainfall (m)</td>
<td>0.75</td>
</tr>
<tr>
<td>Mined Area (m²)</td>
<td>92871030</td>
</tr>
<tr>
<td>Total void Volume Below Decant Elevation (m³)</td>
<td>336342600</td>
</tr>
<tr>
<td>Decant from underground areas (m³/annum)</td>
<td></td>
</tr>
<tr>
<td>Low recharge</td>
<td>1790193</td>
</tr>
<tr>
<td>Most Probable recharge</td>
<td>3201833</td>
</tr>
<tr>
<td>High recharge</td>
<td>4613472</td>
</tr>
<tr>
<td>Voids (m³):</td>
<td></td>
</tr>
<tr>
<td>50% Porosity</td>
<td>168171300</td>
</tr>
<tr>
<td>Average Time to Decant (Years):</td>
<td>53</td>
</tr>
</tbody>
</table>

It is estimated that the decant from the Impumelelo mine workings will be in the order of 8 770 m³/day.

It should be noted that it is assumed in this report that the 4 seam workings will all be hydraulically connected. The potential decanting point is presented in Figure 40 below.
The decant elevation is estimated at 1560 m asl. This will be the position where decanting will occur in the case of cracking to the surface due to subsidence.

Figure 40: Potential decanting point for the Impumelelo Mine.

5.4 THE POTENTIAL FOR ACID ROCK DRAINAGE (ARD) OR POOR QUALITY LEACHATES

Long-term groundwater pollution on coal mines and associated processing and disposal operations is synonymous with acid-rock-drainage (ARD) reactions. The root of the problem lies in chemical and bacteriological oxidation of pyrite occurring in the coal and other carbonaceous material. The pyrite oxidation model of Stumm and Morgan (1981) is one of the ways to present the reaction group:

\[
\begin{align*}
\text{FeS}_2(s) &+ 3.5\text{O}_2^- + \text{H}_2\text{O} \rightarrow \text{Fe}^{2+} + 2\text{SO}_4^{2-} + 2\text{H}^+ \quad (1) \\
\text{Fe} &+ 0.25\text{O}_2^- + \text{H}^+ \rightarrow \text{Fe}^{3+} + 0.5\text{H}_2\text{O} \quad (2) \\
3\text{FeS}_2 &+ 14\text{Fe}^{3+} + 8\text{H}_2\text{O} \rightarrow 15\text{Fe}^{2+} + 2\text{SO}_4^{2-} + 16\text{H}^+ \quad (3) \\
\text{Fe}^{3+} &+ 3\text{H}_2\text{O} \rightarrow \text{Fe(OH)}_3 (s) + 3\text{H}^+ \quad (4)
\end{align*}
\]
Of importance is the fact that reactions 1 and 2 are chemical reactions whereas the reaction 3 is also the result of bacteriological action. This bacteriological reaction flourishes in a pH environment of between 2 and 6, which is often reached by water leaching through coal mine operations.

Another distinction is that reactions 1 and 2 are oxidation reactions while reaction 3 is anaerobic. Exclusion of oxygen or elimination of the bacteria will thus greatly limit acid formation. Exclusion of oxygen will occur automatically when water levels in the mined pits and underground workings start to recover after closure through seepage and aquifer recharge.

A positive effect is especially obtained in the underground workings where recharge is clean as it does not occur through semi-consolidated or loose carbonaceous material. The ideal situation would thus be to flood mined out underground workings as soon as possible with water that is not polluted by mining activities and within the acceptable WUL ranges to drive out oxygen. When the water level approach the decant elevation, recharge should be minimised so that the decant volume of poor quality water is minimised.

Static acid-base accounting (ABA) tests were performed on coal samples from selected exploration boreholes in the Impumelelo Mine area during the 2009 study. Acid-base accounting is performed to determine whether the rock material can lead to acid generation when exposed to oxygen.

Acid generation will occur when the net neutralizing potential (NNP) is negative. The NNP is obtained by subtracting the acid potential (AP) from the base potential (BP). In an open system (CO$_2$ can escape) only five of the samples have an acid generation potential (negative NNP) while in the closed system most of the samples indicate an acid generation potential. In a closed system the CO$_2$ released cannot escape and lead to the formation of carbonic acid (H$_2$CO$_3$). In the open system only one sample (P543090 C2) have an acid generating potential.
Most of the samples have a relatively neutral initial pH between 6 and 8. Calcium/magnesium carbonate is an acid generation buffer at a pH level of approximately 6.5. If the calcium/magnesium carbonate content are insufficient no more buffering and a further drop in pH will occur. From figures 42 and 43 it is clear that all of the samples have inadequate calcium/magnesium carbonate to buffer against a drop in pH. Only two samples have a final pH higher than 4 units.

