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## RECORD OF REVISIONS AND ISSUES REGISTER

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SYNOPSIS

Sasol Synfuels (Pty) Ltd (Sasol) is proposing to construct Fine Ash Dam 6 (FAD 6), to the south of the existing Fine Ash Dam 5 (FAD 5) on the farm Rietvley 320 IS.

SRK Consulting (SRK) appointed Jones & Wagener (J&W) in 2014 to develop a groundwater model to assess the potential impact from FAD 6 on the geohydrological regime for different dam construction and lining options. The groundwater study was incorporated into the Waste Licence Application (WLA), as well as the Water Use Licence Application (WULA), which were undertaken by SRK (J&W Report No. JW98/14/E250, July 2014).

As per condition 6.2.1 of the Waste Management Licence (Licence number 12/9/11/L45369/6), a geophysical study was to be undertaken and a monitoring borehole network established around FAD 6. Following the drilling and testing of these boreholes the numerical groundwater model was updated (J&W Report No. JW068/16/E250, April 2016).

Underground coal mining by the Brandspruit Colliery, at a depth of approximately 125m below surface, underlies the FAD 6 footprint. An assessment of the surface stability of FAD 6 risks due to the underground workings was conducted by Professor N. van der Merwe of Stable Strata Consulting in 2014. His findings indicated that a portion of the underground mine workings should be backfilled to ensure the long-term stability of FAD 6. The question was raised if the proposed backfilling will have an adverse impact on the groundwater resources underneath or near FAD 6.

This report is an updated version of the previous geohydrological report to incorporate the potential impact of the ash backfill on the groundwater quality. The purpose of this study is to assess the potential impact from the proposed ash backfill underneath a portion of the FAD 6 on the groundwater resources in the region.

Sasol Synfuels is situated just outside the town of Secunda, Mpumalanga Province. The towns of Secunda and eMbalenhle are located 3km north-east and 1km west of the study area respectively. The proposed FAD 6 is located on the Farm Rietvley 320 IS to the south of the existing FAD 5 of the Waste Ash Disposal Sites (WADS) of the Sasol Synfuels Complex. Apart from Sasol's mining and industrial development the land use in the region is predominantly agriculture. Most of the footprint of FAD 6 is currently fallow, but has previously been, and is still partially used for crop (maize) and stock farming (SRK, 2011). Part of the site is underlain by mining operations by Sasol Coal.

The study area is located within the catchment of the Grootspruit and in particular the sub-catchments of the Kleinspruit, Trichardspruit, Klipspruit and the Bossiespruit.

The waste facilities at Sasol Synfuels and particularly FAD 6 are situated on interbedded siltstone/sandstone and shale of the Vryheid Formation, underlain by a dolerite sill. Based on the geological information the following aquifers underlie the site, or are in close proximity to the site:

- **Weathered Aquifer**: A shallow, weathered aquifer exists in the weathered shale and sandstone at an average depth of 12m below ground level (based on the average depth to the top of the dolerite sill). At FAD 6, the depth of weathering varies between 0m (FAD6 BH4) and 24m. The most consistent water strike is located at the fresh bedrock / weathering interface. Groundwater elevations vary between 0m (artesian) and 9.55 mbs (PB 09A).

- **Fractured Aquifer**: The primary porosity of the Vryheid Formation is very low. Any water bearing capacity is therefore associated with secondary joints, bedding planes and faults. The contact zones of dolerite intrusions are characterised by cooling joints and fractures, which are considered the primary source of groundwater flow within the deeper formations. The depth to groundwater in this aquifer ranges from 0m (artesian) to 30.43 mbs (PB 07). The variation in groundwater levels is attributed to confining layers and the undermining in parts of the study area.
The calculated parameters for the weathered and fractured aquifers are indicative of poorly developed aquifers that underlie the study area. These aquifers do not constitute economically sustainable and exploitable hydrological units. It is, however, important to note that individual fractures may yield higher volumes of water and flow rates may be faster within these features.

Parts of the Sasol Synfuels area are undermined and there is evidence of localised dewatering in certain areas. In several of the boreholes at FAD 6 the groundwater levels are relatively deep.

Typically, in this geological terrain the groundwater table mimics the topography in undisturbed areas. If the FAD 6 boreholes are included there is a 69% correlation with the topography the weathered aquifer. If the FAD 6 boreholes are excluded a 97% correlation is achieved in the weathered aquifer. The boreholes at FAD 6 were drilled into a dolerite sill, which is commonly believed to be a barrier for groundwater flow, but in this instance the deeper groundwater table could possibly be explained by fracturing in the sill connecting it to the underlying mine workings. This may have caused dewatering of the aquifer, which appears to be localised in places.

Some boreholes in the fractured aquifer also have deeper groundwater levels. This resulted in a relatively poor correlation with the topography of only 62%. If the borehole with deep water levels are removed the correlation with the topography improves to 97% for the fractured aquifer.

It is therefore concluded that both the weathered and fractured aquifers mimic the topography, but that localised dewatering occurs in areas where the structural geology links the aquifer with the underlying mine workings.

The groundwater flow in the vicinity of FAD 6 is affected by the localised dewatering of the aquifers. Such dewatering is potentially occurring in the vicinity of the proposed return water dam as boreholes FAD6 BH3, PB 06, PB 07 and PB 08 (dry) have all very low groundwater levels. The FAD 6 is in the construction phase and the current groundwater chemistry is expected to reflect the pre-construction quality.

Based on the analyses the groundwater chemistry can be described as follows:

- The groundwater quality in both aquifers is good.
- The sodium concentration in borehole FAD6 BH2 exceeds the allowable limit, whereas the elevated TDS and sulfate concentrations are still allowable.
- The aluminium concentration in borehole PB7 and the manganese concentration in borehole PB9A exceed the allowable limits.

A numerical groundwater flow and contaminant transport model was developed to evaluate the suitability of the proposed liner system underneath FAD 6 and associated water management dams.

A three-layered aquifer model was constructed and calibrated for the Sasol Synfuels site using the finite element 3D-modelling package FEFLOW 6.2.

- Layer 1 – Shallow weathered aquifer. This aquifer has an estimated depth of 15m;
- Layer 2 – Deeper fractured aquifer. This aquifer has an estimated depth of 60m; and
- Layer 3 – Underground mining (2m).

The calibrated flow model was used to simulate the expected contaminant migration (TDS concentrations) without any liner system from the proposed development. Intervention in the form of a liner and drainage system was then introduced to simulate the effectiveness thereof. The following scenarios were simulated at FAD 6:

**Scenario 1**: Groundwater quality impact (represented by the TDS concentration) without any liner. The estimated leakage rate for this scenario is $5.80 \times 10^{-4} \text{ m}^3/\text{m}^2/\text{day}$. 
Scenario 2: Groundwater quality impact with a liner and drain system underneath FAD 6 and the associated water return dams. The estimated leakage rate for this scenario is $8.75 \times 10^{-5} \text{ m}^3/\text{m}^2/\text{day}$.

Scenario 2a, b and c: Potential liner failure was also simulated and Scenario 2a represents a 5% failure, Scenario 2b a 10% failure and Scenario 2c simulated what is considered unacceptable liner failure. The estimated leakage rates for these scenarios are as follows:

- Scenario 2a: $9.19 \times 10^{-5} \text{ m}^3/\text{m}^2/\text{day}$;
- Scenario 2b: $9.63 \times 10^{-5} \text{ m}^3/\text{m}^2/\text{day}$;
- Scenario 2c: $2 \times 10^{-4} \text{ m}^3/\text{m}^2/\text{day}$;

In all instances the development of a contaminant plume over an operational period of 50 years (up to 2066) was simulated. The assumption was made that operation will cease in 2066 and that the dam will be rehabilitated. The source was theoretically capped and the improvement in the TDS concentrations over the next 50 years (until 2115) was simulated.

Based on the simulations the effectiveness of the proposed liner is summarised below. This is based on the maximum flow rates and contaminant loads during the simulation period.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Contaminant Load into River System (Tons/day)</th>
<th>% Improvement from Base Case</th>
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<td></td>
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<td>Stream A (Grootspruit)</td>
<td>Stream B (Bossiespruit Tributary)</td>
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<tr>
<td>1</td>
<td>No liner (Base case)</td>
<td>0.15</td>
<td>0.16</td>
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<tr>
<td>2</td>
<td>Liner – 100% effective as per design</td>
<td>0.0020</td>
<td>0.011</td>
</tr>
<tr>
<td>2a</td>
<td>Liner – 95% effective as per design</td>
<td>0.0020</td>
<td>0.011</td>
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<td>2b</td>
<td>Liner – 90% effective as per design</td>
<td>0.0021</td>
<td>0.012</td>
</tr>
<tr>
<td>2c</td>
<td>Liner – unacceptable liner failure</td>
<td>0.0032</td>
<td>0.085</td>
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In terms of flow to the surface streams the following is concluded:

- In an unlined situation, the contaminant plume is expected to migrate a distance of 485m in an easterly direction from FAD 6 and 350m in a westerly direction. In a lined situation, the contaminant plume will only migrate 70m in an easterly direction and 220m in a westerly direction.

- The expected maximum contaminant load contribution to surface streams in an unlined situation is 0.31 tons per day. In the lined situation the load reduces to 0.013 tons per day, or a 96% improvement. Even in a situation where the liner system fails the impact on the groundwater regime is significantly reduced.

The groundwater flow in the vicinity of FAD 6 is affected by the partial dewatering of the aquifers. As indicated above such dewatering is potentially occurring in the vicinity of the proposed return water dam. In order to assess the potential impact from the proposed Fine Ash Dam 6 on the underground mine workings, the model was used to simulate the flow volume and contaminant load to the workings. The results of this assessment show that in the vicinity of FAD 6 the unlined flow and contaminant load is expected to be in the order of 190 m$^3$/day and 0.10 tons/day TDS respectively. This will further reduce to around 169 m$^3$/day and 0.012 tons/day TDS respectively for the lined scenario.
The proposed liner system shows a significant reduction in the estimated impact from FAD 6 and is therefore considered adequate to protect the underlying aquifers from groundwater contamination.

A portion of the underground mine workings, underlying FAD 6, will be backfilled to ensure the long-term stability of the dam. The question was raised if the proposed backfilling will have an adverse impact on the groundwater resources underneath or near FAD 6. Laboratory testing was undertaken to classify the waste characteristics of the cement – ash mixture and to determine the quality of the leachate that can potentially emanate from the backfill. This study concluded that:

- The fine ash to be used in the cement – ash mixtures has been classified as non-hazardous, therefore a general waste.
- The 4% cement – wet ash and the 6% cement dry-ash mixtures have both been assessed as Type 3 wastes.
- Based on the distilled water leach concentration results on crushed cubes, the 4% cement – wet ash mixture is assessed as inert, a Type 4 waste, while the 6% cement – dry ash mixture is assessed as a Type 3 waste.
- In terms of the results of the 1:10 distilled water leach conducted on the whole cubes, and is believed to be representative of the actual application of this material, the two ash – cement mixtures are classified as inert, Type 4, wastes.

The potential impact in terms of the groundwater level drawdown and water inflow into the mine, was simulated. This simulation assumed that the boreholes are not cased and that all the boreholes are drilled simultaneously and left open for one year. This assessment concluded that:

- The maximum radius of influence of each borehole is 35m. The combined influence remains within the boundaries of FAD 6 and will not impact on any groundwater users in the area.
- The groundwater levels are expected to recover within 6 months after being grouted.
- The estimated combined maximum groundwater inflow into the mine, is 1 600 m$^3$/day.

