4.8 Peak Rainfall Data

4.8.1 Maximum Monthly Rainfall Data

The maximum monthly rainfall data was distilled from the daily rainfall record (discussed in section 4.4.1) and is presented in Table 4.

Table 4: Maximum monthly rainfall data (mm)

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
202.7	250.7	308	360.5	345.9	184	144.5	143.8	104.1	75.7	37.8	135.5

4.9 Flood Flow Analysis

The 50-year and 100-year flood peak for the above rivers and streams were calculated and the results are presented in Table 5. The flood peaks were calculated where the streams exit the study area. The catchments are shown in Figure 1. The methodology to calculate the peak flows, presented in Table 5, is discussed in sections 4.9.2.

Table 5: Peak flows in the rivers and streams

Recurrence Interval	Blesboklaagtespruit (m^3/s)	Tributary of the Blesboklaagtespruit (m^3/s)	Tributary of the Spookspruit (m^3/s)
50-year	46.4	105.7	72.4
100-year	65.6	149.3	102.2

4.9.1 Peak 24-hr Rainfall Data

The peak 24-hour rainfall depths are presented in Table 6.

Table 6: Peak 24-hour rainfall depths for the site

Recurrence Interval (year)	24 hour rainfall depth (mm)
2	52
10	79
20	94
50	116
100	136
200	160

The daily rainfall record, discussed in section 4.4.1, was analysed and the annual maximum series was extracted from the data. This annual maximum series was statistically analysed to determine various T-year recurrence interval 24-hour storm depths. A Log Extreme Value Type 1 fit was selected as the most appropriate statistical fit. The fit is slightly conservative but results are appropriate to the region.This fit is shown in Figure 5. The rainfall record is long, consists of good data, is representative of the site, and is suitable be used to calculate peak rainfall. This data is preferred over peak rainfall depths calculated by Adamson (Adamson, 1981) as it is more up to date. Adamson's data does not benefit from the last 30 years of recorded data.

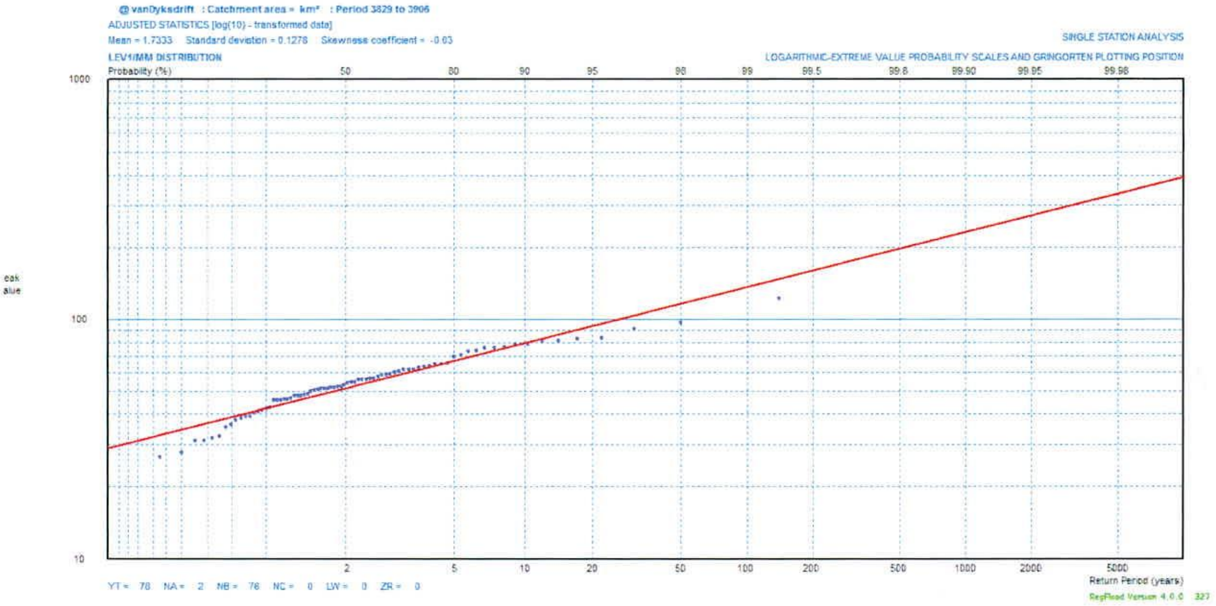

Figure 5: Log Extreme Value Type 1 statistical fit to the annual maximum series

4.9.2 Flood peak calculation

The rational method was used to determine the flood peaks. The old Department of Water Affairs' calculation sheet was used to determine the runoff coefficients. The time-to-concentration of the sub-catchments was calculated using the SCS method which is suitable for relatively undeveloped catchments. Adamson's TR102 (Adamson, 1981) was used to convert the 24-hour peak rainfall data to rainfall intensities appropriate to the time-to-concentration of the catchment. The 1085 method was used to calculate catchment slope. The results of these calculations are summarised in Table 7 and Table 8.

Table 7: Summary of 50-year flood peak calculations

Parameter	**Blesboklaagtespruit**	**Tributary of the Blesboklaagtespruit**	**Tributary of the Spookspruit**
Catchment size	725 ha	2 532 ha	1 207 ha
Runoff coefficient	0.29	0.29	0.29
Time to concentration	0.79 hrs	1.45 hrs	0.87 hrs
Adamson's TR102 D_{Hour} factor (R_1)	0.54	0.65	0.56
Peak rainfall intensity	80 mm/hr	52 mm/hr	75 mm/hr
Flood peak	**46.8 m^3/s**	**105.7 m^3/s**	**72.4 m^3/s**

Table 8: Summary of 100-year flood peak calculations

Parameter	**Blesboklaagtespruit**	**Tributary of the Blesboklaagtespruit**	**Tributary of the Spookspruit**
Catchment size	725 ha	2 532 ha	1 207 ha
Runoff coefficient	0.35	0.35	0.35
Time to concentration	0.78 hrs	1.45 hrs	0.87 hrs
Adamson's TR102 D_{Hour} factor (R_1)	0.54	0.65	0.84
Peak rainfall intensity	94 mm/hr	61 mm/hr	88 mm/hr
Flood peak	**66.1 m^3/s**	**149.3 m^3/s**	**102.2 m^3/s**

5 FLOODLINE

5.1 Backwater analysis

The backwater analysis was performed using HEC-RAS. Cross sections were taken from the 2 m contour data provided by Goedehoop Colliery. A Manning's n of 0.1 was used for heavily reeded areas, and 0.035 for grassland areas.

The flood peaks presented in Section 4.9 were used to calculate the floodlines.

The 50-year and 100-year floodlines are shown in Appendix A.

6 WATER QUALITY

Goedehoop colliery samples water quality on various surface water bodies on and outside of their property, including the Goedehoop North operations. Sampling frequency is generally monthly. Data from prior to 2000 to December 2011 was made available for the purposes of this study.

6.1 Surface Water Users

The water quality data was compared against the South African water quality guidelines (Department of Water Affairs and Forestry, 1996). In selecting which guidelines to compare the data against, the likely downstream users need to be considered. The likely downstream users were determined by examining aerial photography, literature surveys and observations made during a site visit of the proposed mining area and the catchment.

All three streams in the study area flow into the Spookspruit. The Spookspruit is a tributary of the Olifants River, joining the Olifants River just downstream of the Witbank and Doornpoort Dams. The confluence is upstream of the Loskop and Flag Boshielo Dams. These dams are an important source of domestic, irrigation and industrial water to their surrounding areas. The Olifants River is an international river, flowing through the Kruger National Park and into Mozambique. With the Olifants River flowing through the Kruger National Park, provision for meeting ecological requirements is one of the controlling factors for managing water resources throughout the Olifants River catchment.

The flow in the Spookspruit is small in comparison to the flow in the Olifants River. The Olifants River is a highly impacted river system. Impacts are largely caused by coal mining, similar to impacts that are likely to be foundin the Spookspruit. Water quality of the Olifants River is likely to dominate the water quality once the Spookspruit and the Olifants Rivers converge.The downstream users were therefore considered in the Spookspruit. The downstream usage classes are evaluated below:

- Domestic users –farm labourers and local inhabitants may consume this river water.
- Recreational users – it is likely that farm labourers and local inhabitants will swim in the streams and will use the water for washing.
- Industrial users – there are mining activities downstream of the proposed operations. However, these operations are not sensitive to poor quality water.
- Aquatic users – the catchments are heavily impacted by agriculture and mining, and sensitive aquatic users are unlikely to be present
- Irrigation users – the river water is likely to be used for small-scale or informal irrigation
- Livestock watering – the river water is likely to be used for livestock watering

The water quality guidelines considered are therefore the Domestic, Irrigation, Livestock watering and Recreational water quality guidelines. The water quality at the sampling points was compared to these guidelines.

6.2 Sample Locations

Four of Goedehoop Colliery's sampling locations were selected or the purposes of this surface water specialist report. One sample was selected on the Blesboklaagtespruit, two on the tributary of the Blesboklaagtespruit and one sample on the tributary of the Spookspruit.

Sample S10, located where the tributary of the Spookspruit crosses the R35, represents the baseline conditions of thetributary of the Spookspruit prior to any impacts resulting from the proposed mining development.***During operations, this point should form the downstream sampling point on this stream. An additional surface water monitoring point should be located upstream of the proposed underground operations.***Sample S8 represents baseline water qualities in the tributary of the Blesboklaagtespruit. Samples S4 and S5 currently also represent baseline water qualities in the Blesboklaagtespruit and its tributary. ***During operations, two points should be located between the proposed conveyor and the Bankfontein Dam to form downstream points, below the conveyor crossing.*** No sampling points in the Bankfontein dam, and downstream of the Bankfontein dam were considered as this water is likely to be influenced by other water streams (natural and process) that flow into and out of this dam. These locations are shown in Figure 6.

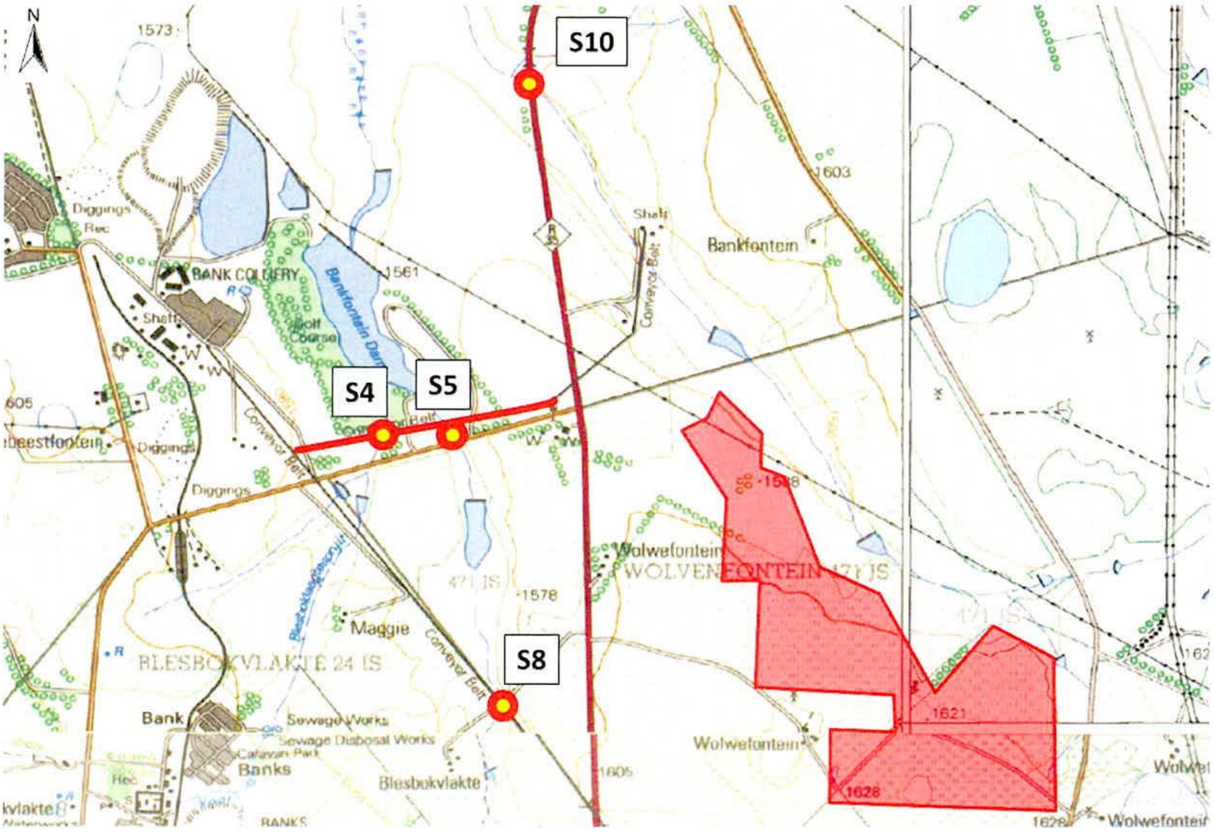

Figure 6: Locations of sampling points

6.3 Baseline Water Quality Analysis

The water quality samples were taken monthly from prior to 2000 till December 2011.Data from 2009 onwards was statistically analysed and compared to the South African Water Quality Guidelines. The findings are summarised below.

6.3.1 Tributary of the Spookspruit (Sample location S10)

The water quality in the tributary of the Spookspruit is good. The catchment is rural and predominantly under dry-land crops. Limited mining activities are present upstream of sampling point S10. The impacts of these activities on the tributary are uncertain. A nearby mine, located north-east of the tributary has open-cast operations close to the watershed of the tributary. It is unlikely that these operations have impacts on the surface water quality of the tributary, but groundwater impacts may emerge as surface water impacts. Groundwater impacts are not known as there are no borehole water quality sites in this location. The 50 000 topographical sheets (2529CD) indicate a shaft is also located upstream of the monitoring point.The most noticeable elevated concentrations are:

- **Iron**concentrations are generally elevated and exceed Class O drinking water quality guideline values 67% of the time. Class I drinking water quality guideline values are exceeded 20% of the time. Wet season concentrations are generally higher than dry season concentrations.
- **Manganese** concentrations exceed Irrigation water quality guideline values 70% of the time. Class O drinking water quality guidelines are exceeded about 30% of the time. Class I drinking water quality guidelines are exceeded approximately 5% of the time.

6.3.2 Tributary of the Blesboklaagtespruit (Sample location S8)

The water quality in this stream has become heavily impacted since May 2011. Prior to that, water quality was generally good. Impacts resemble those typical of coal mining. Underground mining activities are present in the upper reaches of the catchment. The most noticeable elevated concentrations are:

- **Salts**concentrations are elevated, mainly driven by very high **Sulphates**. During 2011, sulphate concentrations generally exceeded Class III drinking water quality guideline values. The trend is a deteriorating water quality. **Chlorides** also show the same deteriorating trend exceeding Class O drinking and Irrigation water quality guideline values since August 2011. However, pH has remained neutral.
- **Calcium** concentrations show the same trend, exceeding Class III drinking water quality guidelines since August 2011.
- **Manganese** concentrations show the same trend, exceeding Class I drinking water quality guidelines since August 2011.
- **Magnesium**concentrations show the same trend, exceeding Class III drinking water quality guidelines since August 2011.

6.3.3 Tributary of the Blesboklaagtespruit (Sample location S5)

The water quality in this stream is good, and shows an improving trend which is the opposite of the trend shown in S8. There are no noticeable elevated concentrations.