Table 11: Results of acid-base tests on coal seams at Impumelelo Mine

<table>
<thead>
<tr>
<th>Samples</th>
<th>Initial pH</th>
<th>Final pH</th>
<th>AGP (Open)</th>
<th>AGP (Closed)</th>
<th>BP</th>
<th>NNP (Open)</th>
<th>NNP (Closed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H522058C4</td>
<td>6.83</td>
<td>1.42</td>
<td>57.29</td>
<td>114.58</td>
<td>49.06</td>
<td>-8.23</td>
<td>-65.52</td>
</tr>
<tr>
<td>H535068C4</td>
<td>7.12</td>
<td>4.12</td>
<td>10.02</td>
<td>20.05</td>
<td>56.68</td>
<td>46.66</td>
<td>36.64</td>
</tr>
<tr>
<td>H535068C4</td>
<td>7.16</td>
<td>3.95</td>
<td>7.51</td>
<td>15.03</td>
<td>48.92</td>
<td>41.40</td>
<td>33.89</td>
</tr>
<tr>
<td>C536052C4</td>
<td>6.55</td>
<td>1.26</td>
<td>86.42</td>
<td>172.84</td>
<td>9.42</td>
<td>-77.00</td>
<td>-163.42</td>
</tr>
<tr>
<td>H535063C4</td>
<td>7.13</td>
<td>4.06</td>
<td>30.02</td>
<td>60.04</td>
<td>47.50</td>
<td>17.48</td>
<td>-12.54</td>
</tr>
<tr>
<td>P543090C4</td>
<td>6.09</td>
<td>1.38</td>
<td>49.36</td>
<td>98.71</td>
<td>7.31</td>
<td>-42.04</td>
<td>-91.40</td>
</tr>
<tr>
<td>S542037C4</td>
<td>6.14</td>
<td>1.61</td>
<td>109.34</td>
<td>218.67</td>
<td>0.86</td>
<td>-108.47</td>
<td>-217.81</td>
</tr>
<tr>
<td>W580047C4</td>
<td>7.39</td>
<td>3.57</td>
<td>31.97</td>
<td>63.94</td>
<td>41.05</td>
<td>9.09</td>
<td>22.88</td>
</tr>
<tr>
<td>H537058C4</td>
<td>7.15</td>
<td>1.49</td>
<td>29.31</td>
<td>58.62</td>
<td>30.98</td>
<td>1.67</td>
<td>-27.64</td>
</tr>
<tr>
<td>R52420C4</td>
<td>7.34</td>
<td>3.94</td>
<td>26.89</td>
<td>53.77</td>
<td>48.75</td>
<td>21.86</td>
<td>-5.02</td>
</tr>
</tbody>
</table>
**Groundwater Complete Impumelelo Project**

<table>
<thead>
<tr>
<th>Code</th>
<th>AGP</th>
<th>BP</th>
<th>NNP</th>
<th>Initial pH</th>
<th>Final pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>R524020C2</td>
<td>6.94</td>
<td>2.48</td>
<td>23.21</td>
<td>46.42</td>
<td>27.12</td>
</tr>
<tr>
<td>H535063C2</td>
<td>7.34</td>
<td>3.93</td>
<td>4.23</td>
<td>8.46</td>
<td>44.99</td>
</tr>
<tr>
<td>W580047C2</td>
<td>7.32</td>
<td>3.98</td>
<td>6.26</td>
<td>12.52</td>
<td>55.90</td>
</tr>
<tr>
<td>P543090C2</td>
<td>6.99</td>
<td>1.33</td>
<td>49.80</td>
<td>99.61</td>
<td>34.53</td>
</tr>
<tr>
<td>H522058C2</td>
<td>6.94</td>
<td>3.45</td>
<td>34.57</td>
<td>69.14</td>
<td>1.06</td>
</tr>
<tr>
<td>C536052C2</td>
<td>7.81</td>
<td>3.65</td>
<td>3.31</td>
<td>6.63</td>
<td>24.70</td>
</tr>
</tbody>
</table>

**Note:**
- AGP - Acid generation potential (kg CaCO$_3$/tonne)
- BP - Base potential (kg CaCO$_3$/tonne)
- NNP - Nett neutralisation potential (kg CaCO$_3$/tonne)

**Figure 42:** Initial and final (oxidized) pH-levels versus their net neutralising potentials in an open system.
Figure 43: Initial and final (oxidized) pH-levels versus their net neutralising potentials in a closed system.

Figure 44: Water soluble constituents in kg/t.

Water soluble constituents are present in the coal samples. Sulphate is the most soluble in water that comes into contact with the rock material followed by calcium, sodium and magnesium.
Groundwater Complete  Impumelelo Project

Figure 45: Constituents released during complete oxidation in kg/t

Sulphate, iron and calcium are the most significant constituents to be released during complete oxidation (Figure 45). Calcium, Iron, Magnesium, Aluminium and Sodium are the constituents that are most soluble in acid (Figure 46).

Figure 46: Acid (H$_2$SO$_4$) soluble constituents in kg/t.

In conclusion it can be stated that the mine would in all probability turn acid after closure. Insufficient buffer capacity is available in the coal horizon to neutralize the acidity that is expected to be released through oxidation. Further geochemical assessment of the coal seams as well as the floor and roof of the coal seams is recommended to refine the estimation on future water quality in the mine workings.

The majority of the samples had a negative or very low net neutralizing potential when oxidized.
5.5 **NUMERICAL GROUNDWATER FLOW MODEL**

The numerical flow model was constructed to simulate current aquifer conditions and impacts and to provide a tool for evaluation of different management options for the future. A risk analysis could also be performed where effects of different flow and concentration parameters as well as the impacts of nearby existing operations and management options could be evaluated.

The modeling package PMWIN Pro (Processing Modflow Professional for Windows) was used for the simulation. The regional model that includes the new mining area covers an area of ± 770 km² (24 by 32 km). The model was run in steady state conditions until representative transmissivity and recharge distributions were obtained with a simulated hydraulic head distribution closely mimicking the average measured conditions. Two model layers were constructed in the model. Layer 1 simulates the upper weathered zone aquifer condition, layer 2 represents the fractured secondary aquifer.

The aquifer parameters assigned to the different layers in the model will now be discussed. The transmissivity in layer 1 was set to 1.1 m²/d and that of layer 2 at 0.3 m²/d. The dykes have a much lower transmissivity (0.05 m²/d) since they act as barriers for groundwater flow.

![Calculated vs observed groundwater elevation](image)

Figure 47: Correlation between observed and calculated water level elevations.