The Brandspruit Mine workings underneath FAD 6 is currently dry, but will be flooded with mine water once mining ceases. The contaminated water in the flooded workings will be largely stagnant, but a localised impact at the elevation of the coal seam, is predicted over time. In terms of the Brandspruit Colliery IGS (2016) concluded that:

"It is unforeseen that mine water will decant through any un-mined outcrop area, due to the pressure required and depth below the ground surface. It is thus also unforeseen that decant will occur along any secondary feature, based on the assumption that these features (such as shafts, subsidence areas and boreholes) are correctly sealed/managed as per the EMP".

The backfilled volume compared to the overall mined out volume is less than 1%. In addition, the proposed backfill area is located towards the centre of the simulated mine water contaminant plume and thus the limited impact from the backfill material is expected to remain within the mining void. Based on the above and considering the expected leachate quality, it is concluded that the added contribution of the leachate from the backfilled area to the overall impact from the mine water is negligible.

The closest private borehole to the backfill area are located 1.6km to the west. This distance, as well as the shallow depth of all the measured boreholes indicate that the backfill will not impact on private groundwater users. In addition, Sasol Mining will develop a groundwater management plan that will govern the future additional groundwater usage within the areas affected by mining.
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1. INTRODUCTION

Sasol Synfuels (Pty) Ltd (Sasol) is proposing to construct Fine Ash Dam 6 (FAD 6), to the south of the existing Fine Ash Dam 5 (FAD 5) on the farm Rietvley 320 IS.

SRK Consulting (SRK) appointed Jones & Wagener (J&W) in 2014 to develop a groundwater model to assess the potential impact from FAD 6 on the geohydrological regime for different dam construction and lining options. The groundwater study was incorporated into the Waste Licence Application (WLA), as well as the Water Use Licence Application (WULA), which were undertaken by SRK (J&W Report No. JW98/14/E250, July 2014).

As per condition 6.2.1 of the Waste Management Licence (Licence number 12/9/11/L45369/6), a geophysical study was to be undertaken and a monitoring borehole network established around FAD 6. Following the drilling and testing of these boreholes the numerical groundwater model was updated (J&W Report No. JW068/16/E250, April 2016).

Underground coal mining by the Brandspruit Colliery, at a depth of approximately 125m below surface, underlies the FAD 6 footprint. A risk assessment of the surface stability of FAD 6 due to the underground workings was conducted by Professor N. van der Merwe of Stable Strata Consulting in 2014. His findings indicated that a portion of the underground mine workings should be backfilled to ensure the long-term stability of FAD 6. The question was raised if the proposed backfilling will have an adverse impact on the groundwater resources underneath or near FAD 6.

This report is an updated version of the previous two geohydrological reports to incorporate the potential impact of the ash backfill on the groundwater quality.

2. STUDY PURPOSE

The purpose of this study is to assess the potential impact from the proposed ash backfill underneath a portion of the FAD 6 on the groundwater resources in the region.

3. PREVIOUS STUDIES AND INFORMATION SOURCES

Two previous studies were mainly consulted in developing the 2014 numerical model. The Institute for Groundwater Studies, University of the Free State, subsequently undertook a groundwater modelling exercise in 2016, on behalf of Sasol Mining, that studied the potential impact from the flooded underground workings on the groundwater regime. These studies are briefly summarised below.
3.1 Groundwater Modelling at the Sasol Synfuels Site, Secunda (Rison Groundwater Consulting, 2006)

A groundwater model was developed by Rison Groundwater Consulting in 2006. The 2006 study evaluated the impacts from various sources at the Secunda facility on the groundwater quality. This model information was utilised to develop a new model for the FAD 6 complex. The construction and methodology of the updated groundwater model is discussed in detail in Section 6.

3.2 Hydrogeological Assessment for the Proposed Fine Ash Dam 6 for Sasol Synfuels, Secunda (SRK Consulting, 2011)

SRK undertook a geohydrological investigation to identify the conditions of the groundwater systems in the vicinity of the proposed FAD 6, and to assess impacts that FAD 6 may present. The aim of the study was also to understand mitigation and management measures proposed by Sasol Synfuels in the design and operation of the proposed FAD 6 in respect of potential groundwater impacts, and to recommend additional mitigation and management measures, where appropriate.

The hydrogeological assessment for the proposed FAD 6 area concluded that (SRK, 2011):

- There is no existing use of groundwater within the immediate vicinity of the proposed FAD 6 location, although boreholes are registered with the National Groundwater Database.
- Historical, non-operational farmstead boreholes have been located in the area, indicating that groundwater was utilised in the past.
- Sasol Coal mining activities in the area are considered to have affected the regional groundwater regime, including the location of exploration boreholes and operational boreholes in the proposed regional area.
- Sasol Coal indicates no objections to the construction of the proposed FAD 6 in the area of their mineral resources and mine workings.
- Natural groundwater flow from FAD 6 is expected to be predominantly to the southern directions towards the tributary of the Grootspuit. However, underground mining operations and existing Waste Ash Disposal Sites (WADS) may have an impact on, and influence groundwater flow, as a result of possible preferential fracture flow and possible mounding from the WADS respectively.
- The weathered aquifer beneath FAD 6 area overlies semi-permeable bedrock that may restrict ingress of groundwater from the shallow weathered rock aquifer to the underlying fractured rock aquifer. It is, however, expected that where the weathering is deep and where preferential downward flow paths exist, the shallow weathered rock aquifer may be hydraulically linked to the deeper fractured rock aquifer. The deeper fractured aquifer may seep into the mine workings that are known to exist below some sections beneath FAD 6.
- Analysis of groundwater for the hydrogeological study indicated groundwater for the proposed FAD 6 area to be of generally good quality, and within the guidelines for drinking water.
- SRK understands that the proposed FAD 6 would be engineered to manage and mitigate potential impacts on groundwater resources and mining activities of the area.
The hydrogeological assessment indicates that the proposed FAD 6 would not have a material impact on the local groundwater resource use potential, and that the risk to surface water resources from groundwater recharge is also limited, although the proposed FAD 6 may affect the local groundwater levels and quality, by providing some additional hydraulic head and recharge potential.

The impact assessment indicated that with management options proposed by Sasol Synfuels, and considering a relatively low seepage potential to the underlying aquifer, impacts will be:

- Low to medium during construction and operation.
- Low post-closure.
- As there is a groundwater use exclusion zone around Sasol Synfuels Complex, and the area is extensively under-mined affecting local groundwater movements and availability and municipal water is available to residents in the area, there is no immediate exposure path for groundwater direct use impacts to occur.

The Rison and SRK reports provided background information on the geohydrology of the site and no additional fieldwork was therefore undertaken at the time (2014). Recent information on groundwater levels and quality was, however, obtained from groundwater monitoring routinely undertaken by the Institute for Groundwater Studies, University of the Free State. The groundwater monitoring database, containing historical data, was also made available by Sasol.

3.3 Sasol Secunda Synfuels (SSO) Hub and Sasol Mining Pollution Plume Model (Institute for Groundwater Studies, September 2016).

The main aim of the project was to determine the current and future impact by Sasol Secunda Collieries and Industrial Complex, to both groundwater and surface water resources. The effect of potential pollution sources, related to both Sasol Secunda Mining and Synfuel operations, on the surface water and groundwater systems were investigated by means of numerical transport models.

The study evaluated all the Sasol Mining collieries in the region in terms of the potential contamination of the groundwater resources after closure and flooding of the underground workings. The numerical modelling indicated that the water quality in the defunct underground coal mines contain contaminants that can migrate into the adjacent aquifer over time. The contaminated water in the flooded workings will be largely stagnant and the impact will be localised at the elevation of the coal seam.

In terms of the Brandspruit Colliery it was concluded that:

“It is unforeseen that mine water will decant through any un-mined outcrop area, due to the pressure required and depth below the ground surface. It is thus also unforeseen that decant will occur along any secondary feature, based on the assumption that these features (such as shafts, subsidence areas and boreholes) are correctly sealed/managed as per the EMP”.

The information from this study was utilised in evaluating the potential impact from the backfill on the groundwater resources. This is discussed in more detail in Section 8.
4. SITE DESCRIPTION

4.1 Site Locality

Sasol Synfuels is situated just outside the town of Secunda, Mpumalanga Province. The towns of Secunda and eMbalenhle are located 3km north-east and 1km west of the study area respectively (Figure 4.1).

The proposed FAD 6 is located on the Farm Rietvley 320 IS to the south and south west of the existing FAD 5 of the WADS of the Sasol Synfuels Complex, Secunda (Figure 4.2). Apart from Sasol’s mining and industrial development the land use in the region is predominantly agriculture. Most of the footprint of FAD 6 is currently fallow, but has previously been, and is still partially used for crop (maize) and stock farming (SRK, 2011). Part of the site is underlain by the Brandspruit Colliery, Sasol Mining.

4.2 Topography and Drainage

The elevation at Sasol Synfuels varies between 1 580 metres above mean sea level (mamsl) and 1 620 mamsl.

The study area is located within the catchment of the Grootspruit and in particular the sub-catchments of the Kleinspruit, Trichardspruit, Klipspruit and the Bossiespruit (Figure 4.3).

4.3 Climate and Rainfall

The annual average rainfall is 710mm (Rison, 2006). Recharge to the aquifers is primarily from rainfall and is a component that has been incorporated into the groundwater model. The regional groundwater recharge is estimated at 3% of the Mean Annual Precipitation (MAP).
Figure 4.1: Site locality
Figure 4.3: Regional topography and drainage
4.4 Geological Setting

The regional and local geology has been described in both the Rison and SRK reports. The following extract from those reports is included for reference.

4.4.1 Regional Geology

Sediments of the Vryheid Formation of the Ecca Group underlie the study area (Figure 4.4). The Vryheid Formation (Ecca Group) mainly comprises mudstone, siltstone and fine- to coarse-grained sandstone (pebbly in places). Large sections of the study area are underlain by alluvium, especially along the river floodplains, as well as dolerite sills. These lithologies influence groundwater flow and hence contaminant migration.

Typically the different lithofacies of the Karoo Basin are mainly arranged in upward-coarsening deltaic cycles (up to 80m thick in the southeast). Linear coastline cycles are, however, fairly common particularly in the thin north-western part of the basin. A relatively thin fluvial interval (60 m thick) which grades distally into deltaic deposits towards the southwest and south occurs approximately in the middle of the formation in the east and northeast. Fining-upward fluvial cycles, of which up to six are present in the east, are typically sheet-like in geometry, although some form valley-fill deposits. They comprise coarse-grained to pebbly, immature sandstones - with an abrupt upward transition into fine-grained sediments and coal seams.

Dolerite intrusions represent the roots of the volcanic system and are presumed to be of the same age as the extrusive lavas (Fitch and Miller, 1984). The level of erosion that affected the Main Karoo Basin has revealed the deep portions of the intrusive system, which displays a high degree of tectonic complexity. The Karoo dolerite, which includes a wide range of petrological facies, consists of an interconnected network of dykes and sills and it is nearly impossible to single out any particular intrusive or tectonic event. It would, however, appear that a very large number of fractures were intruded simultaneously by magma and that the dolerite intrusive network acted as a shallow stockwork-like reservoir.