6.3.4 Blesboklaagtespruit (Sample location S4)

The water quality in the Blesboklaagtespruit at this monitoring location can be described as poor. Impacts resemble those typical of coal mining. There are no active mining activities in the catchment. However decant from historical activities may be contributing to the poor water quality. The most noticeable elevated concentrations are:

- **pH** is generally acidic, exceeding all water quality guideline values.
- **Salts** are elevated and are mostly within Class II drinking water quality guidelines. Class II guidelines are exceeded approximately 30% of the time. Irrigation guideline values are exceeded 100% of the time. This will affect crops sensitive to salinity. **Total dissolved solids**exceed Class III drinking water quality guideline values 45% of the time. Irrigation guideline values are exceeded 75% of the time and livestock watering guidelines approximately 40% of the time. This is predominantly **Sulphate** driven, which generally exceeds all guideline values.
- **Calcium** levels are elevated and exceed Class II drinking water guidelines 70% of the time.
- **Magnesium** levels are elevated and exceed Class II drinking water guidelines 40% of the time.
- **Sodium** concentrations are generally within Class I drinking water quality guidelines. The irrigation water quality guideline values are exceeded 75% of the time.
- **Iron** concentrations are very high. These values should be checked.
- **Manganese** qualities exceed all guideline values.
- **Aluminium**qualities exceed all guideline values.

7 IMPACT ASSESSMENT

7.1 Project Description

The project involves the development of underground mine with and a conveyor linking the underground mine to the existing Goedehoop North surface operations. Contaminated storm water from the shaft or adit areashould be collected in a dedicated pollution control dam.

7.2 Methodology for Impact Assessment

Activities on the proposed expansion project have been taken through an impact assessment prior to and post mitigation measures. The recommended mitigation measures have been included in the impact assessments. Impacts are assessed for the construction, operational, decommissioning and closure phases of the project. The methodology used for the impact assessments is presented below:

Occurrence

- Probability of occurrence (how likely is it that the impact will occur)
- Duration of occurrence (how long impacts will last)

Severity

- Magnitude of impact (the severity of the impact)
- Scale of impact (the extent of the impact).

The following ranking scales were used:

Probability (P)	**Duration (D)**
5: Definite/don't know 4: Highly probable 3: Medium probability 2: Low probability 1: Improbable 0: None	5: Permanent 4: Long-term (ceases with the operational life) 3: Medium term (5-15 years) 2: Short term (0-5 years) 1: Very short term (0-1 week)
Scale (S)	**Magnitude (M)**
5: International 4: National 3: Regional (within a 100 km radius) 2: Local (within a 5 km radius) 1: Site only 0: None	10: Very high/don't know 8: High 6: Moderate 4: Low 2: Minor

The impact is calculated as: Impact score = (M + D + S) x P. The maximum Impact score is 100. The impact ratings were based on the Impact score and are rated as follows:

- High environmental impact: Impact score between 60 and 100.
- Medium environmental impact: Impact score between 30 and 59.
- Low environmental impact: Impact score between 0 and 29.

7.3 Impacts During the Construction Period

7.3.1 Impacts due to topsoil stripping

Impact assessment

During the construction phase, topsoil from all facility footprints will be stripped and stockpiled for future use. This may result in the following impacts:

- Areas that have been stripped of vegetation and topsoil will be prone to erosion. This could lead to increased suspended solids being deposited into the Spookspruit.
- The topsoil stockpile will be prone to erosion prior to it being vegetated. Natural re-vegetation will likely take more than 1 season to completely cover the topsoil

stockpile. The resultant erosion could lead to increased suspended solids being deposited into the Spookspruit.

The affected areas will be relatively small. Erosion impacts will be short term and will cease once the facilities are constructed and the topsoil stockpile is vegetated.

Mitigation

Mitigation of the impacts should include the following:

- Areas that are stripped should be optimised to limit unnecessary stripping.
- Storm water from upslope of the stripped areas should be diverted around these areas to limit the amount of storm water flowing over from these areas.
- The timing of the topsoil stripping should be optimised to limit the time between stripping and construction. Where practical constraints exists and areas need to left stripped for long periods, contour ploughing or ripping could reduce runoff and hence reduce erosion.
- Dry season construction is preferable.
- Hydro seeding of the topsoil stockpile is recommended to speed up vegetation cover. An appropriate seed mix should be designed by a vegetation specialist.

Residual impact

The residual impacts will probably be very low due to the temporary nature of the impact. Large storm flows in the Spookspruit will wash the excess sediment into downstream river systems. These sediment loads are likely to be very small in relation to the sediment loads in the Olifants River. This sediment may ultimately reach the Loskop Dam.

Cumulative impact

Topsoil stripping will add to sediment loads produced by erosion from upstream agricultural activities. While it occurs the, impact will be significant compared to upstream impacts of similar nature. However, the impact will be temporary and will cease shortly after construction commences and the topsoil stockpile is vegetated.

Impact rating table

Construction Impact: Topsoil stripping					
Prior to mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
5	2	2	6	50	Medium
Post mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
5	2	2	2	30	Low

7.3.2 Impacts due to construction related pollution

Impact assessment

During the construction phase a significant number of vehicles will be driving around the site. In addition to this, fuels are stored on site and chemicals are used during normal construction activities. This may result in the following impacts:

- If the construction vehicles are poorly maintained hydrocarbon spills could cause pollution if washed off roads by storm water.
- Vehicle wash bays are a common source of hydrocarbon pollutants.
- Leaks from fuel depots could result in surface water pollution.
- Spillage and unsafe storage of chemicals could result in surface water contamination.

The affected areas will be the entire construction site. Spillage impacts will be short term and will cease after the completion of construction. However if soils have become contaminated, this will leach out over a prolonged period.

Mitigation

Mitigation of the impacts should include the following:

- All construction vehicles should be well maintained and inspected for hydrocarbon leaks weekly.
- Wash bay discharge water should flow through an oil separator.
- Fuel depots and refuelling areas should be bunded.
- Chemicals should be stored in a central secure area.
- Regular toolbox talks on the responsible handling of chemicals should be undertaken.

Residual impact

If limited soil contamination occurs, the residual impacts will probably be very low.

Cumulative impact

There are no significant upstream sources of hydrocarbon pollutants apart from farming activities. Hydrocarbons are currently not measured in the streams and it is unlikely that significant amounts of hydrocarbon pollution exists in the streams.

Impact rating table

Construction Impact: Construction related pollution					
Prior to mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
3	2	2	4	24	Low
Post mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
2	2	2	4	16	Low

7.4 Impacts During the Operational Phase

7.4.1 Impacts due to contaminated water discharge

Impact assessment

Some areas of proposed works should be considered as dirty areas. These areas typically include the conveyor and the area around the shaft/adit. Storm water and seepage generated from these areas will likely be contaminated and have a detrimental effect on the water quality in the rivers. These impacts will be most acute during the dry season when stream flows are low.

Mitigation

Goedehoop North colliery should have an undertaking to comply with Government Notice 704 of the South African National Water Act. This act limits discharges of contaminated water from mining related activities to less than once in 50 years on average. Contaminated water should be reused or treated to adequate discharge standards prior to release.

Should a legal discharge occuras a result of extreme rainfall conditions, the rivers should have sufficient capacity to dilute poor quality spillage water. The impacts from extreme rainfall conditions should be low and will last for a short duration. Impacts resulting from negligence or mismanagement could be more severe. The severity of the impacts would be related to the volume and quality of water that is spilled. Impacts relating to small spillages would probably be relatively low to medium and would be short in duration. Impacts relating to large spillages would be high. The effects would be short to medium term.

Mitigation of the impacts should include the following:

- The conveyor should be covered.
- Shallow seepage and contaminated storm water runoff from the dirty areas around the shaft/adit should be collected and routed to a pollution control dam.

- Pollution control dams should be adequately sized to account for storage build-up during periods of high rainfall. These should be sized and operated in accordance with Government Notice 704 of the National Water Act.
- Pollution control dam water levels should be constantly monitored. Steps and procedures should be put in place to manage situations where excess water builds up in the pollution control dam.
- Pollution control dams should generally be operated empty and cannot fulfil the same role as a water storage dam, unless specifically designed to fulfil both purposes.
- Water reuse from the pollution control dams should be maximised.

Residual impact

Proper water management should result in no accidental spillages, other than those resulting from extreme rainfall and discharges within the ambit of the law. Based on the assumption that proper management will take place, the residual impacts will be low. Impacts could occur during the life of the mine.

Cumulative impact

The Spookspruit is already impacted by mining activities. The impacts resulting from contaminated water discharges are likely to be similar to existing impacts, and further water quality deterioration will occur.

Impact rating table

Operational Phase Impact: Contaminated water discharge					
Prior to mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
5	4	3	6	65	High
Post mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
1	1	3	6	10	Low

7.4.2 Impacts due to wash bays and workshops

Impact assessment

Organic and nutrient pollution may result from the wash bays and workshop areas around the shaft/adit. These areas should be bunded and all water should be contained, collected and routed to an appropriate treatment facility. Impacts are likely to be low and will last during the life of mine.

Mitigation

Mitigation of the impacts should include the following:

- All drains that collect the wash water and stormwater should be maintained regularly. These should be free of debris and silt.
- All diversion canals, trenches and conduits must be designed to convey runoff from a 50-year design storm.
- The wash bays and workshops should be equipped with oil separators to remove hydrocarbons from wash down water.

Residual impact

The residual impacts of the wash bays and workshops will probably be low. The impacts will occur for the duration of the life of the mine.

Cumulative impact

There are no significant upstream sources of hydrocarbon pollutants apart from farming activities. Hydrocarbons are currently not measured in the Spookspruit and it is unlikely that significant amounts of hydrocarbon pollution exists in the Spookspruit.

Impact rating table

Operational Phase Impact: Wash bays and workshops					
Prior to mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
2	1	3	4	16	Low
Post mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
1	1	3	4	8	Low

7.4.3 Impacts due to Coal Spillages from the Conveyor

Impact assessment

The conveyor will transport coal from the underground workings to the plant. The conveyor crosses the Blesboklaagtespruit and a tributary of the Blesboklaagtespruit. Coal spills from the conveyor will result in surface water pollution, especially in the vicinity of stream crossings.

Mitigation

Mitigation of the impacts should include the following:

- The conveyor should be covered.
- At river crossings, the conveyor should have a facility to catch coal spills and prevent coal from falling into the streams.
- The conveyor should be subjected to frequent patrols and spilled coal should be collected.

Residual impact

The residual impacts of coal spills from the conveyor could be the contamination of the soil in the location of the spill. Contaminants will continue to be leached into the water systems over a long period (1-5 years) following a spill. Spills over rivers will result in coal being transported into the river systems.

Cumulative impact

The Spookspruit is already impacted by mining activities. The impacts resulting from coal spills are likely to be similar to existing impacts, and further water quality deterioration will occur.

Impact rating table

Operational Phase Impact: Coal spillages from the conveyor					
Prior to mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
5	2	3	8	65	High
Post mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
3	2	3	4	27	Low

7.4.4 Loss of catchment yield

Impact assessment

During the operational phase,storm water generated from the areas considered dirty, will be collected in the dirty water system. This water would have contributed to the flow in the rivers. If subsidence occurs above the underground workings, surface water yield will be reduced. The loss of catchment yield will result in a significant reduction in flow in the tributary of the Spookspruit.

Mitigation

As is best practice, dirty areas should be minimised. This will have the dual benefit of smaller dirty water management systems and reduction in catchment yield loss.

The loss of catchment yield due to underground subsistence can be mitigated by preventing subsidence and surface cracking. The underground mining plan should accommodate this.

Residual impact

If subsidence above the underground occurs, the effects will be long term. The tributary of the Spookspruitwill be significantly affected. If subsidence does not occur, then the residual impacts will be insignificant.

Cumulative impact

The impacts on the Spookspruit will be insignificant, provided subsidence does not occur.

Impact rating table

Operational Phase Impact:Loss of catchment yield					
Prior to mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
5	4	2	6	60	High
Post mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
5	4	0	1	25	Low

7.5 Impacts During the Decommissioning Phase of the Project

7.5.1 Impacts due to the removal of surface infrastructure

Impact assessment

During the decommissioning phase, most impacts will be associated with the removal of surface infrastructure. Roads will be removed, as will berms and diversion trenches.

During this process, short-term impacts will be moderate, as heavy earth-moving machinery will disturb large areas. Previously vegetated areas may be disturbed which increase erosion potential. These short-term impacts will give way to long-term benefits.

Mitigation

Apart from due diligence care while performing decommissioning tasks, no mitigation is necessary. Due diligence care includes the following:

- Plant should be well maintained to ensure that hydrocarbon spills are minimised.
- Existing roads should be used where possible.
- New disturbed areas should be minimised.

Residual impact

The residual impacts will probably be very low due to the temporary nature of the impact. Large storm flows in the Spookspruit will wash the excess sediment into downstream river systems. These sediment loads are likely to be very small in relation to the sediment loads in the Olifants River. This sediment may ultimately reach the Loskop Dam.

Cumulative impact

The newly disturbed areas will add to sediment loads produced by erosion from upstream agricultural activities. While it occurs, the impact will be significant compared to upstream impacts of similar nature. However, the impact will be temporary and will cease shortly after the disturbed areas have been vegetated.

Impact rating table

Decommissioning Phase Impact: Removal of surface infrastructure					
Prior to mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
5	2	2	6	50	Medium
Post mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
5	2	2	2	30	Low

7.6 Impacts After the Closure Phase of the Project

7.6.1 Impacts due to decant from underground workings

Impact assessment

At the time of writing, the results of the groundwater study were not available. After the colliery is closed, contaminated water management becomes passive. Groundwater inflows may create decant. Should decant occur, it will be discharged into the environment. This decant will be driven by groundwater recharge into the mine voids. The decant water quality is likely to be poor and will contaminate the rivers. The water quality is likely to remain poor in the long term (>20 years). Eventually as pollutants are leached out of the system, the seepage water quality will improve.

Mitigation

Mitigation of the impacts (should decant occur) should include the following:

- Passive mitigation measures should be investigated to remove salts and other pollutants from the water to a level suitable for release. Alternatively, plugs could be considered if practical to prevent decant.
- If not suitable, active alternatives should be considered such as some form of treatment, prior to release.

Residual impact

Assuming decant does occur, the residual impacts will be dependent on the quality of mitigation. If the quality of mitigation is good, then limited to no residual impacts should occur. If the quality of mitigation is poor or non-existent, then the residual impacts will be significant and further deterioration will occur in the Spookspruit, particularly during the dry season when there is little assimilative capacity in the rivers.

If decant does not occur, then there are no residual impacts.

Cumulative impact

Assuming decant occurs, if the quality of mitigation is good and decant is prevented or the decant water quality is suitable for release, the cumulative impacts will be negligible. Should decant of polluted water occur, the impacts resulting from decant will result in long-term water quality deterioration in the Spookspruit.The Spookspruit appears to be relatively impacted. The impacts resulting from decant are likely to be similar to existing impacts, and further water quality deterioration will occur in the Spookspruit.

If decant does not occur, then there are no cumulative impacts.

Impact rating table

If no decant occurs, then this impact assessment is not valid.

Should decant occur, and If mitigation prevents this decant or improves the decant water quality to acceptable discharge levels, the following table applies:

Closure Phase Impact: Underground water decant					
Prior to mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
5	5	3	6	70	High
Post mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
0	0	0	0	0	Low

Should mitigation be unsuccessful and decant of poor quality water occurs, the following table applies:

Closure Phase Impact: Underground water decant					
Prior to mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
5	5	3	6	70	High
Post mitigation					
Probability	**Duration**	**Scale**	**Magnitude**	**Impact score**	**Impact**
5	5	3	6	70	High

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ILANDA WATER SERVICES CC

BN Randell

APPENDIX A

FLOODLINES

Appendix 5

Geohydrological Report for the proposed Access Brown Shaft II Project Area

GEOHYDROLOGICAL REPORT

FOR

THE PROPOSED UNDERGROUND MINING AT BROWN SHAFT 2
GOEDEHOOP NORTH COLLIERY, MPUMALANGA PROVINCE.