Calibration of the flow model was aided largely by water level information from the hydrocensus executed at the mining area.
The model simulation was subdivided into 19 different stress periods. A stress period in the model is a period where groundwater flow and mass transport conditions are constant. All time dependent parameters in the model, like drains, rivers, aquifer recharge, contaminant sources, sinks and contaminant concentrations remain constant during the course of a stress period. For the mining area, the following conditions were used to divide the simulation into stress periods in the transient state model run after steady state was simulated:

**Table 12: Stress periods in the numerical model**

<table>
<thead>
<tr>
<th>Stress Period</th>
<th>Duration (years)</th>
<th>Conditions and impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2012-2015</td>
<td>Mining has commenced in the Impumelelo Mine area</td>
</tr>
<tr>
<td>2-14</td>
<td>1 year each</td>
<td>2016 to 2028 to simulate existing dewatering impact when mining at the project continues, seam 2 start in 2019.</td>
</tr>
<tr>
<td>15 to 19</td>
<td>6 years each</td>
<td>Mining continues, progressive dewatering simulated, mining ends in 2058</td>
</tr>
</tbody>
</table>

To show the most important impacts on groundwater level, groundwater level contours have been exported from the model and are presented in Figures 48 to 51. The figures contain water level contours at different times in the life-of-mine, namely at mine closure when maximum impacts occur and 100 years after closure.

It was illustrated in the conceptual model (Section 4) that the shallow aquifer will effectively be dewatered above the mine workings due to goaf formation. The dewatering is however expected to be limited in lateral extent to approximately 1000 meters from the mine workings (Figure 48).

In the secondary deep fractured rock aquifer the drawdown is expected to be up to 250 mbs (Figure 49).
Figure 48: Dewatered shallow aquifer with extent of the cone of depression.

Figure 49: Simulated drawdown at maximum impact towards mine closure in layer 2 (deep aquifer).

It follows from Figure 50 & 51 that the groundwater level recovery in the underground is not yet complete 100 years after mine closure. In fact, the water level will never recover fully due
to the development of the highly transmissive mine voids and subsidence cracks above the voids.

Figure 50: Simulated groundwater level contours 100 years after mine closure - Layer 1 (shallow aquifer)
Figure 51: Simulated groundwater level contours 100 years after mine closure – Layer 2 (deep aquifer).
5.6 NUMERICAL MASS TRANSPORT MODEL – SIMULATED POLLUTION PLUMES AND MOVEMENT

The average groundwater flow velocities in the mining area were estimated using the following equation (after Fetter, 1994):

\[ v = \frac{KI}{\phi} \]

where:
- \( v \) = flow velocity (m/day)
- \( K \) = hydraulic conductivity (m/day) = 0.2 to 0.01
- \( I \) = average hydraulic gradient = 0.008
- \( \phi \) = probable average porosity = 0.1

The hydraulic conductivity and average porosity were chosen so as to provide a very liberal estimation of seepage velocity. In the case of a perched water table or an unconfined / semi-confined aquifer, the hydraulic gradient is equal to the slope of the water table, measured at different points in the aquifer. The hydraulic gradient in the mining area were calculated from the difference in elevation of groundwater levels in the area. The averaged hydraulic conductivities of the saturated zone, as calculated from the low rate pumping tests, were used as approximations of the saturated hydraulic conductivity of the proposed mining area. The average groundwater flow velocities in the mining area were calculated, using the equation above.

The hydraulic conductivity and the average hydraulic gradient are known parameters. By making use of these values, the average steady state flow velocity in the mining areas is estimated as follows:

Table 13: Groundwater gradients and seepage rates

<table>
<thead>
<tr>
<th>Average gradient</th>
<th>Seepage velocity (m/d)</th>
<th>Seepage velocity (m/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.008 (0.8%)</td>
<td>0.0008 to 0.016</td>
<td>0.3 to 5.8</td>
</tr>
</tbody>
</table>

These estimates do however not take into account all known or suspected zones in the aquifer like preferential flow paths formed by igneous contact zones like the intrusive dykes that have higher than average flow velocities. In fractured aquifer media, the transport velocity is usually significantly higher than the average velocities calculated with this formula and may increase several meters or even tens of meters per year under steady state conditions. Under stressed conditions such as at groundwater abstraction areas the seepage velocities could increase another order of magnitude.

The significance of pollution plume migration and the coinciding effect on the groundwater quality of downstream regions is very important because groundwater users occur on and downgradient of the mining area.
The long-term impacts on quality have been estimated through numerical modeling but have to be confirmed through groundwater monitoring during the operational and closure phases. The results of numerical modeling without time-series calibration data and relatively few measuring points cannot be considered as quantitatively correct. The simulated plume movement and geometry should only be considered as a qualitative simulation of the expected plume behavior after mining.

Groundwater contamination does not move away from the underground voids during the operational phases because the mines act as groundwater sink areas and flow with associated mass transport is radially inwards towards the underground.

The post-closure contamination/plume movement for the Impumelelo mining area was simulated by making use of constant concentration nodes after closure. Since the exact concentration or quality of any inorganic parameter is not predictable with a high level of confidence, the source (underground mine) will be assigned a concentration of 100, representing 100% of source. The dilution of the inorganic contamination plume can then be visualized as a diluting source until no impact of the source above the background occurs anymore.

Case studies from nearby mining operations where decant has started to occur indicate that indicator parameters could typically be as follows:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Most likely scenario decant quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5 to 6</td>
</tr>
<tr>
<td>EC</td>
<td>750 to 1000 mS/m</td>
</tr>
<tr>
<td>SO₄</td>
<td>2500 mg/l</td>
</tr>
</tbody>
</table>

The simulated plume dilution from source at 100 years after closure is indicated in Figure 52. The simulation indicates that a pollution plume in the deeper aquifer is expected to remain relatively constraint to the mine boundaries. The plume will migrate less than 500 meters from the workings at 100 years after closure from the lower elevations in the south of the mine workings.
The following events are foreseen in terms of groundwater at the Impumelelo Mine after closure:

- Recharge to the mine will continue after closure at a much higher rate than that of pre-mining recharge.
- Water levels in the mine voids will continue to rise individually in different compartments.
- The 2 seam voids will fill first as well as lowest parts of the 4 seam that are not underlain by 2 seam workings.
- Water levels will rise until each compartment is filled and water from all compartments is interconnected.
- At Impumelelo all compartments will be filled before the decant elevation (±1560 mamsl) is reached.
- The final water level in the mine will be flat because of the high transmissive nature of the goaf material.
- Post closure, a water make of some 8 770 m³/day is predicted.
- Under normal conditions, it would take around 53 years (Table 10) for the water levels in the mine to fill the 2 and 4 seam workings.
- The water level is not expected to recover to the pre-mining conditions due to the highly transmissive nature of the rock matrix above the mined areas.
- A decanting mine will derive its water from recharge that moves down into the goaf, then laterally towards the decanting position and finally through existing cracks to decant onto the surface.
- Recharged water will therefore become contaminated in the goaf before it discharges at the decant point.
- If the mine water is left undisturbed (through pumping) stratification of the water column in the mine will cause the best quality water to remain on top of the water column.
- The potential for acid rock drainage reactions has been confirmed and actions will have to be planned to manage the decant and prevent poor quality water to affect the receiving environment such as surface water, soil and downgradient aquifers.
- Downstream movement of a deeper groundwater pollution plume can occur especially in the decant area after the water level in the mine has recovered to near surface.
6 GROUNDWATER IMPACT ASSESSMENT: RATING OF POTENTIAL GROUNDWATER IMPACTS

6.1 APPROACH AND RATING CRITERIA FOR IMPACT ASSESSMENT AND MANAGEMENT

The EIAMAP is a comprehensive impact rating tool used to manage the negative environmental impacts associated with mining and related activities and consists of two key aspects. Firstly, the EIAMAP includes a full impact assessment according to activity (mining or mining-related), mining phase (construction, operational and decommissioning), and environmental component.

Secondly, an Environmental Management Programme (EMP) proposed for the expected impacts is also provided in the EIAMAP. This section of the EIAMAP includes proposed mitigation measures, time frames for implementation of the proposed mitigation measures and relative financial provisioning for the implementation of the proposed mitigation measure. These aspects comply with applicable legislation, as described in detail below.

Section 31(2)(k), Chapter 3 of the R. 543 (2010) in terms of the NEMA, 1998 requires an assessment of the extent, duration, probability and significance of the identified potential environmental impacts of the mining operation. In order to comply with best practice principles, the evaluation of impacts was conducted in terms of the criteria presented in Table 14.

The significance of the current impacts, which exist even with mitigation measures in place, was determined using the methodology indicated below.

Table 14: Impact assessment criteria

<table>
<thead>
<tr>
<th>Status</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>Impact will be beneficial to the environment (a benefit).</td>
</tr>
<tr>
<td>Negative</td>
<td>Impact will not be beneficial to the environment (a cost).</td>
</tr>
<tr>
<td>Neutral</td>
<td>Where a negative impact is offset by a positive impact, or mitigation measures, to have no overall effect.</td>
</tr>
</tbody>
</table>
### Magnitude

<table>
<thead>
<tr>
<th>Level</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>2</td>
<td>Negligible effects on biophysical or social functions / processes. Includes areas / environmental aspects which have already been altered significantly, and have little to no conservation importance (negligible sensitivity*).</td>
</tr>
<tr>
<td>Low</td>
<td>4</td>
<td>Minimal effects on biophysical or social functions / processes. Includes areas / environmental aspects which have been largely modified, and / or have a low conservation importance (low sensitivity*).</td>
</tr>
<tr>
<td>Moderate</td>
<td>6</td>
<td>Notable effects on biophysical or social functions / processes. Includes areas / environmental aspects which have already been moderately modified, and have a medium conservation importance (medium sensitivity*).</td>
</tr>
<tr>
<td>High</td>
<td>8</td>
<td>Considerable effects on biophysical or social functions / processes. Includes areas / environmental aspects which have been slightly modified and have a high conservation importance (high sensitivity*).</td>
</tr>
<tr>
<td>Very high</td>
<td>10</td>
<td>Severe effects on biophysical or social functions / processes. Includes areas / environmental aspects which have not previously been impacted upon and are pristine, thus of very high conservation importance (very high sensitivity*).</td>
</tr>
</tbody>
</table>

### Extent

<table>
<thead>
<tr>
<th>Level</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site only</td>
<td>1</td>
<td>Effect limited to the site and its immediate surroundings.</td>
</tr>
<tr>
<td>Local</td>
<td>2</td>
<td>Effect limited to within 3-5 km of the site.</td>
</tr>
<tr>
<td>Regional</td>
<td>3</td>
<td>Activity will have an impact on a regional scale.</td>
</tr>
<tr>
<td>National</td>
<td>4</td>
<td>Activity will have an impact on a national scale.</td>
</tr>
<tr>
<td>International</td>
<td>5</td>
<td>Activity will have an impact on an international scale.</td>
</tr>
</tbody>
</table>

### Duration

<table>
<thead>
<tr>
<th>Level</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Immediate</td>
<td>1</td>
<td>Effect occurs periodically throughout the life of the activity.</td>
</tr>
<tr>
<td>Short term</td>
<td>2</td>
<td>Effect lasts for a period 0 to 5 years.</td>
</tr>
<tr>
<td>Medium term</td>
<td>3</td>
<td>Effect continues for a period between 5 and 15 years.</td>
</tr>
<tr>
<td>Long term</td>
<td>4</td>
<td>Effect will cease after the operational life of the activity either because of natural process or by human intervention.</td>
</tr>
<tr>
<td>Permanent</td>
<td>5</td>
<td>Where mitigation either by natural process or by human intervention will not occur in such a way or in such a time span that the impact can be considered transient.</td>
</tr>
</tbody>
</table>

### Probability of occurrence

<table>
<thead>
<tr>
<th>Level</th>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improbable</td>
<td>1</td>
<td>Less than 30% chance of occurrence.</td>
</tr>
<tr>
<td>Low</td>
<td>2</td>
<td>Between 30 and 50% chance of occurrence.</td>
</tr>
<tr>
<td>Medium</td>
<td>3</td>
<td>Between 50 and 70% chance of occurrence.</td>
</tr>
<tr>
<td>High</td>
<td>4</td>
<td>Greater than 70% chance of occurrence.</td>
</tr>
<tr>
<td>Definite</td>
<td>5</td>
<td>Will occur, or where applicable has occurred, regardless or in spite of any mitigation measures.</td>
</tr>
</tbody>
</table>

Once the prediction components have been ranked for each impact, the significance of the potential impacts are evaluated (or calculated) using the following formula:

\[
\text{Significance} = (\text{Magnitude} + \text{Duration} + \text{Extent}) \times \text{Probability}
\]
As is evident from the above equation, the extent (spatial scale), magnitude, duration (time scale) and the probability of occurrence of each identified impact should be assigned a value according to the impact assessment criteria (presented in Table 14, above) and used to calculate the significance of each impact.