4.4.2 Local Geology at the Sasol Waste Facilities

Based on geological borehole logs the local geology is characterised by the following lithologies (Rison, 2006):

**0m – 5m: Hillwash and Alluvium:** The alluvium generally consists of a grey to black, shattered fissured and slickensided silty clay, sandy clay or clayey silt. The alluvial deposits are generally 1m in thickness along tributary streams and might be up to 5m in thickness along the flood plains of the Trichardtspruit. Occasional calcrete concretions might be present. The alluvium is potentially highly active and compressible (WMB, 1999).

**5m – 15m: Siltstone:** The residual siltstone and mudrock typically consists of grey fissured and slickensided silty clay and numerous calcrete nodules. The mudrock is frequently reworked and relict rock structures might not be visible (WMB, 1999). The siltstone is carbonaceous in places.

**15m – 30m: Sandstone:** The residual sandstone consists of pale brown to off-white medium dense slightly silty medium sand and clayey sand. The sandstone is often micaceous and varies from fine to medium grained.

The above stratigraphic description is typically an upwards fining sequence and the siltstone and sandstone shows variable degrees of weathering. A dolerite sill has intruded large parts of the study area and occurs at variable horizons. As a rule of thumb the formations overlying the sills are more extensively weathered than those underlying the sill.
Figure 4.4: Regional surface geology
According to Wates, Meiring & Barnard (WMB, 1999) and with reference to Figure 4.2 the following geological conditions are encountered within the various sections of the Sasol Synfuels Complex:

- **Process Water Dams:** The process water dams are largely underlain by alluvium, siltstone and shale. The alluvium occurs along the northern, western and southern parts of the process water dams and the siltstone and shale underlies the central and eastern parts of the dam. The southern, western and northern portions of the dam are located within the floodplain area of the Trichardt- and Bossiespruit.

- **Salty Water Dams:** The salty water dams are largely underlain by alluvium, siltstone and shale. The alluvium occurs along the northern, western and southern parts of the salty water dams and the siltstone and shale underlies the central and eastern parts of the dams. The southern, western and northern portions of the dam are located within the floodplain area of the Trichardt- and Bossiespruit.

- **Ash Effluent Dams:** The Botha and Van Niekerk Dams are entirely underlain by alluvium. Both are largely located on the Trichardt and Bossiespruit floodplains.

- **Black Products Area:** The Black Products Area is mainly underlain by dolerite. The north-western part of the area is underlain by sandstone. The southern portion of the Black Products Area is underlain by a fault zone, which forms part of a graben structure with an east-west orientation.

- **Ash Disposal Area:** The coarse ash dump is underlain by dolerite, sandstone, siltstone and alluvium. The southern portions of the dump are underlain by dolerite, the central parts by sandstone and the northern part by siltstone. Alluvium bisects the ash dump. The southern portion of the coarse ash dump is underlain by a fault zone, which forms part of a graben structure with an east-west turning southwest-northeast strike at the region of the coarse ash dump.

4.4.3 Local Geology at FAD 6

The near surface geological conditions in the FAD 6 area were investigated by J&W (Report No. JW053/14/E250 – Rev 0) and can be described as follows.

The typical profiles for the fine ash dam and return water dams show two dominant typical profiles, namely a residual Karoo profile and the dolerite profile. Within these two profiles the following stratigraphic horizons are present:

- **Transported horizon;**
- **Residual horizon; and**
- **Bedrock horizon.**

**Transported horizon**

Hillwash – The thickness of the hillwash ranges from 0.5m to 1.0m across the study area. The material consists of a firm, black, shattered, slickensided and pinhole voided sandy clay. On occasions, the material has been reworked through bioturbation processes. On the dolerite profile the hillwash will have scattered, highly weathered, dolerite gravels of boulders. The hillwash is encountered predominantly in the crestal and sideslope units. The hillwash is generally thinner on the crestal terrain (0.6m) while it’s thicker on the sideslope units (1.0m). In the dolerite profile on the crestal unit, gravels and boulders of dolerite are encountered scattered within this horizon.

Alluvium – The alluvium was encountered within the gullywash units and consists of firm olive grey, slickensided and shattered sandy clay with scattered calccrete nodules. The thickness across the proposed developments varied from 0.7m to 2.5m.
**Residual horizon**

Reworked residual sandstone/siltstone - The material consists of a firm to stiff, shattered and slickensided sandy clay soil. The average thickness of this horizon in the study area varied from 0.4m to 1.2m. This horizon is predominantly encountered on the sideslope and gullywash units and underlies the hillwash horizon.

Residual sandstone/siltstone - The average thickness of this horizon ranges from 0.3m to 0.6m. The material consists of either a dense, relict bedded to laminated silty to clayey sand or stiff, thinly laminated clayey silt material. The dense silty sand horizon are encountered on the crestal terrain units while clayey silt material are encountered on the sideslope unit.

Reworked residual dolerite - This horizon is a transition horizon between the hillwash and residual dolerite. The material consists of medium dense, clayey sand soil that exhibits localised zones of “onionskin” or spheroidal weathering, resulting in silty clay with scattered gravels. The average thickness across the proposed development is in the order of 0.4m. The reworked residual dolerite is encountered mostly on the sideslope terrain.

Residual dolerite - This material consists of slightly clayey silty, medium to coarse grained sand. The structure of the horizon exhibits exfoliation and spheroidal weathering with a medium dense to dense consistency. The thickness ranged from 0.8m to 1.3m. Locally, the dolerite horizon is characterised by a highly weathered very soft rock horizon, but after excavation and reworking, the material crumbles into a blocky gravely material with a sandy matrix. The residual dolerite is encountered in the sideslope and crestal terrains. The crestal dolerite covers the most of FAD 6 terrain.

**Bedrock horizon**

Sandstone/Siltstone - The TLB and excavator occasionally refused on a widely jointed thinly laminated, fine grained, soft to medium hard rock, sandstone horizon. The bedrock was generally encountered at depths of about 3.3m to 4.5m but localised zones were encountered with bedrock from 0.4m. In the gullywash unit, very soft rock sandstone/siltstone was encountered at depths ranging from 1.9m to 2.5m.

Dolerite - Refusal occurred on medium to hard rock dolerite at depths ranging from 0.3m to 3.0m. The material consist of a closely to medium jointed, hard rock dolerite. In some test pits the blocky dolerite was excavatable with the TLB or excavator as a highly weathered, angular to sub-angular, gravels and cobbles.

**Sub-Surface Geology at FAD 6**

The deeper geology at FAD 6 is described based on borehole drilling (SRK, 2011). Boreholes drilled for the initial FAD 6 study intersected interbedded siltstone/sandstone and shale of the Vryheid Formation, underlain by a weathered dolerite sill to a depth of approximately 25m to the north, west and south of the site. The dolerite sill is fresh below 25m and outcrops to the south east of FAD 6. The nature and orientation of the weathering/fracturing in the dolerite sill could have an impact on the rate and direction of groundwater flow within the FAD 6 area, possibly following the pattern of the fracturing/weathering.

Based on the 2016 drilling at FAD 6 the deeper sub-surface geology can be summarised as follows (Table 4.1):
Table 4.1: Borehole drilling results

<table>
<thead>
<tr>
<th>Borehole</th>
<th>Clay</th>
<th>Gravel</th>
<th>Sandstone</th>
<th>Dolerite</th>
</tr>
</thead>
<tbody>
<tr>
<td>PB5 and PB5A</td>
<td>0-12 mbs</td>
<td>12-30 mbs</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PB6 and PB6A</td>
<td>0-1 mbs</td>
<td>1-24 mbs</td>
<td>24-32 mbs</td>
<td></td>
</tr>
<tr>
<td>PB7 and PB7A</td>
<td>0-1 mbs</td>
<td>1-6 mbs</td>
<td>6-18 mbs</td>
<td>18-35 mbs</td>
</tr>
<tr>
<td>PB8 and PB8A</td>
<td>0-1 mbs</td>
<td>1-6 mbs</td>
<td>6-35 mbs</td>
<td></td>
</tr>
<tr>
<td>PB9 and PB9A</td>
<td>0-1 mbs</td>
<td>1-6 mbs</td>
<td>12-31 mbs</td>
<td>6-12 mbs</td>
</tr>
<tr>
<td>PB10 and PB10A</td>
<td>6-12 mbs</td>
<td>0-6 mbs and 12-24 mbs</td>
<td>24-32 mbs</td>
<td></td>
</tr>
</tbody>
</table>

Note:  
PB5 = Deep borehole  
PB5A = Shallow borehole  
mbs = metres below surface

The entire site is underlain by a dolerite sill varying between 0 – 24 metres below surface (mbs). Two boreholes (FAD6 BH4 and PB 09) were drilled through the sill and the thickness varied between 28m and 6m respectively.

Overlying the sill is weathered sandstone and gravel of the Vryheid Formation.
5. GEOHYDROLOGICAL SETTING

5.1 Introduction

The geohydrology of the study area was assessed based on available data, literature and previous field investigations. Based on this information a numerical groundwater flow and contaminant transport model was developed, specifically to evaluate the potential impacts on groundwater quality from FAD 6.

The geohydrological setting and conceptual model of the study area is described according to the following criteria:

- Borehole information;
- Aquifer type;
- Aquifer parameters;
- Groundwater gradients and flow;
- Groundwater quality; and
- Aquifer classification.

5.2 Borehole Information

Twelve new groundwater investigative / monitoring boreholes were drilled as per the waste licence instruction (2016). Sasol appointed the Institute for Groundwater Studies (IGS – University of the Free State) to manage the drilling of the required boreholes. M.E.N. Survey and Drilling (Pty) completed the drilling in April 2016 following a detailed geophysical study and target selection by IGS. The geophysics report is attached as Appendix A. A summary of the borehole construction is presented in Table 5.1.

<table>
<thead>
<tr>
<th>BH ID</th>
<th>Coordinates (LO 29)</th>
<th>Depth (m)</th>
<th>Water Level</th>
<th>BH Diameter</th>
<th>Casing Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X</td>
<td>Y</td>
<td>Z</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PB 5</td>
<td>12 492.904</td>
<td>-2 943 939.175</td>
<td>1639.387</td>
<td>30</td>
<td>Dry</td>
</tr>
<tr>
<td>PB 5A</td>
<td>12 493.030</td>
<td>-2 943 936.127</td>
<td>1639.395</td>
<td>10</td>
<td>Dry</td>
</tr>
<tr>
<td>PB 6</td>
<td>11 130.110</td>
<td>-2 943 689.208</td>
<td>1622.521</td>
<td>32</td>
<td>23.68</td>
</tr>
<tr>
<td>PB 6A</td>
<td>11 130.185</td>
<td>-2 943 686.247</td>
<td>1622.408</td>
<td>10</td>
<td>Dry</td>
</tr>
<tr>
<td>PB 7</td>
<td>10 218.743</td>
<td>-2 943 391.823</td>
<td>1592.548</td>
<td>35</td>
<td>30.43</td>
</tr>
<tr>
<td>PB 7A</td>
<td>10 218.876</td>
<td>-2 943 388.743</td>
<td>1592.487</td>
<td>10</td>
<td>Dry</td>
</tr>
<tr>
<td>PB 8</td>
<td>10 714.957</td>
<td>-2 943 479.357</td>
<td>1602.956</td>
<td>35</td>
<td>Dry</td>
</tr>
<tr>
<td>PB 8A</td>
<td>10 714.960</td>
<td>-2 943 476.934</td>
<td>1602.962</td>
<td>10</td>
<td>Dry</td>
</tr>
<tr>
<td>PB 9</td>
<td>11 890.085</td>
<td>-2 942 342.108</td>
<td>1623.950</td>
<td>32</td>
<td>9.60</td>
</tr>
<tr>
<td>PB 9A</td>
<td>11 890.007</td>
<td>-2 942 339.033</td>
<td>1623.966</td>
<td>10</td>
<td>9.55</td>
</tr>
<tr>
<td>PB 10</td>
<td>12 624.836</td>
<td>-2 942 903.882</td>
<td>1621.677</td>
<td>32</td>
<td>28.65</td>
</tr>
<tr>
<td>PB 10A</td>
<td>12 624.982</td>
<td>-2 942 900.854</td>
<td>1621.589</td>
<td>10</td>
<td>Dry</td>
</tr>
</tbody>
</table>