GPT Reference Number: GeBs-12-238
Version: Draft 1.0
Date: September 2012

Compiled for:

GEOVICON ENVIRONMENTAL (PTY) LTD

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Geohydrological Report for the Proposed Underground Mining at Brown Shaft 2 Goedehoop North Colliery, Mpumalanga Province

Report Type: Geohydrological Report
Project Title: The Proposed Underground Mining at Brown Shaft 2 Goedehoop North Colliery, Mpumalanga Province
Compiled For: Geovicon Environmental (Pty) Ltd
Compiled By: M. Burger

GPT Reference GeVB-12-183
Version: Draft 1.0
Date: July 2012

Distribution List (Current Version): PDF by e-mail to Geovicon Environmental (Pty) Ltd
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The results and conclusions of this report are limited to the Scope of Work agreed between GPT and the Client for whom this investigation has been conducted. All assumptions made and all information contained within this report and its attachments depend on the accessibility to and reliability of relevant information, including maps, previous reports and word-of-mouth, from the Client and Contractors. All work conducted by GPT is done in accordance with the GPT Standard Operating Procedures. GPT is an ISO 9001 accredited company.

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I hereby declare:

1. I have no vested interest (present or prospective) in the project that is the subject of this report as well as its attachments. I have no personal interest with respect to the parties involved in this project.
2. I have no bias with regard to this project or towards the various stakeholders involved in this project.
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Customer Satisfaction:
Feedback regarding the technical quality of this report (i.e. methodology used, results discussed and recommendations made), as well as other aspects, such as timeouts completion of project and value of services rendered, can be posted onto GPT's website at www.gptglobal.com.

EXECUTIVE SUMMARY

Geo Pollution Technologies (Pty) Ltd (GPT) was appointed by Geovicon to conduct a hydrogeological impact study at the proposed underground mining of Brown Shaft 2 Goedehoop North Colliery on the farm Wolvenfontein 471JS located approximately 25km south of the town Middelburg in Mpumalanga Province.

Current Groundwater Conditions

Surface drainage from the proposed underground is in a north easterly direction, towards the unnamed tributary of the Spookspruit flowing north. Some perennial and non-perennial surface water bodies (mainly recreational and agricultural dams) are found inside a 2 km radius of the proposed mining area.

A hydrocensus was conducted on and around the proposed mining site (to a distance of approximately two kilometres) during July 2012. Groundwater levels, varying between 4.31 and 88.36 mbgl, were measured in the surrounding area during the survey. The average static water level was measured to be 8.7 mbgl. These values were determined from borehole data where the owner was available on site and where it was possible to gain access to the boreholes for precise measuring of water levels.

A seasonal aquifer perched on the bedrock probably develops in the upper weathered soil layer, especially after high rainfall events. Flow in this perched aquifer is expected to follow the surface contours closely and emerge as fountains or seepage at lower elevations.

From the chemical analysis most of the water samples is of good quality and can generally be classified as Class 0 (Ideal) according to the SABS Guidelines for Drinking Water. Most samples sulphate concentrations are within the target quality water range for the majority of the samples, although high sulphate values were observed in borehole UG3, where an elevated concentration was observed. This indicates that historic mining has influenced the groundwater quality of certain parts of study area.

Predicted Impacts of Mining

The impacts on the groundwater regime normally associated with mining is dewatering of the aquifer during mining and pollution of the groundwater following mine closure. The dewatering is essential to allow access to the mining areas, while the pollution is due to chemical weathering by oxidation of the sulphate containing minerals (mostly pyrite).

During mining, groundwater seeping into the underground will have to be pumped out to facilitate access. This will inevitably lead to a lowering of the groundwater table and the development of a local cone of depression. This cone of depression will also contain pollution resulting from mining. Polluted groundwater pumped from the mine will be used for mining purposes.

Post mining, following the closure of the pit and discontinuing of dewatering, the groundwater levels will return to equilibrium. The cone of depression that contained polluted groundwater will cease to exist and movement of a groundwater pollution plume will commence.

Numerical groundwater modelling is considered to be the best method of anticipating and quantifying these likely impacts on the groundwater regime. For this purpose, a numerical model was created using the Department of Defence Groundwater Modelling System (GMS) software as Graphical User Interface (GUI) for the well-established Modflow and MT3DMS numerical codes

Based on the results of the modelling, the following conclusions can be made this stage:

Construction Phase:

It is accepted for the purposes of this document that the construction phase will consist of preparations for the underground mine, which is assumed to consist mainly of establishment of infrastructure on site, mobilisation of earth moving equipment and the development of the adit.

This phase is not expected to influence the groundwater levels on a regional scale although local dewatering of the adit may be required for access.

Operational Phase:

The dewatering of the aquifer has been calculated for the underground using the calibrated numerical model. A worst-case scenario has been modelled, assuming that all of underground could be dewatered simultaneously. This will obviously not be the case, and the actual drawdown could be less. However, as the recovery of groundwater is expected to be very slow, it could well be that the first mined underground is still in early stages of recovery while the last underground is mined, and this scenario could be approached.

The calculated drawdown of the worst case scenario is depicted in this report as contours of drawdown. It follows from this that:

- A maximum drawdown of 15-20 metres is predicted inside the underground area at the deepest point of the underground, as can be expected.
- The cone of groundwater drawdown is confined to the immediate surroundings of the underground and extends less than 200 metres around the mine.
- There are two boreholes in the potential affected area that might experience a decline in water levels of approximately 5 metres or more.

Post Mining Phase:

Post mining, after closure, the water table will rise to reinstate equilibrium with the groundwater systems. The mined areas will have a large hydraulic conductive compared to the pre-mining situation. This will result in a relative flattening of the groundwater table over the extent of mining, in contrast to the gradient that existed previously.

The following possible impacts were identified at this stage:

- Inspection of the predicted post mining groundwater levels indicates that decanting would probably not occur. However as mining progress and mining plans is finalised, this prediction must be confirmed.
- Following closure of the underground, the groundwater level will rise to an equilibrium that will differ from the pre-mining level due to the disturbance of the bedrock and increase in recharge from rainfall.
- Groundwater within the mined areas is expected to deteriorate due to chemical interactions between the geological and the groundwater. The resulting groundwater pollution plume will commence with downstream movement.
- Movement of the plume will be mostly downstream to the north-east, as can be expected.
- Initial movement of the plume is predicted to be slow due to the slow recovery of the groundwater levels and the low gradients in the area.
- The tributary of the Spookspruit and wetland situated to east and northeast could be affected in a 50 to 100 year period. However, this reflects a worst case scenario as chemical interaction with minerals in the receiving environment has been ignored. Some chemical reaction will inevitably occur, thereby retarding and absorbing chemical substances in solution.

- It is expected that no boreholes might be affected by the sulphate pollution.

It must be kept in mind that the modelling was done within the limitations of the scope of work of this study and the limited amount of monitoring data available. Although all efforts have been made to base the model on sound assumptions and has been calibrated to observed data, the results obtained from this exercise should be considered in accordance with the assumptions made.

Groundwater Management and Mitigation Measures

Since it is inevitable that a mining operation of this scale will impact on the groundwater regime, measures to manage and reduce these impacts to the absolute minimum must be considered. The identified negative impacts of reduction of the groundwater levels during mining and the spread of groundwater pollution after closure of the underground will be addressed in the following paragraphs.

Lowering of Groundwater Levels during Mining

Since the drawdown or the groundwater levels during mining could influence some boreholes, the following measures are recommended:

- In the event of groundwater encountered during the adit development, precementation can and should be used to restrict inflow thereby negating excessive drawdown.
- The static level of groundwater in all boreholes within a distance of less than one kilometre must be measured regularly to establish a database against which future groundwater levels can be compared.
- Such measurements must be made preferably quarterly, but at least twice annually, following the dry and rainy seasons.
- In the event of unacceptable decrease of the yield of any affected boreholes, alternative water supply should be supplied to the affected parties until such time that the groundwater recovers following closure of the pit.
- It is highly recommended that board-and-pillar mining be used in the construction phase with the pillars being left intact with sufficient strength to keep the overlying strata from collapsing in the decommissioning phase.

Rise of Groundwater Levels Post-Mining

Following closure of the underground, the groundwater level will rise to an equilibrium that will differ from the pre-mining level due to the disturbance of the bedrock and surface, with subsequent increase in hydraulic conductivity and recharge from rainfall.

Inspection of the predicted post mining groundwater levels indicates that decanting would probably not occur. However as mining progress and mining plans is finalised, this prediction must be updated.

Spread of Groundwater Pollution Post-mining

Predictions in the previous sections regarding groundwater pollution have been based on the assumption that the rehabilitated pit will be a constant source of sulphate pollution of 2000 mg/l, representing a worst-case scenario. With appropriate measures, the oxidation rate of pyrite can be limited, resulting in lower starting concentrations. Furthermore, the migration of the pollution plume from the void can also be limited by surface rehabilitation measures preventing excessive infiltration of groundwater to the mined area. Thus, , further reduction is achievable.

To minimise the effect of groundwater pollution on the receiving environment, the following measures are suggested.

- Mining should remove all coal and as little as possible should be left in the underground.

- Coal bearing mining wastes must be placed in the lowest practical areas and flooded as soon as possible for similar reasons.
- Furthermore, the underground should be flooded as soon as possible to bar oxygen from reacting with remaining pyrite.
- Sealing worked-out sections of the underground mine and allowing it to flood will aid in limiting oxygen to the underground and reduce oxidation of pyrite.
- Quarterly groundwater sampling must be done to establish a database of plume movement trends and to aid eventual mine closure. It is essential to provide a reliable database to facilitate eventual closure of the mining operation.
- Regular sampling and chemical analyses of the groundwater is imperative to establish a sound database:
- Groundwater in all boreholes within a distance of less than two kilometres must be sampled regularly to establish a database against which future groundwater levels can be compared.
- Sampling must be preferably quarterly, but at least twice annually, following the dry - and rainy seasons.
- If it is found during such a sampling event that groundwater from any extraction borehole is polluted beyond acceptable standards, alternative water will have to be supplied to the affected party.

Impacts Indirectly Related to Mining

During all phases of mining, vehicles and personnel will be operative in the underground. Minor spills such as diesel, petrol and oil could results from machinery operations. Also, domestic water and waste disposal could also affect the groundwater quality. The following is thus recommended:

- It must be ensured that a credible company removes used oil after vehicle servicing.
- A sufficient supply of absorbent fibre should be kept at the site to contain accidental spills.
- Used absorbent fibre must be land-farmed, using approved methodologies.
- Domestic waste water, especially sewage, must either be treated at site according to accepted principles, or removed by credible contractors.
- Solid waste must similarly either be stored at site on an approved waste dump, or removed by credible contractors.

Further work

The following further work is recommended

- At least 4 monitoring boreholes must be constructed around the underground, upstream and downstream of the site. The boreholes must be sited by geophysics surveys.
- A monitoring network should be dynamic. This means that the network should be extended over time to accommodate the migration of contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources. An audit on the monitoring network should be conducted annually.
- The numerical model should be recalibrated as soon as more hydrogeological data such as monitoring holes are made available. This would enhance model predictions and certainty.
- In both cases the monitoring should commence before mining to establish background values for future reference.

- Acid base accounting must be done on available core logs to determine the acid generation capacity of the rocks

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ABBREVIATIONS

Ag = Silver
AH = Auger hole
Al = Aluminium
As = Arsenic
B = Boron
BDL = Below detection limit
BH = Borehole
Ca = Calcium
Cat/an bal% = Cation/anion balancing error
Cd = Cadmium
Cl = Chloride
Co = Cobalt
Cu = Copper
DRO = Diesel Range Organics
EC = Electrical Conductivity
F = Fluoride
Fe = Iron
GC-MS = Gas Chromatography Mass Spectrometer
GPT = Geo Pollution Technologies
GRO = Gasoline Range Organics
GW = Groundwater
HCO_3 = Bicarbonate
ICP-OES = Inductively Coupled Plasma Optical Emission Spectroscopy
K = Potassium
ℓ = litre
m = metres
mamsl = metres above mean sea level
mbgl = metres below ground level
Mg = Magnesium
mg/l = milligram per litre
Mn = Manganese
n.a. = not analysed
Na = Sodium
Ni = Nickel
NO_3 = Nitrate
PAH = Poly Aromatic Hydrocarbons
Pb = Lead
ppm = parts per million
RBCA = Risk Based Corrective Actions
RBSL = Risk Based Screening Levels
Se = Selenium
Si = Silica
SO_4 = Sulphate
SSL = Soil Screening Level
SWL = Static Water Level
TDS = Total Dissolved Solids
Zn = Zinc

1 INTRODUCTION

Geo Pollution Technologies (Pty) Ltd (GPT) was appointed by Geovicon to conduct a hydrogeological impact study at the proposed underground mining of Brown Shaft 2 Goedehoop North Colliery on the farm Wolvenfontein 471JS located approximately 25km south of the town Middelburg in Mpumalanga Province.

This report is not intended to be an exhaustive description of the proposed project, but rather as a specialist geohydrological impact study to evaluate the site, the likely impacts of the proposed mining activity on the groundwater regime and how any negative impacts should be managed.

This geohydrological study aims to contain and relate the following objectives:

- Description of the pre-mining geohydrological environment.
- Prediction of the environmental impact of the proposed mining activity on the geohydrological regime of the area. This includes the description of possible negative impacts during mining, construction, decommissioning and after closure.
- Forecasting the effect of the underground on the receiving environment.
- Compilation of all the relevant data and recommendations in a geohydrological report, structured in such a way that it can be incorporated into the final Environmental Management Program document.

Please note: The report intends to predict on the local impacts of the proposed underground mining at Brown Shaft 2 and is based on the available data at the time, it does not intend to predict the cumulative impacts of mining activities on a regional scale. However the data generated in this study could be used in a regional study if required.

2 SCOPE OF WORK

The following work program was envisaged in order to adhere to the scope of work:

- Detailed site inspection, mapping of relevant geohydrological features and gathering of existing information from topographical maps, ortho-photos, geological maps, hydrological information, meteorological information, previous groundwater studies in the area, discussions with relevant mine personnel, etc.
- Execution of a borehole/spring census in the area to assess groundwater utilisation by neighbours. Based on the information, gathered during the hydrocensus, the groundwater potential (quality & quantity) of the area will be evaluated. The data gathered during this phase will assist in the development of a groundwater-monitoring program. If suitable boreholes exist in the study area they will be incorporated into the monitoring program.
- Groundwater flow and transport modelling to predict the long term impacts on the receiving environment. The impacts, associated with mining activities, can normally be subdivided into two aspects, namely the de-watering of the surrounding aquifer system and the deterioration of the water quality in the receiving aquifer system. Both these aspects will be addressed.
- Inflow into the mining areas from groundwater and from recharge zones will be calculated. This underground water balance will also address possible decanting over time.
- Geochemical interpretation of material associated with the coal seams and overburden will also be undertaken in this study, if exploration drilling cores can be supplied by the mining company.
- Available data will be interpreted and collated for the prediction of the possible environmental impact and to design mitigation measures.

- Recommendation of a groundwater monitoring network will be made and standard operational procedures for groundwater monitoring and management supplied.
- Monitoring boreholes areas will be identified which can then be sited by geophysical means after the most likely spread of the pollution plumes have been established.
- The report will be discussed with the client and authorities.