A Significance Rating should then be calculated by multiplying the Severity Rating with the Probability, and is therefore a product of the probability and the severity of the impact. The maximum value that can be reached through the described impact evaluation process is 100 SP3. The scenarios for each environmental impact are rated as High (SP≥60), Moderate (SP 31-60) and Low (SP<30) significance as shown in Table 15.

### Table 15: Definition of significance rating (positive and negative)

<table>
<thead>
<tr>
<th>Significance of predicted NEGATIVE impacts</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0-30</td>
<td>Where the impact will have a relatively small effect on the environment and will require minimum or no mitigation.</td>
</tr>
<tr>
<td>Medium</td>
<td>31-60</td>
<td>Where the impact can have an influence on the environment and should be mitigated.</td>
</tr>
<tr>
<td>High</td>
<td>61-100</td>
<td>Where the impact will definitely influence the environment and must be mitigated, where possible.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Significance of predicted POSITIVE impacts</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>0-30</td>
<td>Where the impact will have a relatively small positive effect on the environment.</td>
</tr>
<tr>
<td>Medium</td>
<td>31-60</td>
<td>Where the positive impact will counteract an existing negative impact and result in an overall neutral effect on the environment.</td>
</tr>
<tr>
<td>High</td>
<td>61-100</td>
<td>Where the positive impact will improve the environment relative to baseline conditions.</td>
</tr>
</tbody>
</table>

Once the significance rating of an impact before mitigation has been determined, the reversibility of the impact, replaceability of the affected resources and the mitigatory potential of the impact can also be determined. These factors have been included in the Impact Assessment below. These factors play an important role in the determination of the level and type of mitigation to be performed. The Table 16 provides the criteria used to assess the above mentioned factors.

### Table 16: Mitigation prediction criteria

<table>
<thead>
<tr>
<th>Reversibility of impact</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reversible</td>
<td>1</td>
<td>The impact on natural, cultural and / or social structures, functions and processes is totally reversible.</td>
</tr>
<tr>
<td>Partially</td>
<td>2</td>
<td>The impact on natural, cultural and / or social structures, functions and processes is partially reversible.</td>
</tr>
<tr>
<td>Irreversible</td>
<td>3</td>
<td>Where natural, cultural and / or social structures, functions or processes are altered to the extent that it will permanently cease, i.e. impact is irreversible.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Irreplaceable loss of resources</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replaceable</td>
<td>1</td>
<td>The impact will not result in the irreplaceable loss of resources.</td>
</tr>
</tbody>
</table>
The impacts expected to occur as result of the activities that are anticipated to take place at the project site may combine with those resulting from surrounding activities and land uses to form cumulative impacts, or to contribute to cumulative impacts that already exist. The EIAMAPs for cumulative impacts are slightly different from the others, since potential mitigation measures are excluded, as they will have been addressed in the other activity-specific EIAMAPs.

### 6.2 Construction Phase

The Impumelelo Mine is currently in the operational phase. No construction of any sorts is proposed for this project, only the extension of the current mining plan.

### 6.3 Operational Phase

This phase entails the period during which the underground mining areas are actively mined. The operational phase continues while underground mining and related activities such as coal extraction and conveying are conducted until these activities have ceased. The following activities have been identified to take place at the mining areas during the operational phase:

- Progressive underground development of the coal reserve by means of board-and-pillar in both the 4 seam and 2 seam areas,
- High extraction mining (stooping) of the pillars when board-and-pillar method is done.

### 6.3.1 Potential Impact

**Groundwater levels - availability**

Because the mining will cause aquifer dewatering, the water supply potential of surrounding users is at risk as a result of the mining. Water levels around and ahead of the progressing mine developments will be monitored to timeously determine the extent and intensity of adverse water level impacts.
**Groundwater quality**
The impact on salinity levels of the aquifer is expected to be intermediate during the operational phase, since any groundwater ingress into the mine will be controlled and contained for re-use. In the operational phase the overall inorganic salinity of water in the mine workings will increase over time as will be evident in the total dissolved solids (TDS) content of the water. Indicator parameters like sulphate and magnesium can also be expected to increase significantly from the ambient concentrations.

With ARD reactions becoming active the pH and bicarbonate alkalinity values of the water can be expected to decrease. The majority of metals have very low solubility in water at the normal (pH 6 to 8) pH range but will go into solution as a result of the lower pH environment (see reactions 2 and 3 above).

Over the long-term, the groundwater quality will improve because of dilution effects with high quality recharging water. Such recharge will result in a stratified water quality distribution in the underground void with the best quality water on top and the more saline (and with slightly higher specific gravity) water in the bottom of the mine.

6.3.2 **MANAGEMENT OBJECTIVES AND PRINCIPLES**

Regional influx from the surrounding shallow and especially deeper aquifer will be a major water source to the underground workings. There are few available surface rehabilitation methods that can be used to minimize adverse groundwater impacts caused by the total extraction mining method:

- Ploughing over of surface cracks can help in minimizing influx but sufficient soil cover is required. In outcrop areas such methods are not practicable.

- Minimizing pond formation on surface subsidence areas, especially on the sides of panels where cracks are most pronounced, will help a lot in preventing bulk ingress of water.

- A free-draining surface area should be aspired for but this is also not possible in flat-lying areas.

The excess mine water forming at the Impumelelo Mine can be expected to be relatively saline with high sodium, chloride, sulphate, calcium, magnesium, and fluoride if nearby mines can be used as a benchmark or case study.