The newly drilled boreholes, as well as several boreholes from previous studies were used in the groundwater assessment. The localities of the closest boreholes to FAD 6 are shown on Figure 5.1.
Figure 5.1: Monitoring boreholes
5.3 Aquifer Type

The waste facilities at Sasol Synfuels and particularly FAD 6 are situated on interbedded siltstone/sandstone and shale of the Vryheid Formation, underlain by a dolerite sill. These lithologies are not known to contain economic aquifers. Based on the geological information the following aquifers underlie the site, or are in close proximity to the site:

- **Weathered Aquifer:** A shallow, weathered aquifer exists in the weathered shale and sandstone at an average depth of 12m below ground level (based on the average depth to the top of the dolerite sill). At FAD 6, the depth of weathering varies between 0m (FAD6 BH4) and 24m. The most consistent water strike is located at the fresh bedrock/weathering interface. Groundwater elevations vary between 0m (artesian) and 9.55 mbs (PB 09A). The hydraulic conductivity of the weathered aquifer ranges from 0.045 m/day to 0.178 m/day. The vertical permeability is in the order of 0.001 m/day to 0.00010 m/day, which is sufficiently low to confine the groundwater in the underlying fractured rock aquifer (Rison, 2006).

- **Fractured Aquifer:** The primary porosity of the Vryheid Formation is very low. Any water bearing capacity is therefore associated with secondary joints, bedding planes and faults. The contact zones of dolerite intrusions are characterised by cooling joints and fractures, which are considered the primary source of groundwater flow within the deeper formations. The hydraulic conductivity of the fractured rock aquifer varies from 0.006 m/day to 0.116 m/day (Rison, 2006), based on the lithology. The depth to groundwater in this aquifer ranges from 0m (artesian) to 30.43 mbs (PB 07). The variation in groundwater levels is attributed to confining layers and the undermining in parts of the study area.

Although the aquifer is not completely dewatered it appears that some water is seeping into the underlying workings, causing localized dewatering cones. The groundwater levels at FAD 6 and surrounds is discussed in more detail in Section 5.5.

5.4 Aquifer Parameters

The aquifer parameters of the weathered and fractured aquifers were determined during a previous study (Rison, 2006). The localities of the tested boreholes are shown on Figure 5.2 and the results from the testing is summarised in Table 5.2.
Figure 5.2: Pump tested boreholes (Rison, 2006)

Table 5.2: Aquifer parameters (Rison, 2006)

<table>
<thead>
<tr>
<th>Borehole ID</th>
<th>Weathered Aquifer</th>
<th>Fractured Aquifer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calculated Transmissivity (m²/day)</td>
<td>Constant Rate Test</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weathered Aquifer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1S</td>
<td>0.68</td>
<td>2.45</td>
</tr>
<tr>
<td>2S</td>
<td>0.50</td>
<td>0.56</td>
</tr>
<tr>
<td>3S</td>
<td>2.19</td>
<td>0.41</td>
</tr>
<tr>
<td>5S</td>
<td>0.46</td>
<td>0.80</td>
</tr>
<tr>
<td>6S</td>
<td>0.76</td>
<td>0.33</td>
</tr>
<tr>
<td>7S</td>
<td>0.48</td>
<td>0.41</td>
</tr>
<tr>
<td>8S</td>
<td>5.61</td>
<td>0.19</td>
</tr>
<tr>
<td>12S</td>
<td>0.42</td>
<td>0.67</td>
</tr>
<tr>
<td>Average</td>
<td>1.39</td>
<td>3.11</td>
</tr>
<tr>
<td>Fractured Aquifer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1D</td>
<td>2.45</td>
<td>0.53</td>
</tr>
<tr>
<td>2D</td>
<td>0.56</td>
<td>0.25</td>
</tr>
<tr>
<td>3M</td>
<td>0.41</td>
<td>0.53</td>
</tr>
<tr>
<td>3D</td>
<td>0.80</td>
<td>0.53</td>
</tr>
<tr>
<td>4D</td>
<td>0.25</td>
<td>0.80</td>
</tr>
<tr>
<td>5D</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>6D</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>7D</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>8D</td>
<td>0.57</td>
<td>0.86</td>
</tr>
<tr>
<td>12D</td>
<td>0.64</td>
<td>1.01</td>
</tr>
</tbody>
</table>
The FAD 6 boreholes that weren’t dry were pump tested. The results from these tests are included as Appendix B and summarised in Table 5.3.

**Table 5.3: Aquifer parameters (FAD 6, 2016)**

<table>
<thead>
<tr>
<th>Borehole ID</th>
<th>Calculated Transmissivity (m²/day)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Constant Rate Test</td>
<td>Recovery Test</td>
</tr>
<tr>
<td>PB 06 (Weathered Aquifer)</td>
<td>0.85</td>
<td>1.49</td>
</tr>
<tr>
<td>PB 07 (Weathered Aquifer)</td>
<td>1.16</td>
<td>1.03</td>
</tr>
<tr>
<td>PB 09 (Fractured Aquifer)</td>
<td>0.38</td>
<td>0.24</td>
</tr>
<tr>
<td>PB 10 (Weathered Aquifer)</td>
<td>2.37</td>
<td>4.35</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>1.19</td>
<td>1.78</td>
</tr>
</tbody>
</table>

The calculated aquifer parameters indicate variable transmissivity between the weathered formation and the fracturing. Based on the above information the following average aquifer parameters were calculated:

<table>
<thead>
<tr>
<th>Aquifer</th>
<th>Transmissivity (T)</th>
<th>Hydraulic Conductivity (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weathered Aquifer (Sasol Waste)</td>
<td>1.02 m²/day</td>
<td>0.041 m/day</td>
</tr>
<tr>
<td>Weathered Aquifer (FAD 6)</td>
<td>1.87 m²/day</td>
<td>0.078 m/day</td>
</tr>
<tr>
<td>Fractured Aquifer</td>
<td>0.83 m²/day</td>
<td>0.021 m/day</td>
</tr>
<tr>
<td>Fractured Aquifer (FAD 6)</td>
<td>0.38 m²/day</td>
<td>0.017 m/day</td>
</tr>
</tbody>
</table>

The boreholes that were drilled at the FAD 6 primarily measures the weathered aquifer on top of the dolerite sill. The exception is borehole PB 09 that was drilled through the sill into the underlying fractured aquifer. The estimated aquifer parameters at FAD 6 compares favourably with that of the larger study area, but the calculated aquifer parameters for the weathered and fractured aquifers are indicative of poorly developed aquifers. These aquifers do not constitute economically sustainable and exploitable hydrological units.

### 5.5 Groundwater Gradients

It is known that in similar geological terrains a relationship exists between the groundwater table and the topography. This relationship is known as the Bayesian relationship. The borehole collar elevations of the boreholes at FAD 6, as well as in the WADS area, were plotted against the measured groundwater elevation to test if this relationship is applicable to the study area.

With reference to Figure 5.3 to Figure 5.6 the following is noted:

- The SRK (2011) report states that the boreholes drilled at FAD 6 targeted the shallow aquifer. However, the groundwater levels in the FAD 6 boreholes (excluding FAD6 BH4) are deeper than the other shallow boreholes in the area. The geological logs of the boreholes drilled at FAD 6 (SRK, 2011) indicate a dolerite sill underlying the entire site. The depth of this sill varies between 0m (FAD6 BH4) and 24 mgl. The logs indicate that the shale and sandstone overlying the dolerite is weathered. The sill was intersected at the following depths:
  - FAD6 BH1 Sill at 10m, Borehole depth to 25m;
  - FAD6 BH2 Sill at 17m, Borehole depth to 25m;
  - FAD6 BH3 Sill at 18m, Borehole depth to 25m;
  - FAD6 BH4 Sill from 0m to 28m, Borehole depth to 40m;
  - PB 05 Sill from 12m, Borehole depth to 30m;
- PB 06  Sill from 24m,  Borehole depth to 32m;
- PB 07  Sill from 18m,  Borehole depth to 35m;
- PB 08  Sill from 6,  Borehole depth to 35m;
- PB 09  Sill from 6m to 12m,  Borehole depth to 31m; and
- PB10  Sill from 24m,  Borehole depth to 32m.

- If the FAD 6 boreholes are included in the Bayes correlation a 91% correlation with the topography is achieved for the weathered aquifer (Figure 5.3). If the FAD 6 boreholes are excluded a 97% correlation is achieved in the weathered aquifer (Figure 5.4).

- Some boreholes in the fractured aquifer also have deeper groundwater levels, as indicated on Figure 5.5. This resulted in a relatively poor correlation with the topography of only 47%. If the boreholes with deep water levels are removed the correlation with the topography improves to 95% for the fractured aquifer (Figure 5.6).

- It is therefore concluded that both the weathered and fractured aquifers mimic the topography, but that localised dewatering in the fractured aquifer occur in areas where the structural geology links the aquifer with the underlying mine workings.

- The groundwater flow in the vicinity of FAD 6 is affected by the partial dewatering of the aquifers. Such dewatering is potentially occurring in the vicinity of borehole FAD6 BH3, PB 06, PB 07 and PB 10, which was taken into consideration in the groundwater model.

![Figure 5.3: Correlation between topography and groundwater level — Weathered aquifer including FAD 6 boreholes](image)
Figure 5.4: Correlation between topography and groundwater table – Weathered aquifer excluding some FAD 6 boreholes

Figure 5.5: Correlation between topography and groundwater table – Fractured aquifer including FAD 6 boreholes
Figure 5.6: Correlation between topography and groundwater table – Fractured aquifer excluding shallow FAD 6 boreholes

Figure 5.7 depicts the regional groundwater level elevations and groundwater flow directions. Areas where potential dewatering of the aquifers is taking place is also shown.
Figure 5.7: Groundwater gradients and flow
5.6 Hydrochemistry

The groundwater chemistry was discussed in detail in the latest available groundwater monitoring report “Groundwater Quality Monitoring at Sasol Synfuels, Secunda. (Annual Report November 2016). Institute for Groundwater Studies, University of the Free State.” The inorganic groundwater quality in the vicinity of FAD 6 is summarised in Table 5.4. (see Figure 5.1 for borehole positions). Three of the shallow boreholes (PB5A, PB6A & PB8A) and two of the deep boreholes (PB5 & PB8) are dry. FAD6 BH1 and FAD6 BH3 are also dry.

The water samples are compared to the SANS 241 (2015) Drinking Water Specification. Results that exceed the limits are highlighted in red. The SANS 241 (2015) Drinking Water Specification effectively summarises the suitability of water for drinking water purposes for lifetime consumption.