The product of this investigation will be a report, with the following aspects addressed:

- Prediction of the environmental impacts as described above, with specific reference to the possible impact on the surface- and groundwater regimes.
- Description of alternative mitigation measures
- The compilation of a geohydrological report.

3 METHODOLOGY

The impact of the proposed underground mining areas was investigated through field investigations, data analyses and the use of numerical models (flow and transport models). The work completed for the purposes of compiling a geohydrological report comprised the following:

3.1 Desk Study

A complete desk study was conducted, entailing the gathering of information from the relevant topographical maps (1:50 000-scale 2629AB and BA, 2529CD and DC Topographic Sheet), geological map (1:250 000 2528 Pretoria Geological Sheet) and Geohydrological map (Groundwater Resources of South Africa Sheets 1 and 2).

A simplistic mine layout plan was made available at the time of this study. Meteorological information was obtained from the Department of Water Affairs (DWA) Hydrological Services. The desk study also included the gathering of available information from previous geohydrological reports and studies done by GPT in the vicinity for the Brown Shaft 2 and Black Wattle Collieries.

3.2 Hydrocensus

A detailed hydrocensus was conducted on and around the site to a distance of about two kilometres so as to obtain a representative population of the boreholes in the area. During the hydrocensus, all available details of boreholes and borehole-owners were collected and included in the hydrocensus forms. Water samples were collected from boreholes as described in the relevant paragraph below. Information was collected on the use of the boreholes in the area, the water levels and yields of boreholes, etc. The information can be used to assess the risk which potential groundwater pollution poses to groundwater users.

3.3 Sampling and Chemical Analysis

Groundwater was sampled according to the GPT Standard Operating Procedure[1] for groundwater samples by bailing. In summary, the procedure is to measure the groundwater level before introducing any equipment in the borehole. Pump samples were collected from boreholes with restricted access by purging the hole for a period to ensure that a representative sample of the aquifer is obtained. The groundwater samples were contained in pre-cleaned one litre plastic bottles. All samples were kept on ice or in a refrigerator until delivered to a laboratory.

A total of 9 hydrocensus boreholes were sampled during the hydrocensus of July 2012. The water samples were sent to UIS analytical laboratory in Pretoria for major ion analysis to determine water quality in the area.

3.4 Recharge Calculation

The groundwater recharge was estimated using the RECHARGE program[2], which includes using qualified guesses as guided by various schematic maps. The following methods/sources were used to estimate the recharge:

- Soil information

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[1] Available on request from morne@gptglobal.com

[2] Gerrit van Tonder, Yongxin Xu: RECHARGE program to Estimate Groundwater Recharge, June 2000. Institute for Groundwater Studies, Bloemfontein RSA.

- Geology
- Groundwater Recharge Map (Vegter)
- Acru Recharge Map (Schulze)
- Harvest Potential Map
- Chloride (Cl) method

The above-mentioned programme incorporates all the different methods to calculate recharge. The following assumptions are necessary for successful application of the Cl Method:

- There is no source of chloride in the soil water or groundwater other than that from precipitation
- Chloride is conservative in the system
- Steady-state conditions are maintained with respect to long-term precipitation and chloride concentration in that precipitation, and in the case of the unsaturated zone
- A piston flow regime, which is defined as downward vertical diffuse flow of soil moisture, is assumed.

3.5 Slug tests

In hydrogeology, a slug test is a controlled field experiment in which the water level in a control well is caused to change (rise or fall) instantaneously and the subsequent water level response (displacement from static) is measured in the borehole through time. The goal of a slug test, as in any aquifer test, is to gain an estimate into the hydraulic properties of the aquifer system such as hydraulic conductivity

3.6 Numerical Modelling

The finite difference numerical model was created using the US Department of Defence Groundwater Modelling System (GMS8.2) as Graphical User Interface (GUI) for the well-established Modflow and MT3DMS numerical codes.

MODFLOW is a 3D, cell-centred, finite difference, saturated flow model developed by the United States Geological Survey. MODFLOW can perform both steady state and transient analyses and has a wide variety of boundary conditions and input options. It was developed by McDonald and Harbaugh of the US Geological Survey in 1984 and underwent several overall updates since. The latest update (Modflow 2000) incorporates several improvements extending its capabilities considerably, the most important being the introduction of the new package called the Layer-Property Flow Package.

MT3DMS is a 3-D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3DMS uses a modular structure similar to the structure utilized by MODFLOW, and is used in conjunction with MODFLOW in a two-step flow and transport simulation. Heads are computed by MODFLOW during the flow simulation and utilized by MT3DMS as the flow field for the transport portion of the simulation.

4 REGIONAL SITE INFORMATION

The proposed underground mining is located on Anglo Coal's Goedehoop North Colliery (Wolvenfontein 471JS). Goedehoop North is situated approximately 25km south of the town of Middelburg in Mpumalanga. The locality map is shown in Figure 1.

4.1 Climate

Climatic data was obtained from the DWA weather station for the Rondebosch area at the Middelburg Dam, Mpumalanga (Table 1)[3].The proposed site is located in the summer rainfall region of Southern Africa with precipitation usually occurring in the form of convectional thunderstorms. The average annual rainfall (measured over period of 29 years) is approximately 656.9mm, with the high rainfall months between October and March.

Table 1: Climatic Data for the Middelburg Area

Month	Average Monthly Rainfall (mm)	Mean Monthly Evaporation
January	111.3	198.8
February	87.0	175.1
March	74.0	163.4
April	28.3	130.2
May	10.3	107.4
June	7.4	83.2
July	3.6	92.0
August	8.8	127.6
September	20.9	171.4
October	76.0	193.7
November	107.9	192.0
December	119.9	199.1
Annual	656.9	1797.8

4.2 TOPOGRAPHY AND DRAINAGE

The topography (Figure 2: Topographical Map) can normally be used as a good first approximation of the hydraulic gradient in an unconfined aquifer. This discussion will focus on the slope and direction of fall of the area under investigation, features that are important from a groundwater point of view.

Slopes of less than 1:40 (<0.025) occur throughout the site. Surface drainage from the proposed underground is in a north easterly direction, towards the unnamed tributary of the Spookspruit flowing north. Some perennial and non-perennial surface water bodies (mainly recreational and agricultural dams) are found inside a 2 km radius of the site.

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[3] Department of Water Affairs (DWA): www.dwa.gov.za

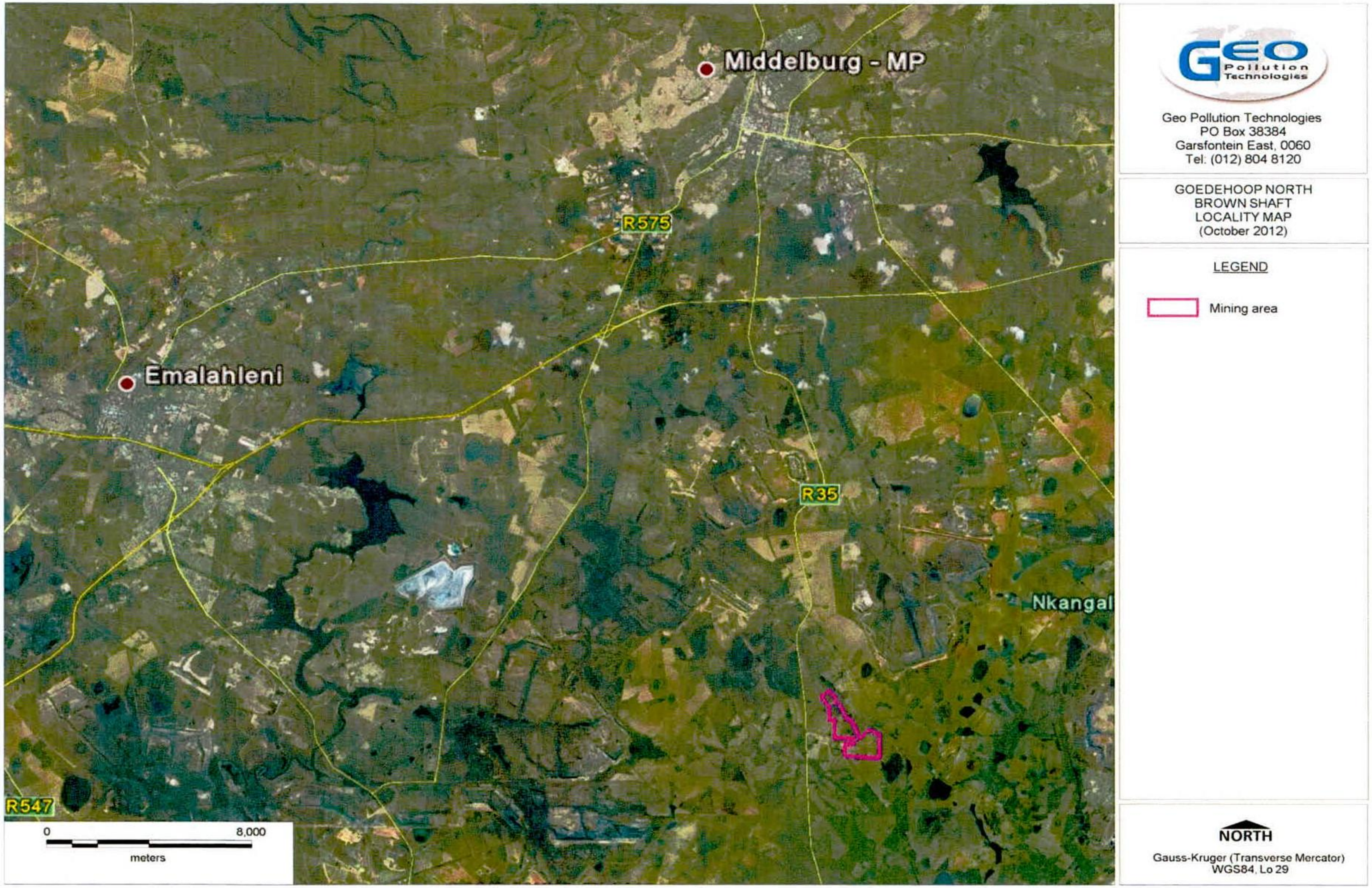


Figure 1: Locality Map

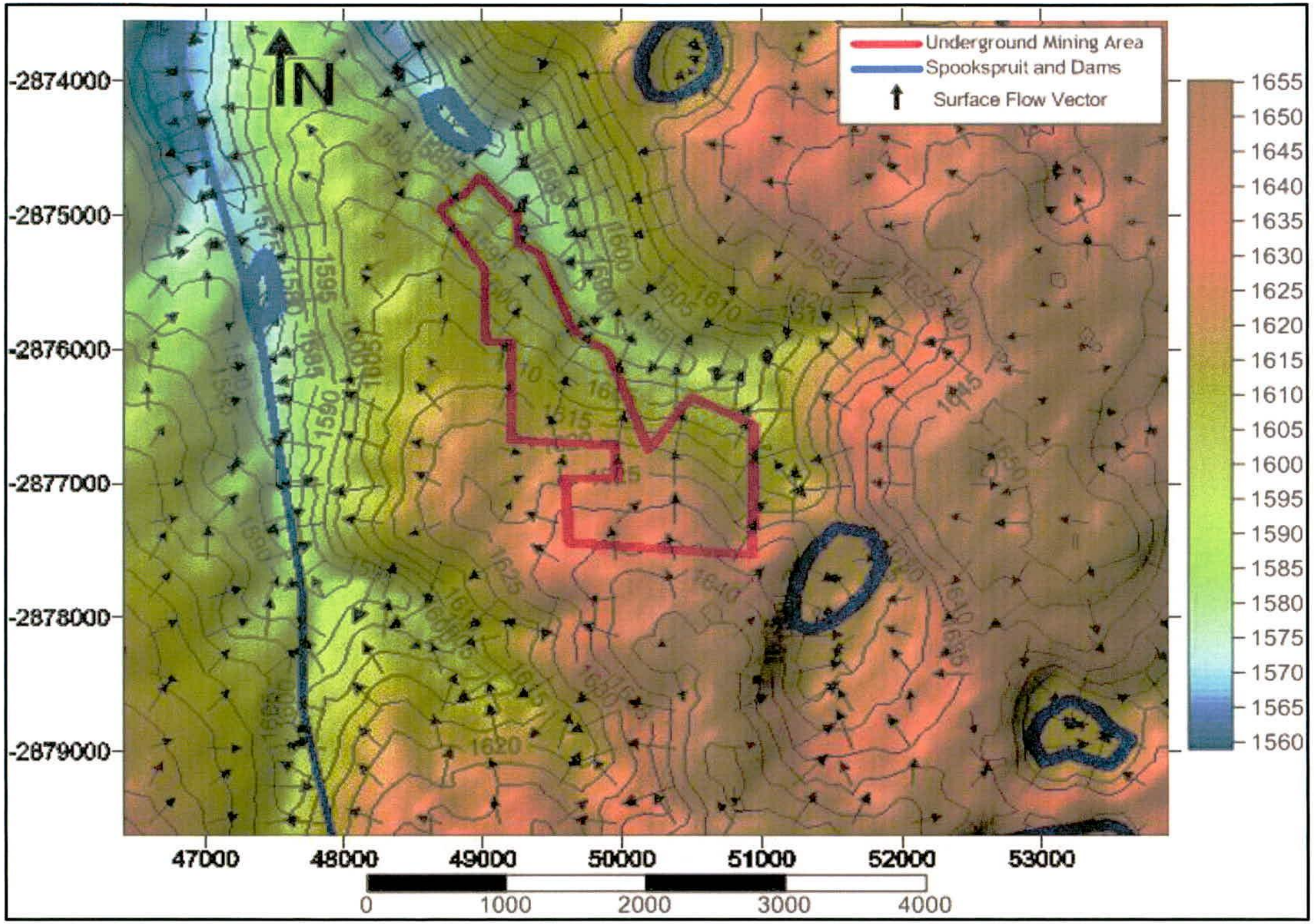


Figure 2: Topographical Map

5 PREVAILING GROUNDWATER CONDITIONS

Most mines and mining-related activities impact on groundwater quality and quantity. Quantification of such impacts on the groundwater regime requires knowledge of the pre-mining environment.

The purpose of this section is to describe the pre-mining environment; thus the current prevailing groundwater conditions. This will serve as a reference baseline for quantifying potential mining impacts on the existing groundwater regime. In this case, however, the area under investigation cannot be classified as a pristine pre-mining environment due to current underground and historic underground mining activities of the Goedehoop Colliery and Banks Colleries.

5.1 Geology

5.1.1 Regional Geology

According to the 2528 Pretoria 1:250 000 geology series map the site is situated on Permian (245 000 - 290 000 million years) sandstone, shale and coal beds of the Vryheid Formation of the Ecca Group, Karoo Supergroup (Figure 3). Jurassic (145 000 - 208 000 million years) dolerite sills intruded into the older sediments through vertical feeder dykes. Quaternary surficial deposits of alluvium and ferricrete can be found throughout the site.

The Ecca Group, which is part of the Karoo Supergroup, comprises of sediments deposited in shallow marine and fluvial-deltaic environments with coal accumulated as peat in swamps and marshes associated with these environments. The sandstone and coal layers are normally reasonable aquifers, while the shales tend to act as aquitards. Several layered aquifers perched on the relative impermeable shale are common in such sequences. The generally horizontally deposited sediments of the Karoo Supergroup are typically undulating with a gentle regional dip to the south. The extent of the coal is largely controlled by the pre-Karoo topography. Steep dips can be experienced where the coal buts against pre-Karoo hills. Displacements, resulting from intrusions of dolerite sills, are common.