6.3.3 **MANAGEMENT ACTIVITY OR MITIGATION MEASURES**

Mining will aim at avoiding surface water courses and features such as dams and pans where surface water accumulates. This would minimize clean water ingress to the underground workings and limit the volume of water that becomes contaminated as a result of the mining activity.
Dirty water will be contained in fit-for-purpose holding facilities.

Berms around the shafts will be implemented and maintained to divert clean water around dirty areas.

Localized dewatering of the surrounding aquifer cannot be prevented, unless the base of the mining operation is above the local groundwater level.

If the monitoring program indicates that nearby groundwater users are affected by the dewatering, the users need to be compensated for the loss. The supply network to replace groundwater lost by farmers due to the dewatering, need to run concurrent with the mining operation.

Surface water management measures around the mining areas will be implemented before commencing with mining development to prevent clean run-off water from entering the mine voids.

At underground/stooping mining areas, any surface cracks will be remediated by ploughing or filing above subsidence areas (if any) as soon as possible to reduce groundwater ingress from rainfall.

Trenching or other landscaping will be performed on subsidence areas where pans form on surface to retain a free-draining surface.

The following is a list of generic water management strategies in a high extraction mining operation that should receive serious consideration for both operational, closure and post-closure phases:

**Operational phase:**

No shafts are currently planned as part of the Impumelelo Extension project.

**Mining sequence**

- Mining should ideally proceed from deep to shallow. This would necessitate long develop ends to reach low-lying areas, from where underground high extraction retreats towards the shafts.
- It would however maximize void space utilization during flooding of the mined-out area. No water seals would then be required. Water management risk and cost would be minimized.
- Underground high extraction underneath a dam, pan and stream should be avoided. Although this has been done in many places, sudden inrush of water is a distinct possibility. Mining underneath these features should always be quantified in terms of probable volumes of water. Cracks underneath streams may seal themselves through
the ingress of clay, but this does not always happen and very costly engineering actions and damage to the surface environment are caused.

**Compartments**

- The principle of having underground compartments that could be flooded while mining progresses in other areas is well established and works well. Improved mine planning should ensure that entrances to compartments are always at the highest coal floor elevation. This will obviate the need for water seals and compartments can be flooded to their maximum capacities. This will also guard against acidification of the water in the compartments.

**Operational, closure and post-closure phases:**

**Surface rehabilitation**

- Surface rehabilitation of subsided areas would decrease the rate of water recharge. This could be done through ensuring that subsidence areas have free drainage to the outside; filling in of cracks or destroying cracks by ploughing across them; contouring the surface, thus diverting surface run-off from subsidence areas.

**Desalination**

- Desalination is a complex procedure that requires constant maintenance, brine disposal, significant capital outlay and high operating costs. Despite these almost overwhelming difficulties, desalination is probably still the only available technology after storage capacity has been exhausted. With the water demand and costs of water constantly increasing in South Africa and desalination technology becoming relatively cheaper, desalination of the mine water is an increasingly viable option. Desalination will however have to continue for decades (if not centuries) after the mine has closed down.

**Monitoring**

- Diligent monitoring of all potential groundwater impacts is critical to enable informed management decisions based on scientific information. All potential sources and downgradient areas should be covered by monitoring boreholes for all known aquifers.
- Water level measurement, groundwater influx rates (water balance) and groundwater quality should be measured regularly and interpreted scientifically to ensure a sound understanding of risks and impacts at all times.
- Operational monitoring focuses more on the water level impacts where availability of groundwater for existing users are monitored.
- Post-closure monitoring focuses on water level rebound in mine voids and mine water quality to ensure that decant time, place, volume and water quality is known and management measures are taken in time.
6.4 **DECOMMISSIONING PHASE**

This phase commences when the active mining of coal in the different mining areas ceases. This phase will continue until the post-closure phase begins. The following activities will take place during the Decommissioning Phase:

- a. Removal of equipment from the underground workings,
- b. Sealing of the shaft openings.
- c. Removing carbonaceous material from areas such as shaft footprints,
- d. Rehabilitation of shaft surfaces and of all surface areas indirectly affected by mining activities, such as subsided areas
- e. Monitoring and maintenance.

Decommissioning phase activities such as the removal of carbonaceous material from disturbed surface areas and rehabilitation of the shaft surface will have a positive impact on groundwater due to the improvement of the quality of surface water infiltration and reduction of poor quality seepage to groundwater.

During the rehabilitation period, the underground mine voids will start filling with groundwater seepage to reinstate the equilibrium with surrounding aquifers.

According to the groundwater investigation results, no decanting is expected from the closed Impumelelo Mine workings during the decommissioning phase, mainly because of the short duration of the decommissioning period. The decommissioning phase will last until the post-closure phase starts, therefore not allowing the 53 years needed for the water level to rise to decanting elevation.

It is anticipated that the groundwater quality will improve away from the Impumelelo Mine underground workings as the dilution effect of the entire aquifer increases further away from the mine. The water quality in the mined out underground workings is also expected to be better than in opencast mines, for example, due to the much smaller contact area with carbonaceous material. Once filled, most oxygen will have been removed from the workings so that acid-mine-drainage reactions will be minimized in the reducing chemical environment.

The results from the groundwater investigation will be verified through monitoring during the operational phase of the mine and suitable mitigation measures implemented should the results not confirm the initial conclusion regarding decommissioning phase groundwater related impacts.

**6.4.1 MANAGEMENT OBJECTIVES AND PRINCIPLES**

- To prevent or minimize seepage to the goaf areas which may increase contaminated water volumes.

**6.4.2 MANAGEMENT ACTIVITY OR MITIGATION MEASURES**
Management activities are limited but those available to minimize impacts have already been discussed in the previous section with the operational phase. The applicable activities should continue during the decommissioning phase and into the closure period.

The berms to divert clean water around dirty areas can be removed once the dirty water management areas were rehabilitated and re-vegetated.