<table>
<thead>
<tr>
<th>BH ID</th>
<th>Weathered Aquifer</th>
<th>Fractured Aquifer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SANS 241 2015</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PB7A</td>
<td>PB9A</td>
</tr>
<tr>
<td>pH</td>
<td>5.5-9.7</td>
<td>7.3</td>
</tr>
<tr>
<td>EC mS/m</td>
<td>170</td>
<td>50</td>
</tr>
<tr>
<td>TDS</td>
<td>1200</td>
<td>376</td>
</tr>
<tr>
<td>Ca</td>
<td>NG</td>
<td>34</td>
</tr>
<tr>
<td>Mg</td>
<td>NG</td>
<td>29</td>
</tr>
<tr>
<td>Na</td>
<td>200</td>
<td>34</td>
</tr>
<tr>
<td>K</td>
<td>NG</td>
<td>3</td>
</tr>
<tr>
<td>M Alk</td>
<td>NG</td>
<td>211</td>
</tr>
<tr>
<td>F</td>
<td>1.5</td>
<td>0.14</td>
</tr>
<tr>
<td>Cl</td>
<td>300</td>
<td>16</td>
</tr>
<tr>
<td>NO3</td>
<td>11</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>SO4</td>
<td>500</td>
<td>47</td>
</tr>
<tr>
<td>Al</td>
<td>0.3</td>
<td>0.013</td>
</tr>
<tr>
<td>Fe</td>
<td>2</td>
<td>0.092</td>
</tr>
<tr>
<td>Mn</td>
<td>0.4</td>
<td>0.115</td>
</tr>
<tr>
<td>NH4</td>
<td>1.5</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Note: Values in mg/l, unless otherwise stated.

The FAD 6 is in the construction phase and the current groundwater chemistry is expected to reflect the pre-construction quality.

Based on the analyses the groundwater chemistry can be described as follows:

- The groundwater quality in both aquifers is good.
- The sodium concentration in borehole FAD6 BH2 exceeds the allowable limit, whereas the elevated TDS and sulfate concentrations are still allowable.
- The aluminium concentration in borehole PB7 and the manganese concentration in borehole PB9A exceed the allowable limits.
5.7 Aquifer Classification

An aquifer classification system provides a framework and objective basis for identifying and setting appropriate levels of groundwater resource protection. This would facilitate the adoption of a policy of differentiated groundwater protection. Other uses could include:

- Defining levels of investigation required for decision making;
- Setting of monitoring requirements; and
- Allocation of manpower resources for contamination control functions.

The aquifer classification system used to classify the aquifers is the proposed National Aquifer Classification System of Parsons (1995). This system has a certain amount of flexibility and can be linked to second classifications such as a vulnerability or usage classification. Parsons suggests that aquifer classification forms a very useful planning tool that can be used to guide the management of groundwater issues. He also suggests that some level of flexibility should be incorporated when using such a classification system.

The South African Aquifer System Management Classification is presented by five major classes:

- Sole Source Aquifer System;
- Major Aquifer System;
- Minor Aquifer System;
- Non-Aquifer System; and
- Special Aquifer System.

The following definitions apply to the aquifer classification system:

- **Sole source aquifer system**: “An aquifer that is used to supply 50 % or more of domestic water for a given area, and for which there are no reasonable alternative sources should the aquifer become depleted or impacted upon. Aquifer yields and natural water quality are immaterial”.

- **Major aquifer system**: “Highly permeable formations, usually with a known or probable presence of significant fracturing. They may be highly productive and able to support large abstractions for public supply and other purposes. Water quality is generally very good”.

- **Minor aquifer system**: “These can be fractured or potentially fractured rocks that do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although this aquifer seldom produces large quantities of water, they are both important for local supplies and in supplying base flow for rivers”.

- **Non-aquifer system**: “These are formations with negligible permeability that are generally regarded as not containing groundwater in exploitable quantities. Water quality may also be such that it renders the aquifer unusable. However, groundwater flow through such rocks does occur, although imperceptible, and needs to be considered when assessing risk associated with persistent pollutants”.

- **Special aquifer system**: “An aquifer designated as such by the Minister of Water Affairs, after due process”.

A second variable classification is needed for sound decision making, as the ability of an aquifer to yield water to a particular user is not adequately stated. In this case it was
decided to use the vulnerability of the aquifer to contamination as a second parameter (Table 5.5). A weighting and rating approach is then used to decide on the appropriate level of groundwater protection (Table 5.6).

Table 5.5:  Ratings for the aquifer quality management classification system

<table>
<thead>
<tr>
<th>Class</th>
<th>Points</th>
<th>Class</th>
<th>Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sole Source Aquifer System</td>
<td>6</td>
<td>High</td>
<td>3</td>
</tr>
<tr>
<td>Major Aquifer System</td>
<td>4</td>
<td>Medium</td>
<td>2</td>
</tr>
<tr>
<td>Minor Aquifer System</td>
<td>2</td>
<td>Low</td>
<td>1</td>
</tr>
<tr>
<td>Non-Aquifer System</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special Aquifer System</td>
<td>0-6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5.6:  Appropriate level of groundwater protection required

<table>
<thead>
<tr>
<th>GQM Index</th>
<th>Level of Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1</td>
<td>Limited Protection</td>
</tr>
<tr>
<td>1 – 3</td>
<td>Low Level Protection</td>
</tr>
<tr>
<td>3 – 6</td>
<td>Medium Level Protection</td>
</tr>
<tr>
<td>6 – 10</td>
<td>High Level Protection</td>
</tr>
<tr>
<td>&gt;10</td>
<td>Strictly Non-degradation</td>
</tr>
</tbody>
</table>

After rating the aquifer system management and the aquifer vulnerability, the points are multiplied to obtain a Groundwater Quality Management (GQM) index. Based on the above, the aquifers in the study area are classified as follows:

<table>
<thead>
<tr>
<th>Description</th>
<th>Aquifer</th>
<th>Vulnerability</th>
<th>Rating</th>
<th>Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weathered Aquifer</td>
<td>Minor (2)</td>
<td>2</td>
<td>4</td>
<td>Medium</td>
</tr>
<tr>
<td>Fractured Aquifer</td>
<td>Minor (2)</td>
<td>1</td>
<td>3</td>
<td>Low</td>
</tr>
</tbody>
</table>
6. NUMERICAL GROUNDWATER MODELLING

6.1 Introduction

The basic steps involved in modelling can be summarised as:

- **Collecting and interpreting field data**: Field data are essential to understand the natural system and to specify the investigated groundwater problem. The numerical model develops into a site-specific groundwater model when real field parameters are assigned. The quality of the simulations depends largely on the quality of the input data.

- **Calibration & validation**: Model calibration and validation are required to overcome the lack of input data, but they also accommodate the simplification of the natural system in the model. In model calibration, simulated values like potentiometric surface or concentrations are compared with field measurements. The model input data are altered within ranges, until the simulated and observed values are fitted within a chosen tolerance. Input data and comparison of simulated and measured values can be altered either manually or automatically.

- **Model validation**: is required to demonstrate that the model can be reliably used to make predictions. A common practice in validation is the comparison of the model with a data set not used in model calibration. Calibration and validation are accomplished if all known and available groundwater scenarios are reproduced by the model without varying the material properties or aquifer characteristics supplied to the model.

- **Modelling scenarios**: Alternative scenarios for a given area may be assessed efficiently. When applying numerical models in a predictive sense, limits exist in model application. Predictions of a relative nature are often more useful than those of an absolute nature.

6.2 Assumptions and Limitations

The following conditions typically need to be described in a model:

- Geological and geohydrological features;
- Boundary conditions of the study area (based on the geology and geohydrology);
- Initial groundwater levels of the study area;
- The processes governing groundwater flow; and
- Assumptions for the selection of the most appropriate numerical code.

Field data is essential in solving the conditions listed above and developing the numerical model into a site-specific groundwater model. Specific assumptions related to the available field data include:

- The top of the aquifer is represented by the generated groundwater heads;
- The available geological / geohydrological information was used to describe the different aquifers. The available information on the geology and field tests is considered as correct; and
- Many aquifer parameters have not been determined in the field and therefore have to be estimated.
In order to develop a model of an aquifer system, certain assumptions have to be made. The following assumptions were made:

- The system is initially in equilibrium and therefore in steady state, even though natural conditions have been disturbed;
- No abstraction boreholes were included in the initial model;
- The boundary conditions assigned to the model are considered correct; and
- The impacts of other activities (e.g. agriculture) have not been taken into account.

It is important to note that a numerical groundwater model is a representation of the real system. It is therefore at most an approximation, and the level of accuracy depends on the quality of the data that is available. This implies that there are always errors associated with groundwater models due to uncertainty in the data and the capability of numerical methods to describe natural physical processes.

### 6.3 Model Set-up

In order to investigate the behaviour of aquifer systems in time and space, it is necessary to employ a mathematical model. The modelling area was selected based on a combination of topographical, geological and structural control and covers an area of approximately 155 km² (Figure 6.1).

A three-layered aquifer model was constructed and calibrated for the Sasol Synfuels site using the finite element 3D-modelling package FEFLOW 6.2. The model comprises 3 layers, 173 762 elements and 131 808 nodes. The total depth of the model is 75m deep. The 2 layers build into the model are:

- Layer 1 – Shallow weathered aquifer. This aquifer has an estimated depth of 15m;
- Layer 2 – Deeper fractured aquifer. This aquifer has an estimated depth of 60m; and
- Layer 3 – Underground mining (2m).

The model construction is presented in Figure 6.2.
Figure 6.1: Model domain
6.4 Model Boundary Conditions

One of the first and most demanding tasks in groundwater modelling is that of identifying the model area and its boundaries. Consequently, a model boundary is the interface between the model area and the surrounding environment. Conditions on the boundaries, however, must be specified. Boundaries occur at the edges of the model area and at locations in the model area where external influences are represented, such as rivers, wells, and leaky impoundments.

Criteria for selecting hydraulic boundary conditions are primarily topography, hydrology and geology. The topography, geology, or both, may yield boundaries such as impermeable strata or potentiometric surface controlled by surface water, or recharge/discharge areas such as inflow boundaries along mountain ranges. The flow system allows the specification of boundaries in situations where natural boundaries are a great distance away.

Boundary conditions should be specified for the entire boundary and may vary with time. At a given boundary section just one type of boundary condition can be assigned. As a simple example, it is not possible to specify groundwater flux and groundwater head at an identical boundary section. Boundaries in groundwater models can be specified as:

- Dirichlet (also known as constant head or constant concentration) boundary conditions;
- Neuman (or specified flux) boundary conditions; and
- Cauchy (or a combination of Dirichlet and Neuman) boundary conditions.

Boundaries of the numerical model were chosen to reflect the geometry of the groundwater system. Since it is expected that there is a good correlation between surface topography and depth to groundwater it is possible to select surface drainage catchment watersheds as model boundaries.
6.5 **Initial Conditions**

Initial conditions are vital for modelling flow problems. Initial conditions should be specified for the entire area. Generally, the initial groundwater level / head distribution acts as the starting distribution for the numerical calculation. The groundwater levels shown in Figure 5.7 were used as initial conditions for the model.

6.6 **Sources and Sinks**

Sources and sinks can be defined as recharge and abstraction sources in the aquifer. Sources can be precipitation and inflow from surface water and recharging boreholes. Sinks can be abstraction boreholes, springs, evapotranspiration and outflow to surface water. Initially only recharge due to precipitation was included in the model. The steady state calibration simulations were conducted using recharge values of approximately 21.30 mm per annum, which corresponds to 3% of the estimated annual precipitation (MAP) of 710 mm.

6.7 **Aquifer Parameters**

The aquifer parameters discussed in Section 5.4 were initially used in the numerical model. The model is calibrated using the groundwater level elevations which are a function of the product of the saturated aquifer thickness, the hydraulic conductivity and effective aquifer recharge. Should the average aquifer thickness therefore be under/overestimated, this can be compensated for by adjustment of the hydraulic conductivity values during model calibration.