Abundant dolerite intrusions are present in the Ecca sediments. These intrusions comprise sills, which vary from being concordant to transgressive in structure, and feeder dykes. Although these structures serve as aquitards and tend to compartmentalise the Karoo aquifers, the contact zones with the pre-existing geological formations also serve as groundwater conduits. There are common occurrences of minor slips or faults, particularly in close proximity to the dolerite intrusions. Within the coalfield, these minor slips, displacing the coal seam by a matter of 1 to 2 metres, are likely to be commonplace.

5.1.2 Local Geology

The local geology was concluded from information obtained from an exploration borehole log CBC0021 for the Goedehoop North Colliery. The lithology is best observed in the logs of boreholes drilled at higher elevations, where all coal seams have been encountered. The No 4 coal seam is the highest minable coal seam in this concession. It is overlain by shale, sandstone, siltstone and mudstone of variable thickness, depending on elevation. A generalised geological stratigraphy (Table 2) was derived from borehole log CBC0021, which was obtained from the colliery management.

Table 2: Generalised Geological Stratigraphy

AVERAGE DEPTH (MBGL)	AVERAGE THICKNESS (METRES)	DESCRIPTION
0 - 10.72	10.72	Soil at surface brown, silty
10.72 - 12.00	1.28	Clay, yellowish brown
12.00 - 21.45	9.45	Sandstone, grey, fine grained
21.45 - 29.00	7.55	Sandstone, grey, medium to fine grained
29.00 - 31.8	2.80	Grit, greyish green, massive
31.8 - 34.01	2.21	Sandstone and siltstone finely banded
34.01 - 35.08	**1.07**	**Coal No. 4 a Seam**
35.08 - 35.52	0.44	Sandstone, grey, medium grained
35.52 - 37.70	2.18	Coal No. 4 Upper Seam
37.70 - 38.85	1.15	Siltstone, balck, micaseous
38.85 - 40.88	2.03	Sandstone/Silstone finely banded
40.88 - 41.25	0.37	Sandstone, grey, course to medium grained, finely bedded with bands of siltstone
41.25 - 44.05	**2.80**	**Coal No. 4 Seam**
41.05 - 44.20	0.15	Sandstone, grey, finely grained, micaceous
44.20 - 47.80	3.60	Sandstone, white, course grained, feldspathic
47.8 - 52.17	4.37	Sandstone, greyish white, medium grained, finely bedded siltstone, becomes laminanted
52.17 - 54.17	2.00	Sandstoene, grey, fine grained, finely bedded with grit partings
54.17 - 58.75	4.58	Siltstone, black, finely bedded with thin sandstone partings
58.75		End of Hole

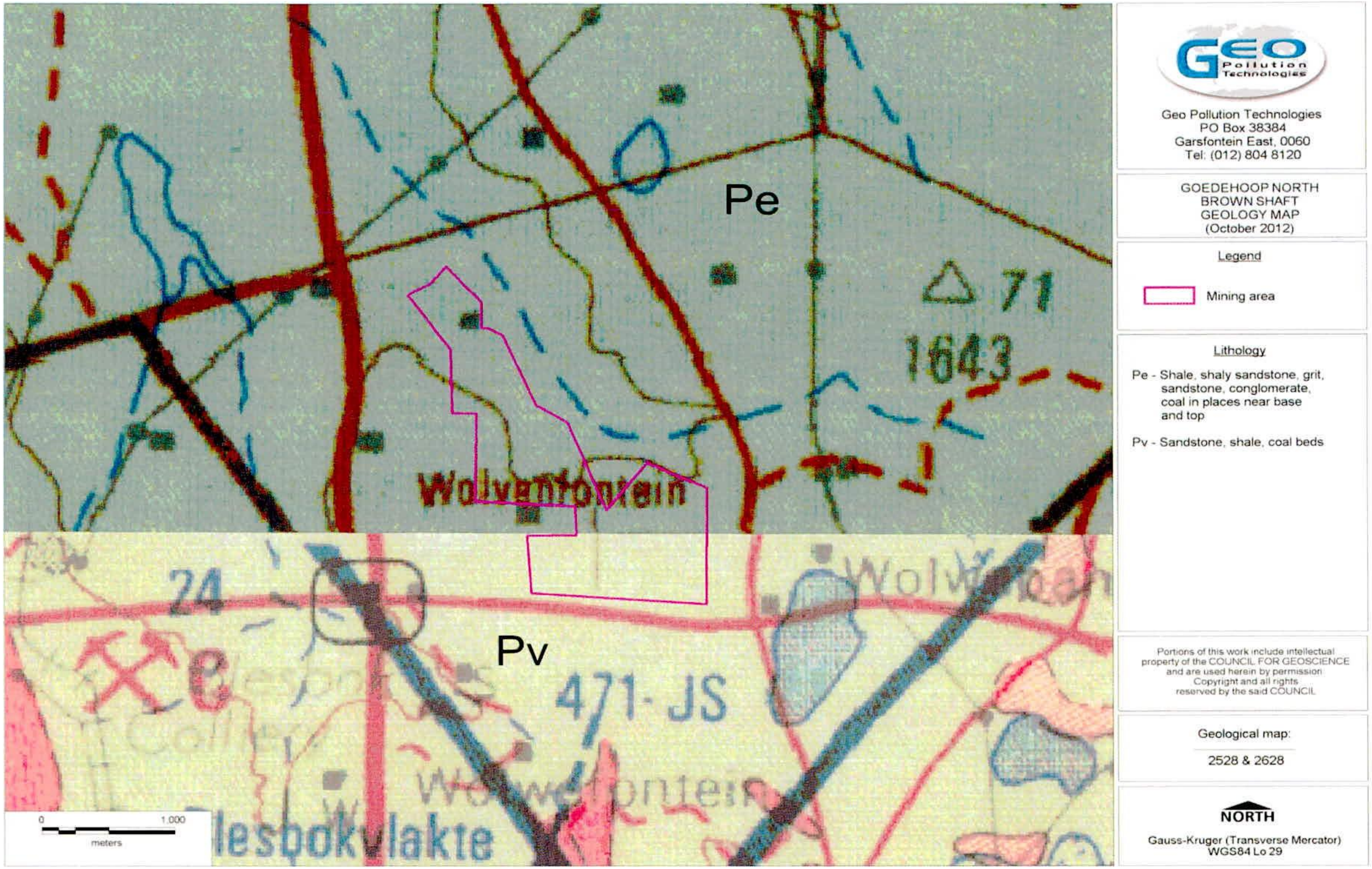


Figure 3: Geology Map

5.2 Hydrogeology

5.2.1 Regional Hydrogeology

According to the 1:50 000 General hydrogeological Map (Johannesburg 2526) groundwater resources are widespread but limited with borehole yields generally between 0.1 and 0.5l/s. Groundwater occurrence is better developed along aquifers associated with the contact zones of the dolerite intrusions where yields of 0.5 - 2.0 l/s are likely to occur. The aquifer represents important source for base flow into the streams draining the area. The hydrogeology of the area can be described in terms of the saturated and unsaturated zones. From the previous studies, the summary below of the aquifer system is given.

The aquifer represents an important source for base flow into the streams draining the area. The hydrogeology of the area can be described in terms of the saturated and unsaturated zones:

5.2.1.1 Saturated Zone

In the saturated zone, at least four aquifer types may be inferred from knowledge of the geology of the area:

- A shallow aquifer formed in the weathered zone, perched on the fresh bedrock.
- An intermediate aquifer formed by fracturing of the Karoo sediments.
- Aquifers formed within the more permeable coal seams and sandstone layers.
- Aquifers associated with the contact zones of the dolerite intrusives.

Although these aquifers vary considerably regarding geohydrological characteristics, they are seldom observed as isolated units. Usually they would be highly interconnected by means of fractures and intrusions. Groundwater will thus flow through the system by means of the path of least resistance in a complicated manner that might include any of these components.

5.2.1.2 Shallow perched aquifer

A near surface weathered zone is comprised of transported colluvium and *in-situ* weathered sediments and is underlain by consolidated sedimentary rocks (sandstone, shale and coal). Groundwater flow patterns usually follow the topography, often coming very close to surface in topographic lows, sometimes even forming natural springs. Experience of Karoo geohydrology indicates that recharge to the perched groundwater aquifer is relatively high, up to 3% of the Mean Annual Precipitation (MAP).

5.2.1.3 Fractured Karoo rock aquifers

The host geology of the area consists of consolidated sediments of the Karoo Supergroup and consists mainly of sandstone, shale and coal beds of the Vryheid Formation of the Ecca Group. Most of the groundwater flow will be along the fracture zones that occur in the relatively competent host rock. The geology map does not indicate any major fractures zones in this area, but from experience it can be assumed that numerous major and minor fractures do exist in the host rock. These conductive zones effectively interconnect the strata of the Karoo sediments, both vertically and horizontally into a single, but highly heterogeneous and anisotropic unit

5.2.1.4 Aquifers associated with coal seams

The coal seam forms a layered sequence within the hard rock sedimentary units. The margins of coal seams or plastic partings within coal seams are often associated with groundwater. The coal itself tends to act as an aquitard allowing the flow of groundwater at the margins.

5.2.1.5 Aquifers associated with dolerite intrusives

Dolerite intrusions in the form of dykes and sills are common in the Karoo Supergroup, and are often encountered in this area. These intrusions can serve both as aquifers and aquifuges. Thick, unbroken dykes inhibit the flow of water, while the baked and cracked contact zones can be highly conductive. These conductive zones effectively interconnect the strata of the Ecca sediments both vertically and horizontally into a single, but highly heterogeneous and anisotropic unit on the scale of mining. These structures thus tend to dominate the flow of groundwater. Unfortunately, their location and properties are rather unpredictable. Their influence on the flow of groundwater is incorporated by using higher than usual flow parameters for the sedimentary rocks of the aquifer.

5.2.1.6 Unsaturated Zone

Although a detailed characterization of the unsaturated zone is beyond the scope of this study, a brief description thereof is supplied.

The unsaturated zone in the proposed mining area is in the order of between 1 and 10 metres thick (based on static groundwater levels measured in the existing boreholes) and consists of colluvial sediments at the top, underlain by residual sandstone/siltstone/mudstone of the Ecca Group that becomes less weathered with depth.

5.2.2 Local Hydrogeology

Groundwater resources are spatially widespread (17 boreholes points were found in the area), but no borehole yields were reported.

5.3 Hydrocensus

A hydrocensus was conducted on and around the proposed mining site (to a distance of approximately two kilometres) during July 2012. The position of all the boreholes relative to the proposed mining area can be seen in Figure 5. A total of 14 boreholes and 3 surface water bodies and streams were identified during this hydrocensus study. The main characteristics of this data are summarized in Table 2. Although there were no privately owned boreholes identified, the area is utilized for grazing of large livestock. All the boreholes are on the mine property. Hydrocensus field forms containing details of the owner and use are attached under Appendix A and Appendix B as separate PDF-files.

5.4 Water Levels

Groundwater levels, varying between 4.31 and 88.36 mbgl, were measured in the surrounding area during the survey. The average static water level was measured to be 8.7 mbgl. These values were determined from borehole data where the owner was available on site and where it was possible to gain access to the boreholes for precise measuring of water levels.

Usually a good relationship should hold between topography and static groundwater level. This relationship can be used to distinguish between boreholes with water levels at rest, and boreholes with anomalous groundwater levels due to disturbances such as pumping or local geohydrological heterogeneities. The relationship using the boreholes from the hydrocensus is shown in Figure 4 below. It is evident that an unrealistic low groundwater level has been measured in UG2, UG3, BH20 and BHX4. Due to the presence of extensive underground mining activities in the area, these boreholes have most probably been drilled into the underground mine and are thus not representative of the general groundwater level in the area. This will most definitely lead to unrealistic water levels, as the water level in the mine is measured in such a case and not the actual groundwater level. A good correlation (98.7%) was found between the static water levels and the topography. This general relationship is useful to make a quick calculation of expected groundwater levels at selected elevations, or to calculate the depth of to the groundwater level (unsaturated zone):

Groundwater level = Elevation x 0.9874
Depth to the groundwater level = Elevation x (1 - 0.9874)
= Elevation x 0.0126

However, due to the heterogeneity of the subsurface, these relationships should not be expected to hold everywhere under all circumstances, and deviations could thus be expected. The calibrated static water levels as modelled have been contoured and are displayed in Figure 6. Groundwater flow direction should be perpendicular to these contours and inversely proportional to the distance between contours. Using this relationship, the inferred groundwater flow directions are depicted as Figure 7 below. As can be expected, the groundwater flow is mainly from topographical high to low areas, eventually draining to local streams.

These static water levels were also subtracted from the elevations to determine the unsaturated aquifer thicknesses of different points over the study area. These values are intrinsically the same as the depth to the natural groundwater level measured from the surface. The average depth to the groundwater levels in the fractured aquifer in the proposed mining area are 8 meters.

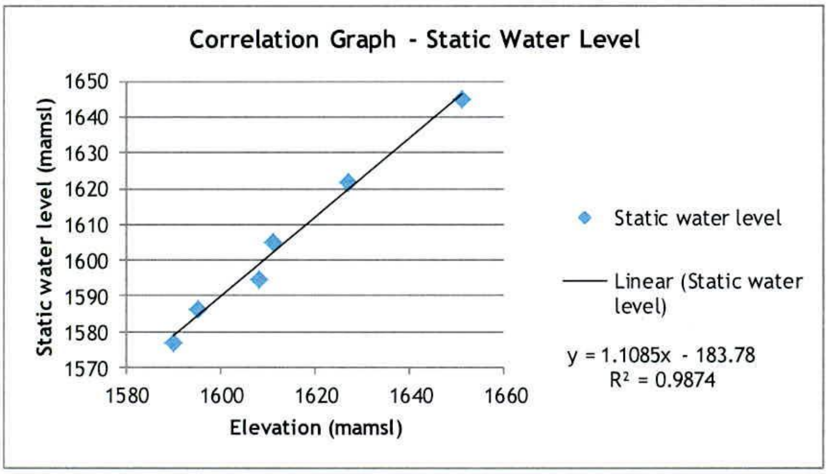


Figure 4: Correlation Graph

This general relationship is useful to make a quick calculation of expected groundwater levels at selected elevations, or to calculate the depth of to the groundwater level (unsaturated zone):

Groundwater level = Elevation x 0.9542
Depth to the groundwater level = Elevation x (1 - 0.9542)
= Elevation x 0.0458

However, due to the heterogeneity of the subsurface, these relationships should not be expected to hold everywhere under all circumstances, and deviations could thus be expected.

The calibrated static water levels as modelled have been contoured and are displayed as Figure 6. Groundwater flow direction should be perpendicular to these contours and inversely proportional to the distance between contours. Using this relationship, the inferred groundwater flow directions are depicted as Figure 7 below. As can be expected, the groundwater flow is mainly from topographical high to low areas, eventually draining to local streams. These static water levels were also subtracted from the elevations to determine the unsaturated aquifer thicknesses of different points over the study area. These values are intrinsically the same as the depth to the natural groundwater level measured from the surface, and are presented graphically in **Error! Reference source not found.**. The average depth to the groundwater level in the fractured aquifer in the proposed mining area is in the order of 5 meters.