The migration of the groundwater plume will be verified through monitoring and modeling during the decommissioning phase and suitable mitigation measures implemented before the closure is applied for, should it prove to be necessary.

6.4.3 Expected Result

The pollution plume will move downgradient from the mining area once the mine has filled up with water to near surface levels. The groundwater quality will improve away from the mine as dilution occurs from water stored in the aquifer and from recharge with fresh water.

Seepage rates, dewatering, post closure decant and plume movement have been simulated by the numerical groundwater modeling.

Should monitoring results confirm the expected decant rates, management or containment measures will be implemented to prevent impact of decant to the receiving surface water environment.

6.5 Closure Phase and Residual Impacts After Closure

Expected impacts and the associated management measures have been discussed extensively in the previous sections, especially Section 5 (concepts) and the first part of Section 6.
<table>
<thead>
<tr>
<th>Environmental Component</th>
<th>Potential Impact</th>
<th>Operational Phase</th>
<th>Proposed Mitigation measures</th>
<th>Residual Impacts after mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Underground mining-board-&amp;-pillar</td>
<td>- Localised dewatering of the deeper aquifer system(s). - Deterioration of water quality.</td>
<td>- The dewatering of the aquifer system cannot be prevented if mining progresses below the static water level.</td>
<td></td>
<td>6 1 5 4</td>
</tr>
<tr>
<td>Stooping</td>
<td>- Subsidence can occur due to total extraction - Dewatering of the shallow weathered and secondary aquifer may occur with cracking due to subsidence</td>
<td>- The dewatering of the shallow weathered and secondary aquifer system cannot be prevented if mining progresses below the static water level and cracking occur. - any surface cracks will be remediated by ploughing or filing above subsidence areas (if any) as soon as possible to reduce groundwater ingress from rainfall.</td>
<td></td>
<td>6 1 5 3</td>
</tr>
</tbody>
</table>
### Underground

<table>
<thead>
<tr>
<th>Decommisioning and Closure Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Groundwater quantity/availability:</strong> The mine will start filling with. The recharge to the aquifer (groundwater availability) will have increased significantly compared to the pre-mining situation.</td>
</tr>
<tr>
<td><strong>Groundwater quality:</strong> Groundwater quality in the underground workings will start to deteriorate as the mine starts filling and the water comes into contact with carbonaceous material and pyrite.</td>
</tr>
</tbody>
</table>

---

<table>
<thead>
<tr>
<th>Post-Closure Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Groundwater quantity/availability:</strong> After closure the mine will keep filling with water. Decant will start after approximately 53 years after closure at around 1 560 mams.  The recharge to the aquifer (groundwater availability) will remain higher than pre-mining but the water level on the surface above the underground mine will not increase above 1 560 mams.</td>
</tr>
<tr>
<td><strong>Groundwater quality:</strong> In spite of stratification expected</td>
</tr>
</tbody>
</table>
Groundwater Complete  Impumelelo Project

<table>
<thead>
<tr>
<th>Groundwater Complete</th>
<th>Impumelelo Project</th>
</tr>
</thead>
<tbody>
<tr>
<td>to cause better overall decant water quality, decant is expected to still be unsuitable for discharge into the receiving natural environment. A deeper pollution plume will move downgradient from the mining area once the mine has filled up with water to near surface levels. Plume movement is however expected to be slow due to low aquifer hydraulic properties.</td>
<td>Minimise further recharge to goaf areas. Monitor mine water quality to plan for decant management. Implement decant management system before decant occurs.</td>
</tr>
</tbody>
</table>
7 GROUNDWATER MANAGEMENT AND MONITORING PLAN

7.1 MONITORING PLAN/PROTOCOL – WHERE, WHAT, HOW

Water samples will be taken in the monitoring boreholes for each area on a quarterly basis. Water levels of these boreholes will also be determined on a quarterly basis when the sampling is done. Samples will be analyzed for chemical and physical constituents (organic and inorganic) normally associated with coal mining. These constituents are listed in Table 18.

It is strongly recommended that the groundwater qualities be assayed on a quarterly basis for inorganic content according to Table 18. It must be mentioned that this monitoring schedule will be re-assessed by a qualified geohydrologist at a later stage in terms of stability of water levels and quality. Should the sampling program be changed, it would be done in consultation with the DWA&F.

<table>
<thead>
<tr>
<th>Monitoring</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarterly</td>
<td>EC, pH, TDS, total hardness, total alkalinity, calcium, magnesium, sodium, potassium, chloride, sulphate, fluoride, nitrate, iron, manganese, aluminium and turbidity, hydro-carbons</td>
</tr>
</tbody>
</table>

Reporting on groundwater quality conditions will be included in the annual report.

The annual report will be an update of the database with time-series graphs, statistical analysis (average, maximum, minimum, 5-, 50- and 95 percentile values as well as linear performance). Data will also be presented in a map format to present a clear picture of the water quality situation. Laboratory results will be analyzed against the target water quality guidelines for domestic use, the aquatic environment, livestock watering and irrigation (according to the South African Water Quality Guidelines, 1996: DWAF). The strictest value between the target water quality objectives or objectives through a reserve determination will be used.

In terms of flow, all water uses and discharges will be measured on an ongoing basis. The flows include:

- Make-up water.
- Volumes of groundwater seepage into the underground workings and pumped from the workings.
- Volumes of contaminated water used for dust suppression.
- An annual detailed evaluation report on the groundwater quality will be prepared that will analyze the water quality situation in detail to investigate trends and non-compliance.
**Data Management**

Monitoring results would be entered into an electronic database as soon as results are available, and at no less than the monitoring interval, allowing:

- Data presentation in tabular format,
- Time-series graphs with comparison abilities,
- Statistical analysis (minimum, maximum, average, percentile values) in tabular format,
- Graphical presentation of statistics,
- Linear trend determination,
- Performance analysis in tabular format,
- Presentation of data, statistics and performance on diagrams and maps, and
- Comparison and compliance to South African Water Quality Guidelines and any other given objectives.