The simulated groundwater level distribution is compared to the measured head distribution and the hydraulic conductivity or recharge values can be altered until an acceptable correlation between measured and simulated heads is obtained. The calibration process was done by adjusting the model parameters for hydraulic conductivity (K) and recharge within a narrow range compatible with the test results and hydrogeological situation. The distribution of the hydraulic conductivity is presented in Figure 6.3.

![Figure 6.3: Hydraulic conductivity](image)
6.8 Mathematical Flow Model

A steady state groundwater flow model for the study area was constructed to simulate undisturbed groundwater flow conditions. These conditions serve as starting heads for the transient simulations of groundwater flow where the effect of for example the discard dumps are taken into account.

The simulation model (FEFLOW) used in this modelling study is based on three-dimensional groundwater flow and may be described by the following equation:

\[
\frac{\partial (K_x \frac{\partial h}{\partial x})}{\partial x} + \frac{\partial (K_y \frac{\partial h}{\partial y})}{\partial y} + \frac{\partial (K_z \frac{\partial h}{\partial z})}{\partial z} \pm W = S \frac{\partial h}{\partial t} \tag{1}
\]

where

- \( h \) = hydraulic head [L]
- \( K_x, K_y, K_z \) = Hydraulic Conductivity [L/T]
- \( S \) = storage coefficient
- \( t \) = time [T]
- \( W \) = source (recharge) or sink (pumping) per unit area [L/T]
- \( x, y, z \) = spatial co-ordinates [L]

For steady state conditions the groundwater flow Equation (1) reduces to the following equation:

\[
\frac{\partial (K_x \frac{\partial h}{\partial x})}{\partial x} + \frac{\partial (K_y \frac{\partial h}{\partial y})}{\partial y} + \frac{\partial (K_z \frac{\partial h}{\partial z})}{\partial z} = 0 \tag{2}
\]

6.9 Calibration of the Steady State Model

According to the conceptual model for the system the calculated head distribution \((h_{x,y,z})\) is dependent upon the recharge from rainfall, hydraulic conductivity and boundary conditions. For a given hydraulic conductivity value (or transmissivity value) and set of boundary conditions specified, the head distribution across the aquifer can be obtained for a specific recharge value. This simulated head distribution can then be compared to the measured head distribution and the recharge and evaporation values can be altered until an acceptable correspondence between measured and simulated heads is obtained.

Steady state calibration was accomplished by varying the hydraulic conductivity values within a realistic range based upon the field data and the recharge rate until a reasonable match between the measured groundwater elevations and the simulated groundwater elevations was obtained. The model was calibrated against measured groundwater levels.

The calibration objective was reached when an acceptable correlation was obtained between the observed and simulated piezometric heads. The steady state calibration results are presented in Table 6.1 and Figure 6.4.
Table 6.1: Steady state calibration result

<table>
<thead>
<tr>
<th>Borehole ID</th>
<th>Observed Water Level (mamsl)</th>
<th>Simulated Water Level (mamsl)</th>
<th>ME(m)</th>
<th>MAE(m)</th>
<th>RMS(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(WLm-WLs)i</td>
<td></td>
<td>(WLm-WLs)</td>
</tr>
<tr>
<td>ETF20DP</td>
<td>1592.49</td>
<td>1592.27</td>
<td>0.22</td>
<td>0.22</td>
<td>0.05</td>
</tr>
<tr>
<td>ETF2D</td>
<td>1585.22</td>
<td>1589.38</td>
<td>-4.15</td>
<td>4.15</td>
<td>17.23</td>
</tr>
<tr>
<td>FAD6 BH4</td>
<td>1633.28</td>
<td>1633.84</td>
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<td>0.56</td>
<td>0.31</td>
</tr>
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<td>REGM-126</td>
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<td>1573.03</td>
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<td>1.05</td>
<td>1.10</td>
</tr>
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<td>REGM-134</td>
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<td>1593.34</td>
<td>2.46</td>
<td>2.46</td>
<td>6.05</td>
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<tr>
<td>REGM-151M</td>
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<td>1587.57</td>
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<td>12.67</td>
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<td>1596.51</td>
<td>-1.02</td>
<td>1.02</td>
<td>1.04</td>
</tr>
<tr>
<td>REGM-201S</td>
<td>1583.21</td>
<td>1586.85</td>
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<td>3.65</td>
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</tr>
<tr>
<td>REGM-202D</td>
<td>1577.78</td>
<td>1581.00</td>
<td>-3.22</td>
<td>3.22</td>
<td>10.36</td>
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<td>REGM-219M</td>
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<td>1577.08</td>
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<tr>
<td>REGM-238S</td>
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<td>1.07</td>
<td>1.15</td>
</tr>
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<td>4.93</td>
<td>24.31</td>
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<td>1567.98</td>
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<td>1.83</td>
<td>3.35</td>
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<td>REGM-88</td>
<td>1607.92</td>
<td>1603.44</td>
<td>4.48</td>
<td>4.48</td>
<td>20.11</td>
</tr>
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<td>1593.45</td>
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<td>1.30</td>
<td>1.69</td>
</tr>
<tr>
<td>PB06</td>
<td>1598.84</td>
<td>1593.54</td>
<td>5.30</td>
<td>5.30</td>
<td>28.09</td>
</tr>
<tr>
<td>PB07</td>
<td>1562.12</td>
<td>1560.30</td>
<td>1.82</td>
<td>1.82</td>
<td>3.31</td>
</tr>
<tr>
<td>PB09</td>
<td>1614.35</td>
<td>1614.85</td>
<td>-0.50</td>
<td>0.50</td>
<td>0.25</td>
</tr>
<tr>
<td>PB10</td>
<td>1593.03</td>
<td>1595.30</td>
<td>-2.27</td>
<td>2.27</td>
<td>5.15</td>
</tr>
<tr>
<td>Max=</td>
<td>1633.28</td>
<td>14.12</td>
<td>51.44</td>
<td>343.77</td>
<td></td>
</tr>
<tr>
<td>Min=</td>
<td>1566.15</td>
<td>0.74</td>
<td>2.71</td>
<td>14.95</td>
<td></td>
</tr>
<tr>
<td>Range=</td>
<td>67.13</td>
<td></td>
<td></td>
<td></td>
<td>RMS% of water level range= 5.76%</td>
</tr>
</tbody>
</table>
Figure 6.4: Steady state calibration results
6.10 Numerical Groundwater Mass Transport Model

Mass transport modelling in this situation refers to the simulation of water contamination or pollution due to deteriorating water quality in response to man’s disturbance of the natural environment (for example residue deposits). Transport through a medium is mainly controlled by the following two processes:

- Advection is the component of contaminant movement described by Darcy’s Law. If uniform flow at a velocity V takes place in the aquifer, Darcy’s law calculates the distance (x) over which a labelled water particle migrates over a time period t as \( x = Vt \).

- Hydrodynamic dispersion comprises two processes:
  - Mechanical dispersion is the process whereby the initially close group of labelled particles are spread in a longitudinal as well as in a transverse direction because of the velocity distribution (as a result of varying microscopic streamlines) that develops at the microscopic level of flow around the grain particles of the porous medium. Although this spreading is both in the longitudinal and transversal direction of flow, it is primarily in the former direction. Very little spreading can be caused in the transversal direction by velocity variations alone.
  - Molecular diffusion mainly causes transversal spreading, by the random movement of the molecules in the fluid from higher contaminant concentrations to lower ones. It is thus clear that if \( V = 0 \), the contaminant is transported by molecular diffusion, only or in other words the higher the velocity of the groundwater, the less the relative effect of molecular diffusion on the transportation of a labelled particle.

In addition to advection, mechanical dispersion and molecular diffusion, several other phenomena may affect the concentration distribution of a contaminant as it moves through a medium. The contaminant may interact with the solid surface of the porous matrix in the form of adsorption of contaminant particles on the solid surface, deposition, solution of the solid matrix and ion exchange. All these phenomena cause changes in the concentration of a contaminant in a flowing fluid.

The required input into the model includes:

- Input concentrations of contaminants;
- Transmissivity values;
- Porosity values;
- Longitudinal dispersivities;
- transversal dispersivities; and
- Hydraulic heads/water levels in the aquifer over time.

Transmissivities for the aquifer were specified according to the values obtained during the scenario of the steady state groundwater level calibration. A longitudinal dispersivity value of 50 m was selected for the simulations (see Table D.3 – Field-Scale Dispersivities in Spitz and Moreno, 1996). Bear and Verruijt (1992) estimated the average transversal dispersivity to be 10 to 20 times smaller than the longitudinal dispersivity. An average value of 5.0 m was selected for this parameter during the simulations.

Input concentrations in the model were specified at cells over the areas where contamination is expected. This study specifically focussed on the existing fine ash dams, but in particular on the proposed fine ash dam no. 6 (FAD 6).

The input concentration was based on the FAD 6 Waste Classification (J&W Report JW003/14/E250 – Rev 0, 2014). As the chemistry of the fine ash is not expected to
change significantly, ash from FAD 5 was used for the classification. The following tests were conducted on the ash:

- Inorganic and organic analyses of the water fractions of the fine ash slurry samples;
- Total concentrations (TCs) of the constituents of concern of the ash fractions of the fine ash slurry samples after an aqua regia digestion. The solutions were analysed for the inorganic constituents of concern;
- Zero head water extractions of the ash fractions of the fine ash slurry samples followed by analyses of the organic constituents of concern;
- South African Acid Rain Leach Procedure (ARLP) of the ash fractions of the fine ash slurry followed by analyses of the inorganics of concern;
- Distilled water leach extraction of the ash fraction of the fine ash slurry followed by the analyses of the inorganics of concern.

The results of the analyses are shown in Table 6.2.