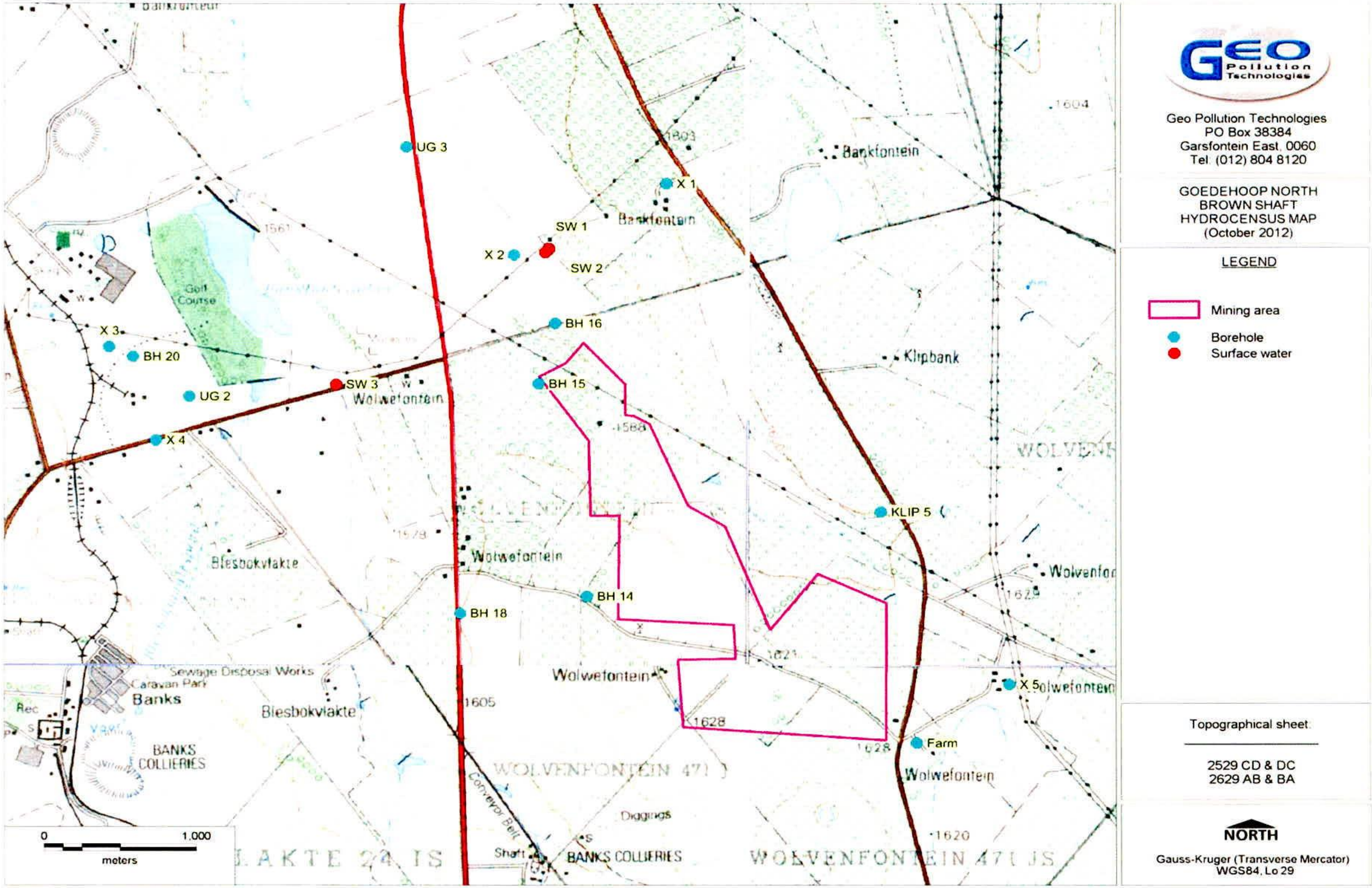


Figure 5: Positions of Hydrocensus Monitored Points

Table 3: Hydrocensus and Borehole Information

Sample ID	Latitude	Longitude	Property	Owner	Water level	Use	Comments
BH 14	-25.99621	29.48936	Wolvenfontein 471 JS	Bank Colliery	5.37	Not in use	
BH 15	-25.98255	29.48617			8.78	Not in use	
BH 16	-25.97866	29.48723			13.13	Not in use	
BH 18	-25.99733	29.48113			13.435	Not in use	
BH 20	-25.98090	29.45963			33.97	Not in use	Slugtest done.
Farm	-26.00554	29.51077	Wolvenfontein 471 JS	SIS Farming (Danie Pienaar)	No access	Not in use	Borehole blocked.
KLIP 5	-25.99071	29.50839	Wolvenfontein 471 JS	SIS Farming (Danie Pienaar)	4.31	Not in use	
X 1	-25.96968	29.49443	Bankfontein 340 JS	Mining area	0	Not in use	Borehole blocked.
X 2	-25.97428	29.48454		Mining area	0	Not in use	Borehole blocked.
X 3	-25.98026	29.45805		Mining area	5.81	Not in use	Drilled in 2005, 40 m deep.
X 4	-25.98627	29.46115		Mining area	88.36	Not in use	
X 5	-26.00177	29.51679	Wolvenfontein 471 JS	SIS Farming (Danie Pienaar)	5.93	Not in use	Borehole was equipped with a wind pump in the past.
UG 2	-25.98344	29.46333	Bankfontein 340 JS	Mining area	63.09	Not in use	
UG 3	-25.96739	29.47744			28.94	Not in use	
SW 1	-25.97388	29.48680			-	Maybe domestic	Zinc dam
SW 2	-25.97410	29.48657			-	Livestock watering, irrigation	Dam
SW 3	-25.98265	29.47291			-	Not in use	Stream

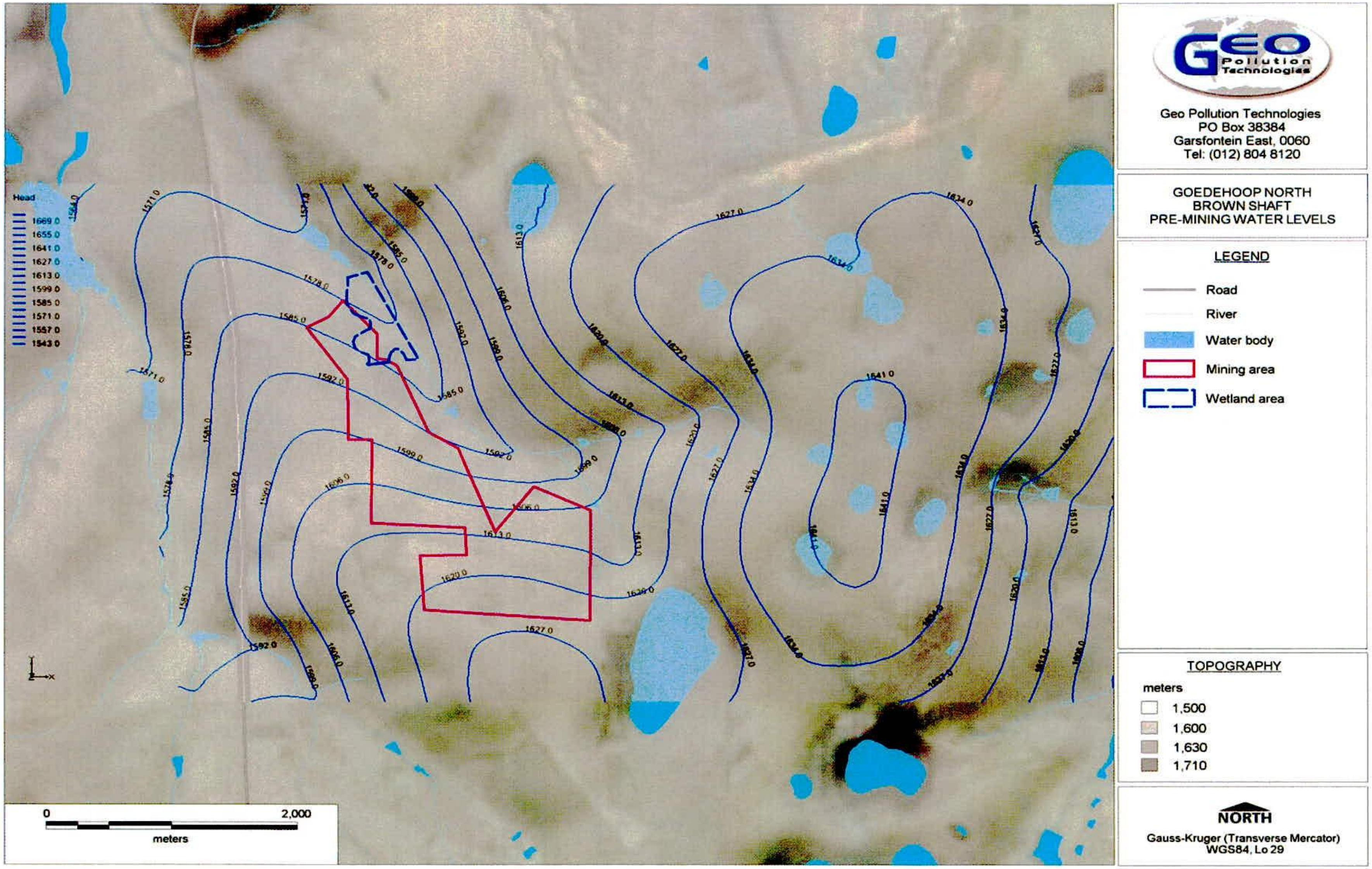


Figure 6: Static Groundwater Levels - Pre mining

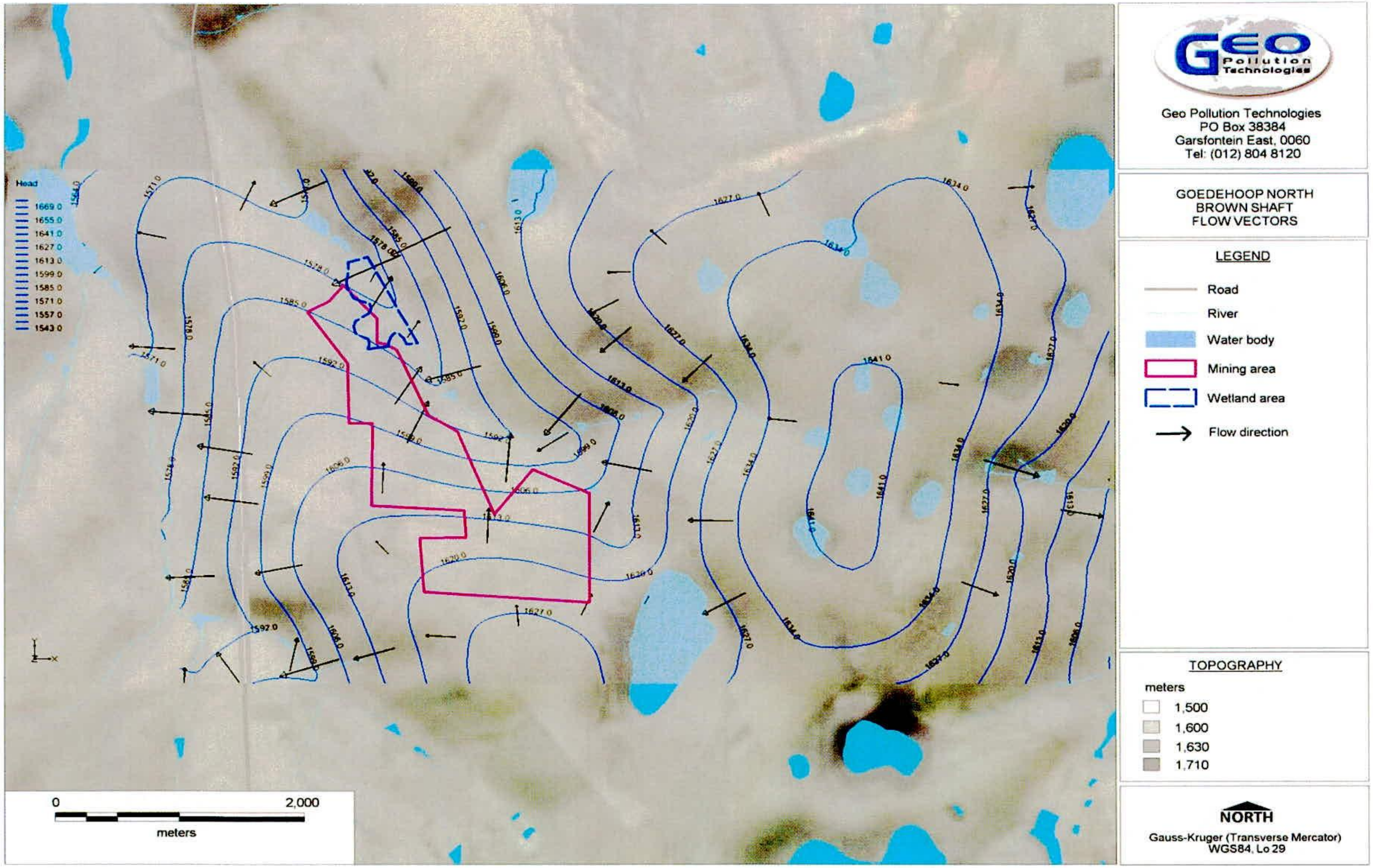


Figure 7: Groundwater Flow Directions - Pre mining

5.5 Water Quality

Seventeen (17) water samples were collected from hydrocensus boreholes, streams and open pits around the site during the investigation. The samples were submitted for major cation and anion analyses to determine water quality in the area. The groundwater results are compared with the maximum recommended concentrations for domestic use. The DWAF guidelines are classified as:

- Class 0 which is ideal concentrations
- Class I which is considered as acceptable
- Class II which stipulates the maximum allowable concentration of the water constituent, which can be tolerated only for a limited period.

The results from these analyses were plotted as Pie diagrams (circular graphs as in Figure 10), Stiff diagrams (Figure 11) and a piper diagram (Figure 12). The laboratory certificate of analyses and monitoring data can be seen attached as a separate Appendix B.

The pie diagrams show both the individual ions present in a water sample and the total ion concentrations in meq/L or mg/L. The scale for the radius of the circle represents the total ion concentrations, while the subdivisions represent the individual ions. It is very useful in making quick comparisons between waters from different sources and presents the data in a convenient manner for visual inspection.

A Stiff pattern is basically a polygon created from four horizontal axes using the equivalent charge concentrations (meq/L) of cations and anions. The cations are plotted on the left of the vertical zero axis and the anions are plotted on the right. Stiff diagrams are very useful in making quick comparisons between waters from different sources.

On the piper diagram the cation and anion compositions of many samples can be represented on a single graph. Certain trends in the data can be discerned more visually, because the nature of a given sample is not only shown graphically, but also show the relationship to other samples. The relative concentrations of the major ions in mg/L are plotted on cation and anion triangles, and then the locations are projected to a point on a quadrilateral representing both cation and anions.

5.5.1 Groundwater

In general the groundwater is of good quality for most parameters analysed with exceptions of Ca, Mn, Fe F SO_4 and TDS in some samples. Sulphates are within the target quality water range for the majority of the samples, although high sulphate values were observed in borehole UG3, where an elevated concentration was observed.

The major anion constituting the groundwater composition can be observed to be bicarbonate in Figure 10. It can also be seen from this figure that a general tendency of higher sulphates exists around the existing Goedehoop mine. Most boreholes located down-gradient and around the proposed shaft area show groundwater compositions that are of a good quality, with no signs of impact by ARD. However, the boreholes BH14, BH15, BH16, BH18 and KLIP5 located around the proposed underground mining area are likely to be impacted by ARD, given the neutral pH value of the groundwater and likely insufficient carbonate buffering capacity as illustrated in UG3 where bicarbonate has been depleted by sulphate.

Neutral to slightly acidic pH values can be seen in all boreholes. These pH levels may be attributed to the buffering of acid rock drainage (ARD) by the local carbonate rich geology. The ARD process is discussed in more detail in forthcoming paragraphs.