As far as possible, the same monitoring points will be used from the construction phase through the operational and decommissioning phases to after mine closure to develop a long data record and enable trend analysis and recognition of progressive impacts with time.

**7.2 Surface Rehabilitation Insofar it Affects Groundwater**

It was indicated that it is the purpose of the surface rehabilitation to re-establish surface drainage to the pre-mining conditions as far as practical.

The rehabilitation will aim to:

- Restore normal infiltration rates to areas where recharge were reduced due to surface compaction such as at the shaft areas,
- Closing of surface subsidence cracks (ploughing, backfilling etc) to minimize surface water ingress to the mine,
- Prevention of pond formation on surface by creating a free-draining surface through landscaping along slopes and filling of holes in flat-lying areas.

Rehabilitation of especially the surface subsidence areas may (and should) commence before the decommissioning phase. Rehabilitation will occur at the shaft areas.

**7.3 Legitimate Requirements of Groundwater Users**

The project is in short expected to have the following impacts on the legitimate requirements of the surface or surrounding groundwater users in terms of quantity or quality:

- No adverse impact on groundwater quality is expected on the existing groundwater users during the operational phase since flow and mass transport will be towards the depression cone created by the mine.
- Adverse impact is expected on the groundwater user on the mining area and in its immediate surrounds in terms of groundwater availability since dewatering of shallow and deep aquifers is expected to occur due to high extraction mining and associated goafing. The cone-of-depression around the mining areas is not expected to extend more than 1000 m from the subsidence areas.
- The water levels may take more than a century to recover and pollution movement away from the mine will only start to occur once the mine has filled to near surface/pre-mining elevations.
- The receiving surface water environment will also be affected adversely through base flow reduction in the mining region.
- Simulated pollution movement occurs at a relatively low rate (less than 5 meters per year) due to relatively low flow gradients and low aquifer transmissivity.

All of the above predictions and estimations need to be verified with an ongoing monitoring program through the production, closure and post-closure phases.

Management actions will be evaluated to deal with the decant predicted by this investigation at the Impumelelo Mine. **The mine remains committed to a zero effluent operating principle and contaminated water will be prevented from entering the receiving surface water environment through actions like evaporation, reuse or treatment.**

Should it be indicated through monitoring and investigation by a suitably qualified person that any legitimate groundwater users are impacted upon in terms of quantity or quality of borehole water, alternative water sources will be made available to such users by the mine.

Sasol will comply with the target objectives set for the surface- and groundwater resources in terms of a reserve determination under the National Water Act, 1998.

### 7.4 PERFORMANCE ASSESSMENT AND MONITORING OF THE ENVIRONMENTAL MANAGEMENT PROGRAM

In order to ensure compliance with the environmental management program and to assess the continued appropriateness and adequacy of the environmental management program, Sasol commits to:

- Conduct the monitoring of the environmental management program on an ongoing basis.
- Conduct the performance assessments of the environmental management program.
- Compile and submit to the Director: Mineral Development a report on the performance assessment of the environmental management program.
- The performance assessments of the environmental management program and the compilation and submission of the reports will occur every year from the date of approval of the environmental management program.
- The first performance assessment of the environmental management program will be scheduled to take place within 1 year of the approval of this EMP amendment report.
- Sasol will appoint a responsible person(s), in writing, who will monitor all environmental aspects of the site on a regular basis. A copy of this letter of appointment including the relevant emergency numbers will be supplied to the Director: Mineral Development of the DME.
- The appointed person will communicate, on a regular basis, with the local interested and affected parties identified with regards to the project and will report on the progress made with regards to implementation of the mitigation measures. Any complaint, with regards to the mining activity, will be reported to the appointed person and be recorded in the complaint register.

A report with regards to the following issues will be submitted to the DME on a yearly basis:
- Quantities processed to be recorded on a monthly basis.
- Water quality results;
- Water levels of identified boreholes, and
- A copy of the complaints register.

An annual water quality (groundwater) report will be compiled and submitted to the Regional Director: Department of Water Affairs and Forestry; Mpumalanga. The contents of the report will include the quarterly results at groundwater monitoring positions.

A register of environmental monitoring and auditing results will be available for inspection. This will also include compliance with environmental legislation, e.g. Environment Conservation Act, 1989 (Act 73 of 1989), National Environmental Management Act, 1998 (Act 107 of 1998), National Water Act, 1998 (Act 36 of 1998), etc.

The numerical groundwater model should be reviewed on an annual basis and subsequent management actions resulting from the model shall be implemented. The Regional Head shall be formally consulted regarding the outcome of the modelling exercise. When decanting scenarios change, this must be reported immediately to the Regional Head with the supporting mitigation measures, including financial provision and long-term accountability/responsibility.

The Licensee shall annually update and submit a geohydrological, pollution plume, water make, seep and decant model for the mining operations. This includes annual analysis of acid base accounting and leachate information of roof, panel and floor samples of all new mining areas.

The quantity of water removed from underground and pumped from surface to underground must be metered and recorded on a daily basis.

It is strongly recommended that the groundwater levels be measured during the quarterly sampling run.
7.5 **ANNUAL MONITORING OF REHABILITATION SUCCESS**

An annual monitoring report will be submitted to the Regional Head until official closure has been obtained. Once the database shows stability of the various environmental aspects, application for official closure will be made. This will be accompanied by a geohydrologist report with an updated and calibrated model to indicate long-term groundwater conditions and management measures, if required.

**Boreholes**

The following maintenance activities will be adhered to:

- Monitoring boreholes will be capped and locked at all times,
- Borehole depths will be measured once per year and the boreholes will be blown out with compressed air, if required and
- Vegetation around the boreholes will be removed on a regular basis and the borehole casings painted, when necessary, to prevent excessive rust and degradation.
8 REFERENCES


9 APPENDIX A- HYDROCENSUS REPORT

10 APPENDIX B- HYDROCENSUS BOREHOLES STIFF DIAGRAMS