### Table 6.2: Fine Ash Dam 5 chemistry

<table>
<thead>
<tr>
<th>Element</th>
<th>Solid Phase (mg/l)</th>
<th>Water Phase (mg/l)</th>
<th>Leach Concentration (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>As, Arsenic</td>
<td>0.005</td>
<td>0.005</td>
<td>&lt;0.010</td>
</tr>
<tr>
<td>B, Boron</td>
<td>0.043</td>
<td>6.21</td>
<td>5.28</td>
</tr>
<tr>
<td>Ba, Barium</td>
<td>0.401</td>
<td>0.362</td>
<td>0.37</td>
</tr>
<tr>
<td>Cd, Cadmium</td>
<td>0.0025</td>
<td>0.0025</td>
<td>&lt;0.005</td>
</tr>
<tr>
<td>Co, Cobalt</td>
<td>0.0125</td>
<td>0.0125</td>
<td>&lt;0.025</td>
</tr>
<tr>
<td>Cr, Total chromium</td>
<td>0.0125</td>
<td>0.125</td>
<td>0.108</td>
</tr>
<tr>
<td>Cr VI, Chromium VI</td>
<td>0.0050</td>
<td>0.045</td>
<td>0.039</td>
</tr>
<tr>
<td>Cu Copper</td>
<td>0.0125</td>
<td>0.0125</td>
<td>&lt;0.025</td>
</tr>
<tr>
<td>Hg, Mercury</td>
<td>0.0005</td>
<td>0.0005</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Mn, Manganese</td>
<td>0.0125</td>
<td>0.029</td>
<td>0.0265</td>
</tr>
<tr>
<td>Mo, Molybdenium</td>
<td>0.0125</td>
<td>0.71</td>
<td>0.61</td>
</tr>
<tr>
<td>Ni, Nickel</td>
<td>0.0125</td>
<td>0.0125</td>
<td>&lt;0.025</td>
</tr>
<tr>
<td>Pb, Lead</td>
<td>0.0050</td>
<td>0.0050</td>
<td>&lt;0.010</td>
</tr>
<tr>
<td>Sb, Antimony</td>
<td>0.0050</td>
<td>0.0050</td>
<td>&lt;0.010</td>
</tr>
<tr>
<td>Se, Selenium</td>
<td>0.0050</td>
<td>0.218</td>
<td>0.1861</td>
</tr>
<tr>
<td>V, Vanadium</td>
<td>0.0125</td>
<td>0.030</td>
<td>0.027</td>
</tr>
<tr>
<td>Zn, Zinc</td>
<td>0.0125</td>
<td>0.0125</td>
<td>&lt;0.025</td>
</tr>
<tr>
<td>TDS, Total Dissolved Solids</td>
<td>398</td>
<td>8334</td>
<td>7144</td>
</tr>
<tr>
<td>Cl, Chloride</td>
<td>24</td>
<td>990</td>
<td>845</td>
</tr>
<tr>
<td>SO₄, Sulfate</td>
<td>141</td>
<td>3529</td>
<td>3021</td>
</tr>
<tr>
<td>NO₃, Nitrate</td>
<td>0.2</td>
<td>6.4</td>
<td>5.5</td>
</tr>
<tr>
<td>F, Fluoride</td>
<td>0.4</td>
<td>11</td>
<td>9.41</td>
</tr>
<tr>
<td>Phenols (total)</td>
<td>0.010</td>
<td>0.182</td>
<td>0.16</td>
</tr>
</tbody>
</table>

TDS was selected as the constituent of concern used for modelling. TDS can be considered a conservative tracer and will be representative of the groundwater impact from FAD 6.
7. GEOHYDROLOGICAL ASSESSMENT

7.1 Introduction

The calibrated flow and mass transport model was used to simulate the potential impact on the groundwater regime from the proposed FAD 6. The following scenarios were simulated at FAD 6.

**Scenario 1:** Groundwater quality impact (represented by the TDS concentration) without any liner. The estimated leakage rate for this scenario is \(5.80 \times 10^{-4}\) m\(^3\)/m\(^2\)/day.

**Scenario 2:** Groundwater quality impact with a liner and drain system underneath FAD 6 and the associated return water dam. The estimated leakage rate for this scenario is \(8.75 \times 10^{-5}\) m\(^3\)/m\(^2\)/day (Jones & Wagener Technical Note: SASOL FAD6: NEMWA Regulations Design Requirements dated 12 July 2014).

**Scenario 2a, b and c:** Potential liner failure was also simulated and Scenario 2a represents a 5% failure, Scenario 2b a 10% failure and Scenario 2c simulated what is considered unacceptable liner failure (Jones & Wagener Technical Note: SASOL FAD6: NEMWA Regulations Design Requirements dated 12 July 2014). The estimated leakage rates for these scenarios are as follows:

- Scenario 2a: \(9.19 \times 10^{-5}\) m\(^3\)/m\(^2\)/day;
- Scenario 2b: \(9.63 \times 10^{-5}\) m\(^3\)/m\(^2\)/day;
- Scenario 2c: \(2 \times 10^{-4}\) m\(^3\)/m\(^2\)/day;

In all instances the development of a contaminant plume over an operational period of 50 years (up to 2066) was simulated. The assumption was made that operation will cease in 2066 and that the dam will be rehabilitated. The source was removed (theoretically) and the improvement in the TDS concentrations over the next 50 years (until 2115) was simulated.

7.2 Modelling Results – Contaminant Plume Migration and Flow to Surface Streams

The calibrated groundwater model was used to simulate the expected contaminant migration (TDS concentrations) from FAD 6. The model was run for a period of 50 years without any liner or drain system (Scenario 1). This “do-nothing” scenario was then compared to the liner option as proposed for FAD 6 (Scenario 2). This is then also compared to the “rehabilitated” plume after another 50 years (Year 2115).

The results of the plume migration simulations are presented in Figure 7.1 and Figure 7.2 for scenario 1 and 2 respectively.
Figure 7.1: Current and future TDS plumes at FAD 6 – No liner
Figure 7.2: Current and future TDS plumes at FAD 6 – With liner
The following was also estimated for the various scenarios:

- The volume of seepage into the closest river system; and
- The contaminant load entering the closest river system.

With reference to Figure 4.3, the inflow volume and the contaminant load into the river systems are presented in Figure 7.3 to Figure 7.4 (flow volumes) and Figure 7.5 to Figure 7.6 (contaminant loads). The increase in flow and contaminant load to the streams as a result of liner failure is compared to the non-failure liner leakage in the graphs below.
Figure 7.3: Seepage flow volume into Stream A
Figure 7.4:  Seepage flow volume into Stream B
Figure 7.5: Contaminant load into Stream A
Figure 7.6: Contaminant load into Stream B

A summary with relative comparisons of all the simulated scenarios is discussed in Section 9.
7.3 Modelling Results – Flow to Underground Workings

Parts of the Sasol Synfuels area are undermined and there is evidence of localised dewatering in certain areas. In several of the boreholes at FAD 6 the groundwater levels are relatively deep.

The boreholes at FAD 6 were drilled into a dolerite sill, which is commonly believed to be a barrier for groundwater flow, but in this instance the deeper groundwater table could possibly be explained by fracturing in the sill connecting it to the underlying mine workings. This may have caused dewatering of the aquifer, which appears to be localised in places where the structural geology links the aquifer with the underlying mine workings.

The groundwater flow in the vicinity of FAD 6 is affected by the partial dewatering of the aquifers. Such dewatering is potentially occurring in the vicinity of the proposed return water dam as boreholes FAD6 BH3, PB 06, PB 07 and PB 08 (dry) have all very low groundwater levels (see Figure 5.7). In order to assess the potential impact from the proposed Fine Ash Dam 6 on the underground mine workings, the model was used to simulate the flow volume and contaminant load at this point. The results of this assessment are shown in Figure 7.7 to Figure 7.10.

In the vicinity of FAD 6 the unlined flow and contaminant load is expected to be in the order of 190 m$^3$/day and 0.10 tons/day TDS respectively. This will further reduce to approximately 169 m$^3$/day and 0.012 tons/day TDS respectively for the lined scenario.

![Flow to Underground Mine](image)

**Figure 7.7:** Flow into the mine workings – FAD 6 unlined
Figure 7.8: Contaminant load into the mine workings – FAD 6 unlined

Figure 7.9: Flow into the mine workings – FAD 6 lined
Figure 7.10: Contaminant load into the mine workings – FAD 6 lined
8. IMPACT ON THE GROUNDWATER DUE TO ASH BACKFILL OF THE UNDERGROUND WORKINGS

8.1 Introduction

The FAD 6 footprint is underlain by the Brandspruit Mine, who mined coal at a depth of approximately 125 m below surface. An assessment of the surface stability of FAD 6 risks due to the underground workings was conducted by Professor N. van der Merwe of Stable Strata Consulting in 2014. His findings indicated that a portion of the underground mine workings should be backfilled to ensure the long-term stability of FAD 6. The area to be backfilled is indicated on Figure 8.1. It was estimated that approximately 220 000 m$^3$ of backfill material is required to stabilise this section of the mine.

A mixture of cement and fine ash will be used to backfill the mine workings. The cement – ash mixture will be pumped into the underground mine workings through a network of boreholes. Spacing of the boreholes will be based on the flow characteristics of the cement - ash mixture at the design density. The proposed borehole configuration is not yet known.

The question was raised if the proposed backfilling will have an adverse impact on the groundwater resources underneath or near FAD 6. Laboratory testing was undertaken to classify the waste characteristics if the cement – ash mixture and to determine the quality of the leachate that can potentially emanate from the backfill. The results from these tests are described in a Jones & Wagener Report (Report No.: JW044/17/E250 - Rev 2).

8.2 Waste Assessment Conclusions

Based on the laboratory testing the following is concluded:

- The fine ash to be used in the cement – ash mixtures has been classified in terms of SANS 10234 as non-hazardous, therefore a general waste.
- In terms of the “National Norms and Standards for the Assessment of Waste for Landfill Disposal” (GNR 635) the 4% cement – wet ash and the 6% cement - dry ash mixtures have both been assessed as Type 3 wastes for disposal purposes based on the total concentration (TC) results.
- Based on the distilled water leach concentration (LC) results on crushed cubes, the 4% cement – wet ash mixture is assessed as a Type 4 waste, while the 6% cement – dry ash mixture is assessed as a Type 3 waste.
- In terms of the results of the 1:10 distilled water leach, which is a conservative approach, conducted on the whole cubes, the two ash – cement mixtures are classified as inert, Type 4, wastes. This test is the most representative of the actual application of this material, as the ash - cement mixtures have been designed not to crush in situ.
Figure 8.1:  Proposed backfill area
Table 8.1: Waste classification

<table>
<thead>
<tr>
<th>Description</th>
<th>TC Results</th>
<th>LC Results: Distilled Water</th>
<th>1:10 Whole Cube Leach</th>
</tr>
</thead>
<tbody>
<tr>
<td>4% Cement – wet ash cube</td>
<td>Type 3</td>
<td>Type 4</td>
<td>Type 4</td>
</tr>
<tr>
<td>6% Cement – dry ash cube</td>
<td>Type 3</td>
<td>Type 3</td>
<td>Type 4</td>
</tr>
</tbody>
</table>

Based on the results obtained, it is concluded that the 4% cement – wet ash and 6% cement – dry ash mixtures should be assessed as Type 4, inert wastes, as the actual ratio of surface area to volume of the material to be placed underground will be significantly less than that of the test cubes.

8.3 Groundwater Impact

8.3.1 Potential for Impact on Groundwater Levels

It is proposed to drill 65 boreholes for grouting and 27 boreholes for camera inspections. The localities of these boreholes, as well as the drilling, construction and grouting methodologies, are shown on Drawings E250-249-001 and E250-248-003, attached as Appendix C.

These boreholes will be drilled in stages and will be grouted as soon as the grout placement into the mine is completed. Temporary casings will be installed through the weathered material on top of the dolerite sill to a minimum depth of 30m below surface. The groundwater level in this area varies between 14m – 23m below surface and based on the geological logs of the monitoring boreholes at FAD 6, the dolerite sill varies between 0m (PB5) to 30m (PB6) below surface. The borehole construction will therefore be such that the shallow aquifer, in the weathered material on top of the sill, will be sealed off. Although water may still be intersected in fractures in the deeper formations, it is not expected that the grout boreholes will significantly influence the groundwater levels.

The potential impact was nevertheless simulated, assuming the worst-case scenario. In this simulation, it is assumed that the boreholes are not cased and that all the boreholes are drilled simultaneously and left open for one year. The estimated inflows are based on the aquifer parameters discussed in Sections 5.4 and 6.7.

Based on this assessment, the following was concluded in terms of the groundwater level drawdown and water inflow into the mine:

- The maximum radius of influence of each borehole is 35m. The combined influence remains within the boundaries of FAD 6 (Figure 8.2) and will not impact on any groundwater users in the area.
- The groundwater levels are expected to recover within 6 months after being grouted.
- The estimated combined maximum groundwater inflow into the mine, is 1 600 m$^3$/day.
Figure 8.2: Maximum potential radius of influence from grout boreholes
8.3.2 Potential for Impact on Groundwater Quality

Brandspruit is an underground colliery that mines the no. 4 coal seam at depths varying between 110 - 170 m below surface. Brandspruit has a mining height of approximately 3m. The Brandspruit underground mine is reaching completion, with the last planned areas to be mined in 2017.