The elevated metal concentrations (Fe and Mn) in numerous boreholes (BH15, BH16, BH18, BH20, KLIP5, UG3, X3 and X5) are at predominantly at Class II level according to the DWAF standards, with UG3 exceeding the maximum allowable limit for Mn. The cause of this exceedance in Mn concentration can be attributed to an initially lowered pH value. At low pH's certain metals become soluble in water and thus can be attributed to the formation of ARD in the vicinity.

From Figure 11 it can be seen that water in the area has a very similar signature with sulphates causing a single anomaly in the stiff diagram of UG3. The boreholes BH16, BH18, BH20, X3 and X5 have a Ca-HC03 signature, while BH14, BH15 and KLIP5 display a mixed signature between Ca-HCO3 and Na-HCO3 indicating a mixing of younger, fresh groundwater and deep, The groundwater around the proposed mine generally has a low alkalinity and therefore a low buffer capacity.

Table 4: Results of Major Cation and Anion Analyses

Sample Nr.	BH14	BH15	BH16	BH18	BH20	KLIP5	UG3	X3	X5	Class 0 (ideal)	Class I (acceptable)	Class II (maximum)
Ca	12.40	5.45	27.50	52.60	39.80	9.61	242.00	9.17	52.40	< 80	80 - 150	150 - 300
Mg	3.62	2.70	11.50	24.90	20.70	7.90	61.60	5.92	26.90	< 30	30 - 70	70 - 100
Na	21.20	8.67	12.10	38.40	60.60	17.20	41.10	11.10	14.00	< 100	100 - 200	200 - 400
K	3.11	2.97	3.79	11.10	5.98	4.44	7.49	2.74	7.79	< 25	25 - 50	50 - 100
Mn	0.00	0.00	0.00	0.86	0.38	0.13	3.36	0.22	1.25	< 0.1	0.1 - 1.0	1.0 - 2.0
Fe	0.00	0.52	0.02	0.90	0.05	0.00	0.12	0.00	0.07	< 0.1	0.1 - 0.2	0.2 - 2
F	0.00	0.00	0.00	0.46	23.60	0.00	1.13	0.00	0.00	< 1.0	1.0 - 1.5	1.5 - 3.5
NO_3	14.87	0.00	1.24	0.00	0.49	27.80	0.49	0.00	0.00	< 25	25 - 44	44 - 88
Al	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	< 0.15	0.15 - 0.5	-
HCO_3	36.59	30.48	141.00	411.66	330.02	40.24	222.78	76.50	360.61	-	-	-
Cl	34.00	6.50	8.60	18.00	11.00	30.00	28.00	7.40	6.50	< 100	100 - 200	200 - 600
SO_4	1.30	14.00	13.00	4.95	5.40	6.63	783.00	3.17	2.71	< 200	200 - 400	400 - 600
TDS by sum	122.00	60.00	158.00	406.00	348.00	136.00	1268.00	86.00	346.00	< 450	450 - 1000	1000 - 2400
M-Alk($CaCO_3$)	30.00	25.00	116.00	338.00	272.00	33.00	183.00	63.00	297.00	-	-	-
pH	6.52	6.73	7.57	7.25	7.76	6.69	7.35	7.66	7.70	6.0 - 9.0	5.0 - 9.5	4.0 - 10.0
EC	16.60	8.61	25.30	64.60	53.40	20.60	150.00	13.80	52.90	70	70 - 150	150 - 370
Cat/An Bal. %	2.46	0.02	1.56	-4.86	-4.53	-2.37	-3.91	-0.95	-4.20	-	-	-

Notes:

Class 0: Ideal quality

Class I: Target quality

Class II: Moderate effects

Exceeding maximum allowable concentration - adverse effects

na- not analysed

All concentrations are presented in mg/l, EC is presented in mS/m

0 = below detection limit of analytical technique

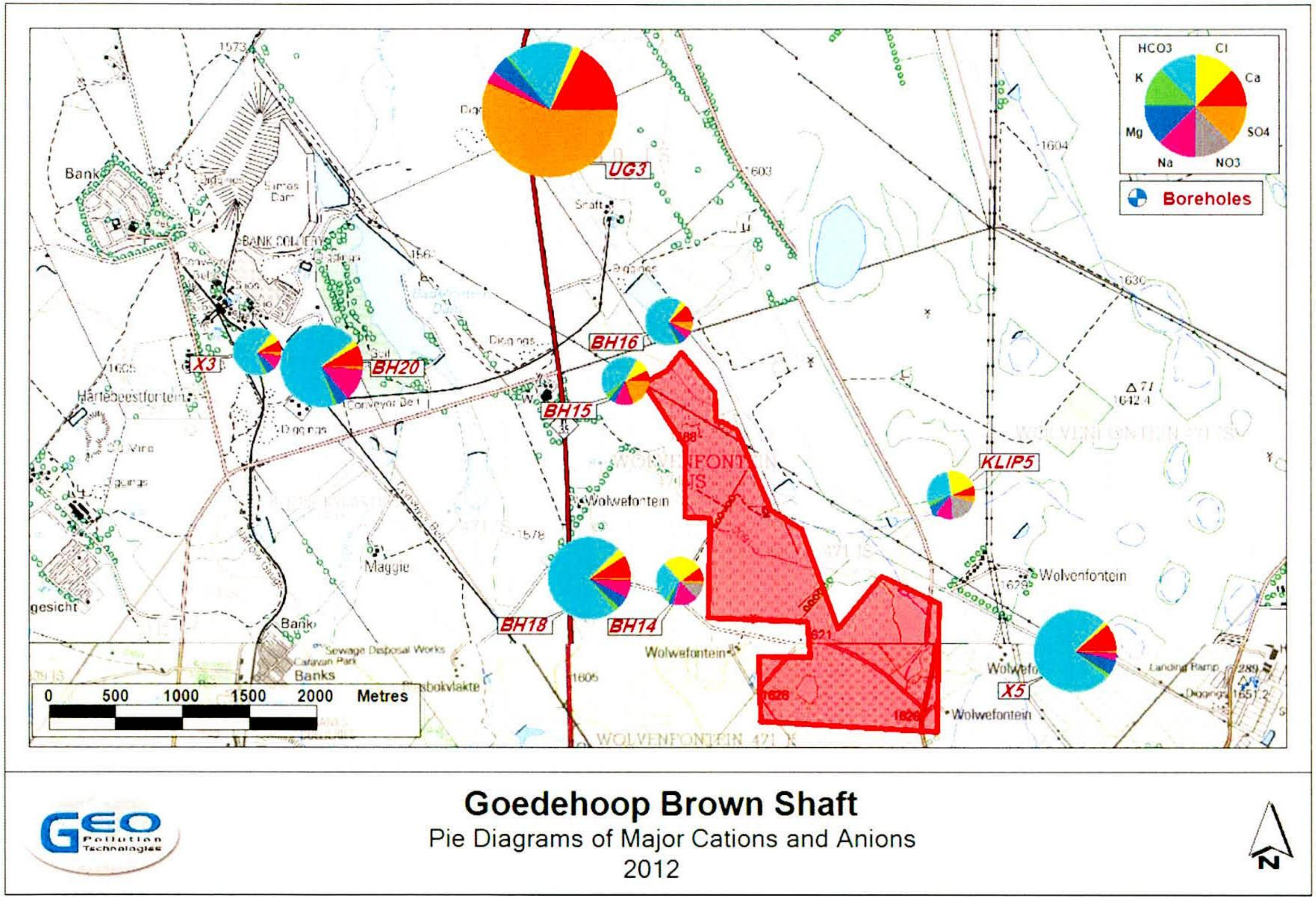
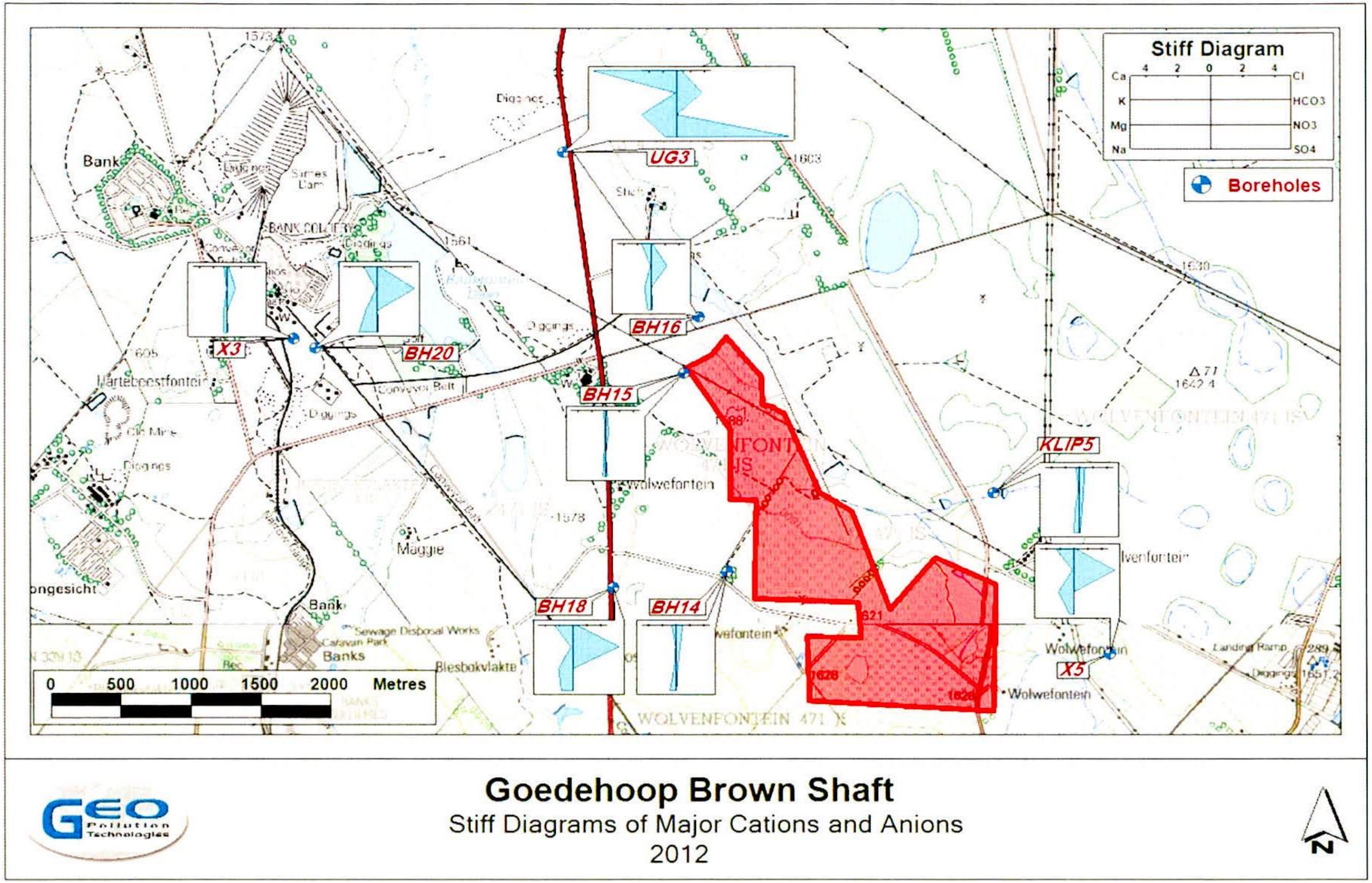


Figure 8: Pie Diagrams



Goedehoop Brown Shaft

Stiff Diagrams of Major Cations and Anions

2012

Figure 9: Stiff Diagram

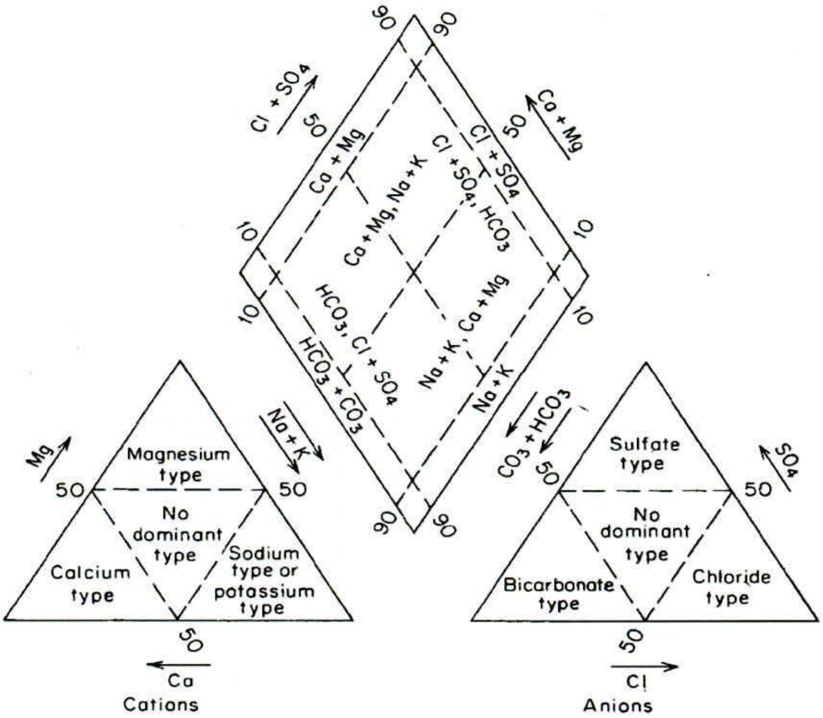


Figure 10: Piper Classification Diagram.[4]

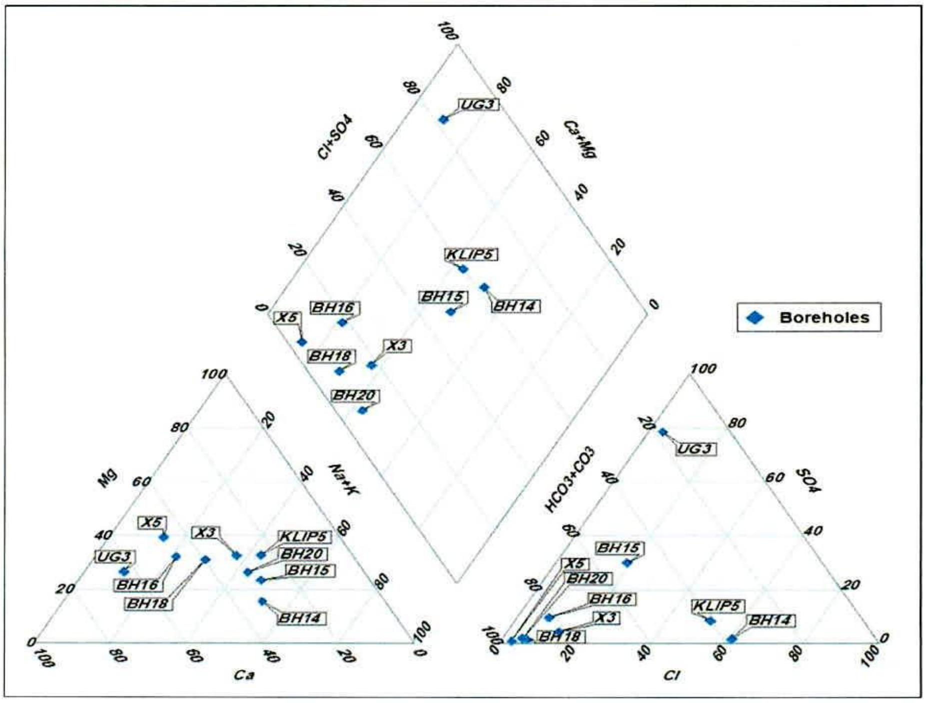


Figure 11: Piper diagram

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[4] Freeze, R. Allan, and John A. Cherry. 1979. *Groundwater*. Prentice Hall Inc, New Jersey.