A total volume of 94 345 000 m$^3$ has been mined from Brandspruit (SASOL Mining presentation, 2016). This equates to a volume of 94 345 Megalitres (M$\ell$). The groundwater inflow into the mine is 276 M$\ell$/month, which suggests that the mine will take approximately 29 years to fill completely. This duration is likely to be less due to collapse of the workings that will reduce the available space. Nevertheless, the backfilled volume compared to the overall mined out volume is less than 1%. The added contribution of the leachate from the backfilled area to overall impact from the mine water is therefore considered negligible.

The Institute for Groundwater Studies (IGS), University of the Free State, undertook a groundwater modelling exercise in 2016 to assess the potential impact from the flooded mine workings on the groundwater resources in the region. IGS concluded that decant from the Brandspruit mine will not decant and that the contaminated mine water will largely remain within the mine void. Minor contaminant migration will, however, occur on the coal seam elevation into the adjacent aquifer. Figure 8.3 illustrates the extent of this impact, 100 years after the mine is flooded (IGS, 2016). The contaminant plume is shown as a percentage of the source term concentration.

The backfilled volume compared to the overall mined out volume is less than 1%. In addition, the proposed backfill area is located towards the centre of the simulated mine water contaminant plume and thus the limited impact from the backfill material is expected to remain within the mining void. Based on the above and considering the expected leachate quality, it is concluded that the added contribution of the leachate from the backfilled area to the overall impact from the mine water is negligible.

The maximum extent of the expected contaminant migration, outside the mining area, is in the order of 750m, at the elevation of the coal seam (110 – 170m below surface). A detailed hydro census was undertaken by SASOL Mining that recorded all the groundwater users within the Brandspruit mining area (see Figure 8.3 for the localities of the private boreholes). There are several private boreholes within the contaminant zone, but the census indicated that all these boreholes are abstracting water from shallow depths, above the potentially affected zone. The closest private borehole to the backfill area are located 1.6km to the west. This distance, as well as the shallow depth of all the measured boreholes indicate that the backfill will not impact on private groundwater users. In addition, Sasol Mining will develop a groundwater management plan that will govern the future additional groundwater usage within the areas affected by mining.
Figure 8.3: Backfilled area in relation to the mine water contaminant plume
9. CONCLUSION AND RECOMMENDATIONS

Sasol Synfuels proposes to construct FAD 6, to the south of the existing FAD 5 on the farm Rietvley 320 IS.

This report is an updated version of the previous geohydrological report to incorporate the potential impact of the ash backfill on the groundwater quality. The purpose of this study is to assess the potential impact from the proposed ash backfill underneath a portion of the FAD 6 on the groundwater resources in the region.

The waste facilities at Sasol Synfuels and particularly FAD 6 are situated on interbedded siltstone/sandstone and shale of the Vryheid Formation, underlain by a dolerite sill. These lithologies are not known to contain economic aquifers. Based on the geological information the following aquifers underlie the site, or are in close proximity to the site:

- **Weathered Aquifer**: A shallow, weathered aquifer exists in the weathered shale and sandstone at an average depth of 12m below ground level (based on the average depth to the top of the dolerite sill). At FAD 6, the depth of weathering varies between 0m (FAD6 BH4) and 24m. The most consistent water strike is located at the fresh bedrock / weathering interface. Groundwater elevations vary between 0m (artesian) and 9.55 mbs (PB 09A).

- **Fractured Aquifer**: The primary porosity of the Vryheid Formation is very low. Any water bearing capacity is therefore associated with secondary joints, bedding planes and faults. The contact zones of dolerite intrusions are characterised by cooling joints and fractures, which are considered the primary source of groundwater flow within the deeper formations. The depth to groundwater in this aquifer ranges from 0m (artesian) to 30.43 mbs (PB 07). The variation in groundwater levels is attributed to confining layers and the undermining in parts of the study area.

Parts of the Sasol Synfuels area are undermined and there is evidence of localised dewatering in certain areas. In several of the boreholes at FAD 6 the groundwater levels are relatively deep.

The boreholes at FAD 6 were drilled into a dolerite sill, which is commonly believed to be a barrier for groundwater flow, but in this instance the deeper groundwater table could possibly be explained by fracturing in the sill connecting it to the underlying mine workings. This may have caused dewatering of the aquifer, which appears to be localised in places in areas where the structural geology links the aquifer with the underlying mine workings.

The groundwater flow in the vicinity of FAD 6 is affected by the localised dewatering of the aquifers. Such dewatering is potentially occurring in the vicinity of the proposed return water dam as boreholes FAD6 BH3, PB 06, PB 07 and PB 08 (dry) have all very low groundwater levels.

A numerical groundwater flow and contaminant transport model was developed (2014) and updated (April 2106) to evaluate the suitability of the proposed liner system underneath FAD 6 and associated return water dam. The calibrated flow model was used to simulate the expected contaminant migration (TDS concentrations) without any liner system from the proposed development. Intervention in the form of a liner and drainage system was then introduced to simulate the effectiveness thereof.

The following scenarios were simulated at FAD 6:

- **Scenario 1**: Groundwater quality impact (represented by the TDS concentration) without any liner. The estimated leakage rate for this scenario is $5.80 \times 10^{-4} \text{ m}^3/\text{m}^2/\text{day}$.

- **Scenario 2**: Groundwater quality impact with a liner and drain system underneath FAD6 and the associated water return dams. The estimated leakage rate for this scenario is $8.75 \times 10^{-5} \text{ m}^3/\text{m}^2/\text{day}$.
Scenario 2a, b and c: Potential liner failure was also simulated and Scenario 2a represents a 5% failure, Scenario 2b a 10% failure and Scenario 2c simulated what is considered unacceptable liner failure. The estimated leakage rates for these scenarios are as follows:
- Scenario 2a: $9.19 \times 10^{-5}$ m$^3$/m$^2$/day;
- Scenario 2b: $9.63 \times 10^{-5}$ m$^3$/m$^2$/day;
- Scenario 2c: $2 \times 10^{-4}$ m$^3$/m$^2$/day;

In all instances the development of a contaminant plume over an operational period of 50 years (up to 2066) was simulated. The assumption was made that operation will cease in 2066 and that the dam will be rehabilitated. The source was removed (theoretically) and the improvement in the TDS concentrations over the next 50 years (until 2115) was simulated.

Based on the simulations the effectiveness of the proposed liner is summarised in Table 9.1. This is based on the maximum flow rates and contaminant loads during the simulation period.

Table 9.1: Simulation results – Flow to Streams

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Flow into River System</th>
<th>Contaminant Load into River System</th>
<th>% Improvement from Base Case</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Stream A (Grootspruit)</td>
<td>Stream B (Bossiespruit Tributary)</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>No liner (Base case)</td>
<td>230</td>
<td>124</td>
<td>354</td>
</tr>
<tr>
<td>2</td>
<td>Liner – 100% effective as per design</td>
<td>194</td>
<td>51</td>
<td>245</td>
</tr>
<tr>
<td>2a</td>
<td>Liner – 95% effective as per design</td>
<td>194</td>
<td>51</td>
<td>245</td>
</tr>
<tr>
<td>2b</td>
<td>Liner – 90% effective as per design</td>
<td>195</td>
<td>52</td>
<td>247</td>
</tr>
<tr>
<td>2c</td>
<td>Liner – unacceptable liner failure</td>
<td>226</td>
<td>69</td>
<td>295</td>
</tr>
</tbody>
</table>

In terms of flow to the surface streams the following is concluded:
- In an unlined situation the contaminant plume is expected to migrate a distance of 485m in an easterly direction from FAD 6 and 350m in a westerly direction. In a lined situation the contaminant plume will only migrate 70m in an easterly direction and 220m in a westerly direction.
- The expected maximum contaminant load contribution to surface streams in an unlined situation is 0.31 tons per day. In the lined situation the load reduces to 0.013 tons per day, or a 96% improvement. Even in a situation where the liner system fails the impact on the groundwater regime is significantly reduced.

The groundwater flow in the vicinity of FAD 6 is affected by the partial dewatering of the aquifers. Such dewatering is potentially occurring in the vicinity of the proposed return water dam as boreholes FAD6 BH3, PB 06, PB 07 and PB 08 (dry) have all very low groundwater levels. In order to assess the potential impact from the proposed Fine Ash Dam 6 on the underground mine workings, the model was used to simulate the flow volume and contaminant load at this point. The results of this assessment show that in the vicinity of FAD 6 the unlined flow and contaminant load is expected to be in the order
of 190 m$^3$/day and 0.10 tons/day TDS respectively. This will further reduce to approximately 169 m$^3$/day and 0.012 tons/day TDS respectively for the lined scenario. The proposed liner system shows a significant reduction in the estimated impact from FAD 6 and is therefore considered adequate to protect the underlying aquifers from groundwater contamination.

A portion of the underground mine workings, underlying FAD 6, will be backfilled to ensure the long-term stability of the dam. The question was raised if the proposed backfilling will have an adverse impact on the groundwater resources underneath or near FAD 6. Laboratory testing was undertaken to classify the waste characteristics if the cement–ash mixture and to determine the quality of the leachate that can potentially emanate from the backfill. This study concluded that:

- The fine ash to be used in the cement–ash mixtures has been classified as non-hazardous, therefore a general waste.
- The 4% cement–wet ash and the 6% cement dry-ash mixtures have both been assessed as Type 3 wastes.
- Based on the distilled water leach concentration results on crushed cubes, the 4% cement–wet ash mixture is assessed as inert, a Type 4 waste, while the 6% cement–dry ash mixture is assessed as a Type 3 waste.
- In terms of the results of the 1:10 distilled water leach, which is a conservative approach conducted on the whole cubes, and is the test most representative of the actual application of this material, the two ash–cement mixtures are classified as inert, Type 4, wastes.

The potential impact in terms of the groundwater level drawdown and water inflow into the mine, was simulated. This simulation assumed that the boreholes are not cased and that all the boreholes are drilled simultaneously and left open for one year. This assessment concluded that:

- The maximum radius of influence of each borehole is 35m. The combined influence remains within the boundaries of FAD 6 and will not impact on any groundwater users in the area.
- The groundwater levels are expected to recover within 6 months after being grouted.
- The estimated combined maximum groundwater inflow into the mine, is 1 600 m$^3$/day.

The Brandspruit Mine workings underneath FAD 6 is currently dry, but will be flooded with mine water once mining ceases. The backfilled volume compared to the overall mined out volume is less than 1% and considering the expected leachate quality, it is concluded that the added contribution of the leachate from the backfilled area to the overall impact from the mine water is negligible.

The backfilled volume compared to the overall mined out volume is less than 1%. In addition, the proposed backfill area is located towards the centre of the simulated mine water contaminant plume and thus the limited impact from the backfill material is expected to remain within the mining void. Based on the above and considering the expected leachate quality, it is concluded that the added contribution of the leachate from the backfilled area to the overall impact from the mine water is negligible.

The closest private borehole to the backfill area are located 1.6km to the west. This distance, as well as the shallow depth of all the measured boreholes indicate that the backfill will not impact on private groundwater users. In addition, Sasol Mining will develop a groundwater management plan that will govern the future additional groundwater usage within the areas affected by mining.