5.6 Potential Contaminants

The potential contaminants associated with the mining activities may emanate from the underground mining area, crusher area, product stockpile, and pollution control dam (PCD) and R.O.M. area.

Workshops and fuel and oil handling facilities are likely sources of hydrocarbon related contaminants. Oils, grease and other hydrocarbon products (such as petrol and diesel) handled in these areas may contaminate the environment by spillages and leakages. Oils and greases are removed and collected in oil traps. Run-off (contained with hydrocarbons) which is not collected may enter the storm water system from where it may contaminate surface water bodies and groundwater. Septic tanks and sewage treatment plants potentially contaminate groundwater. Contaminants associated with these plants include coliforms (e.g. E.coli), bacteria viruses, ammonia, phosphate, sulphate and nitrate. Effluent from these systems usually contains elevated concentrations of organic matter which may lead to elevated COD and BOD. Waste disposal areas may source a wide range of contaminants, ranging from metals, organic matter, hydrocarbons, phosphates, etc.

Sulphate is probably the most reliable indicator of pollution emanating from coal mining. Sulphate concentrations can however increase due to mobilisation during the mining process. The chemistry analyses supplied within this report should henceforth serve as baseline water quality throughout the life of the proposed mining operations. The following few paragraphs contains a brief overview of acid mine drainage (AMD) formation.

The reactions of acid and sulphate generation from sulphide minerals are discussed according to the three stage stoichiometric example of pyrite oxidation after James, (1997) and (Ferguson & Erickson, 1988) in which one mole of pyrite oxidized forms two moles of sulphate:

Reaction (2.1) represents the oxidation of pyrite to form dissolved ferrous iron, sulphate and hydrogen. This reaction can occur abiotically or can be bacterially catalysed by *Thiobacillus ferrooxidans*.

$$FeS_2 + 7/2\ O_2 + H_2O \ \square\ Fe^{2+} + 2SO_4^{2-} + 2H^+ \qquad (2.1)$$

The ferrous iron, (Fe^{2+}) may be oxidised to ferric iron, (Fe^{3+}) if the conditions are sufficiently oxidising, as illustrated by reaction (2.2). Hydrolysis and precipitation of Fe^{3+} may also occur, shown by reaction (2.3). Reactions (2.1), (2.2) and (2.3) predominate at pH > 4.5.

$$e^{2+} + 1/4O_2 + H^+ \ \square\ Fe^{3+} + 1/2H_2O \qquad (2.2)$$

$$Fe^{3+} + 3H_2O \ \square\ Fe(OH)_3\,(s) + 3H^+ \qquad (2.3)$$

Reactions (2.1) to (2.3) are relatively slow and represent the initial stage in the three-stage AMD formation process. Stage 1 will persist as long as the pH surrounding the waste particles is only moderately acidic (pH > 4.5). A transitional stage 2 occurs as the pH decreases and the rate of Fe hydrolyses (reaction 2.3) slows, providing ferric iron oxidant. Stage 3 consists of rapid acid production by the ferric iron oxidant pathway and becomes dominant at low pH, where the Fe^{2+} (ferric iron) are more soluble (reaction 4):

$$FeS_2 + 14\ Fe^{3+} + 8H_2O \ \square\ 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \qquad (2.4)$$

Without the catalytic influence of the bacteria, the rate of ferrous iron oxidation in an acid medium would be too slow to provide significant AMD generation. As such the final stage in the AMD generation process occurs when the catalytic bacteria *Thiobacillus ferrooxidans* have become established. Reactions (2.2) and (2.4) then combine to form the cyclic, rapid oxidation pathway mainly responsible for the high contamination loads observed in mining environments.

According to the SANS Guidelines for Drinking Water, high concentrations of sulphate exert predominantly acute health effects. Sulphate also imparts a salty or bitter taste to water. The taste threshold for sulphate falls in the range of 200 - 400mg/L. Above 400mg/L diarrhoea occurs in most individuals and user-adaptation does not occur. It is also important to note that adverse chronic effects may occur in livestock if sulphate levels exceed 1000mg/L, such as diarrhoea and poor productivity. This contaminated water will eventually seep into the new underground areas. This potential situation should be managed during mining in order to minimise the impact on water resources.

5.7 Slug Test

Three slug tests were performed on the farms Wolvenfontein and Bankfontein during the hydrocensus of 3 July 2012. The tests were performed to obtain a localised first approximation of the hydraulic conductivity of the subsurface in order to aid in the prediction of contaminant transport from the proposed underground mining activities.

Hydraulic conductivity is the constant of proportionalitity in Darcy's Law[5]. It is defined as the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at perpendicular to the flow direction. Hydraulic conductivity provides an indication of the ease with which water moves through the subsurface and is used to calculate rates of groundwater movement.

Table 5: Slug Test Results

Borehole	Farm	Test Date	K-Value
BH16	Wolvenfontein	3 July 2012	0.5 m/d
BH18	Wolvenfontein	3 July 2012	0.7 m/d
BH20	Bankfontein	3 July 2012	unreliable

6 AQUIFER SENSITIVITY

The term aquifer refers to a strata or group of interconnected strata comprising of saturated earth material capable of conducting groundwater and of yielding usable quantities of groundwater to boreholes and /or springs (Vegter, 1994). In the light of South Africa's limited water resources it is important to discuss the aquifer sensitivity in terms of the boundaries of the aquifer, its vulnerability, classification and finally protection classification, as this will help to provide a framework in the groundwater management process.

6.1 Groundwater Vulnerability

According to Lynch et al. aquifer vulnerability is defined as the intrinsic characteristics that determine the aquifer's sensitivity to the adverse effects resulting from the imposed pollutant[6]. The following factors have an effect on groundwater vulnerability:

- Depth to groundwater: Indicates the distance and time required for pollutants to move through the unsaturated zone to the aquifer.
- Recharge: The primary source of groundwater is precipitation, which aids the movement of a pollutant to the aquifer.

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[5] Darcy's Law states that the rate of flow through a porous medium is proportional to the loss of head, and inversely proportional to the length of the flow path and is defined by the following equation

[6] The South African Groundwater Decision Tool (SAGDT), Manual Ver. 1 (Department of Water Affairs and Forestry)

- Aquifer media: The rock matrices and fractures which serve as water bearing units.
- Soil media: The soil media (consisting of the upper portion of the vadose zone) affects the rate at which the pollutants migrate to groundwater.
- Topography: Indicates whether pollutants will run off or remain on the surface allowing for infiltration to groundwater to occur.
- Impact of the vadose zone: The part of the geological profile beneath the earth's surface and above the first principal water-bearing aquifer. The vadose zone can retard the progress of the contaminants6.

The Groundwater Decision Tool (GDT) was used to quantify the vulnerability of the aquifer underlying the site. The depth to groundwater below the site was estimated from water levels measured during the hydrocensus inferred to be ~5 mbgl. A groundwater recharge of ~34.3 mm/a, a sandy clay-loam soil and a gradient of 2.5% were assumed and used in the estimation. The GDT calculated a vulnerability value of 56%, which is moderate or medium. This implies that the aquifer is reasonably sensitive to contamination and care should be taken with any activities that could generate pollutants.

6.2 Aquifer Classification

The aquifer(s) underlying the subject area were classified in accordance *with "A South African Aquifer System Management Classification, December 1995."*

The main aquifers underlying the area were classified in accordance with the Aquifer System Management Classification document[7]. The aquifers were classified by using the following definitions:

- Sole Aquifer System: An aquifer which is used to supply 50% or more of domestic water for a given area, and for which there is no reasonably available alternative sources should the aquifer be impacted upon or depleted. 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 (Electrical Conductivity of less than 150 mS/m).
- Minor Aquifer System: These can be fractured or potentially fractured rocks which do not have a high primary permeability, or other formations of variable permeability. Aquifer extent may be limited and water quality variable. Although these aquifers seldom produce large quantities of water, they are important for local supplies and in supplying base flow for rivers.
- Non-Aquifer System: These are formations with negligible permeability that are 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, although imperceptible, does take place, and needs to be considered when assessing the risk associated with persistent pollutants.

Based on information collected during the hydrocensus it can be concluded that the aquifer system in the study area can be classified as a "Minor Aquifer System", based on the fact that the local population is dependent on groundwater. Furthermore the area is characterised a number of surface water features which can be used if necessary. The aquifer is also important for supplying base flow to the rivers and streams.

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[7] Department of Water Affairs and Forestry & Water Research Commission (1995). A South African Aquifer System Management Classification. WRC Report No. KV77/95.

In order to achieve the Aquifer System Management and Second Variable Classifications, as well as the Groundwater Quality Management Index, a points scoring system as presented in Table 6 and Table 7 was used.

Table 6: Ratings - Aquifer System Management and Second Variable Classifications

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	
Major Aquifer System:	4	
Minor Aquifer System:	2	2
Non-Aquifer System:	0	
Special Aquifer System:	0 - 6	
Second Variable Classification (Weathering/Fracturing)		
Class	Points	Study area
High:	3	
Medium:	2	2
Low:	1	

Table 7: Ratings - Groundwater Quality Management (GQM) Classification System

Aquifer System Management Classification		
Class	Points	Study area
Sole Source Aquifer System:	6	
Major Aquifer System:	4	
Minor Aquifer System:	2	2
Non-Aquifer System:	0	
Special Aquifer System:	0 - 6	
Aquifer Vulnerability Classification		
Class	Points	Study area
High:	3	
Medium:	2	2
Low:	1	

As part of the aquifer classification, a Groundwater Quality Management (GQM) Index is used to define the level of groundwater protection required. The GQM Index is obtained by multiplying the rating of the aquifer system management and the aquifer vulnerability. The GQM index for the study area is presented in Table 8.

The vulnerability, or the tendency or likelihood for contamination to reach a specified position in the groundwater system after introduction at some location above the uppermost aquifer, in terms of the above, is classified as **medium** (See section 6.1).

The level of groundwater protection based on the Groundwater Quality Management Classification:

GQM Index = Aquifer System Management x Aquifer Vulnerability

= 2 X 2 = 4

Table 8: GQM Index for the Study Area

GQM Index	Level of Protection	Study Area
<1	Limited	
1 - 3	Low Level	
3 - 6	Medium Level	4
6 - 10	High Level	
>10	Strictly Non-Degradation	

6.3 Aquifer Sensitivity

A Groundwater Quality Management Index of 4 was estimated for the study area from the ratings for the Aquifer System Management Classification. According to this estimate a **medium level groundwater protection** is required for the fractured aquifer. Reasonable and sound groundwater protection measures are recommended to ensure that no cumulative pollution affects the aquifer, even in the long term.

DWA's water quality management objectives are to protect human health and the environment. Therefore, the significance of this aquifer classification is that if any potential risk exists, measures must be taken to limit the risk to the environment, which in this case is:

- The protection of the underlying aquifer (weathered & fractured)
- The Spookspruit streams/wetlands to the northeast.

7 MODELLING

It is the aim of this chapter to assess the likely hydrogeological impact that the proposed mining might have on the receiving environment. The typical mining stages that will be considered in this section are:

- Pre-Mining Phase: As the surrounding mining in the area (Banks Colliery and Goedehoop Colliery) has been in operation for many years, the groundwater condition in the area is not pristine.
- Operational Phase: This phase will be the conditions expected during the mining of the proposed underground at Brown shaft 2.
- Decommissioning Phase: The closing of mining operations, site cleanup and rehabilitation of the mining area.
- Post-mining Phase: This relates to the steady-state conditions following closure of the underground. It is assumed for the purpose of this study that the underground will be will be backfilled, rehabilitated and allowed to flood.

Numerical groundwater modelling is considered to be the most reliable method of anticipating and quantifying the likely impacts on the groundwater regime. The model construction will be described in detail in the following paragraph, followed by predicted impacts in terms of groundwater quality and quantity for all the relevant mining phases.

The finite difference numerical model was created using the US Department of Defence Groundwater Modelling System (GMS8) as Graphical User Interface (GUI) for the well-established Modflow and MT3DMS numerical codes.

MODFLOW is a 3D, cell-centred, finite difference, saturated flow model developed by the United States Geological Survey. MODFLOW can perform both steady state and transient analyses and has a wide variety of boundary conditions and input options. It was developed by McDonald and Harbaugh of the US Geological Survey in 1984 and underwent several overall updates since. The latest update (Modflow 2000) incorporates several improvements extending its capabilities considerably, the most important being the introduction of the new package called the Layer-Property Flow Package.

MT3DMS is a 3-D model for the simulation of advection, dispersion, and chemical reactions of dissolved constituents in groundwater systems. MT3DMS uses a modular structure similar to the structure utilized by MODFLOW, and is used in conjunction with MODFLOW in a two-step flow and transport simulation. Heads are computed by MODFLOW during the flow simulation and utilized by MT3DMS as the flow field for the transport portion of the simulation.

7.1 Flow Model Set-Up

In this paragraph the setup of the flow model will be discussed in terms of the conceptual model as envisaged for the numerical model, elevation data used, boundaries of the numerical model and assumed initial conditions.

7.1.1 Elevation data

Elevation data is crucial for developing a credible numerical model, as the groundwater table in its natural state tend to follow topography.

The best currently available elevation data is derived from the STRM (Shuttle Radar Tomography Mission) DEM (Digital Elevation Model) data. The SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of

2000, during which elevation data was obtained on a near-global scale to generate the most complete high-resolution digital topographic database of Earth[8]. Data is available on a grid of 30 metres in the USA and 90 metres in all other areas. The data points in the study area are shown in Figure 12 below.

Several studies have been conducted to establish the accuracy of the data, and found that the data is accurate within an absolute error of less than five metres and the random error between 2 and 4 metres for Southern Africa[9]. Over a small area as in this study, the relative error compared to neighbouring point is expected to be less than one metre. This is very good for the purpose of a numerical groundwater model, especially if compared to other uncertainties; and with the wealth of data this result in a much improved model.

7.1.2 Conceptual model

For the purpose of this study, the subsurface was envisaged to consist of the following hydrogeological units, as illustrated in **Error! Reference source not found.** below:

- The upper few meters below surface consist of completely weathered material. This layer is anticipated to have a reasonable high hydraulic conductivity, but in general unsaturated. However, a seasonal aquifer perched on the bedrock probably does form in this layer, especially after high rainfall events. Flow in this perched aquifer is expected to follow the surface contours closely and emerge as fountains or seepage at lower elevations.
- The next few tens of meters are slightly weathered, highly fractured shale/sandstone bedrock with a low hydraulic conductivity. The permanent groundwater level resides in this unit and is generally less than 15 meters below ground level. The groundwater flow direction in this unit is influenced by regional topography and for the site flow would be in a general northerly direction as also confirmed by measured groundwater levels.
- Below a few tens of meters the fracturing of the aquifer is less frequent and fractures smaller due to increased pressure. This results in an aquifer of lower hydraulic conductivity and very slow groundwater flow velocities. As in the previous unit, the flow direction is expected to be mostly north easterly. This trend was confirmed by modelling.

Fracturing of the bedrock could consist of both mayor fault structures and/or minor pressure-relieve joints. On a large enough scale (bigger than the Representative Elemental Volume) the effect of these structures become less important and has been considered as a homogeneous aquifer in this study.

Groundwater, originating from the vertical infiltration of rainwater through the upper layer(s) up to the groundwater level, will flow mostly horizontally in the directions as discussed above. Water flow volumes and velocities will, on average, decrease gradually with depth.

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[8] http://www2.jpl.nasa.gov/srtm/

[9] Rodriguez, E., et al, 2005. An assessment of the SRTM topographic products. Technical Report JPL D-31639, Jet Propulsion Laboratory, Pasadena, California.

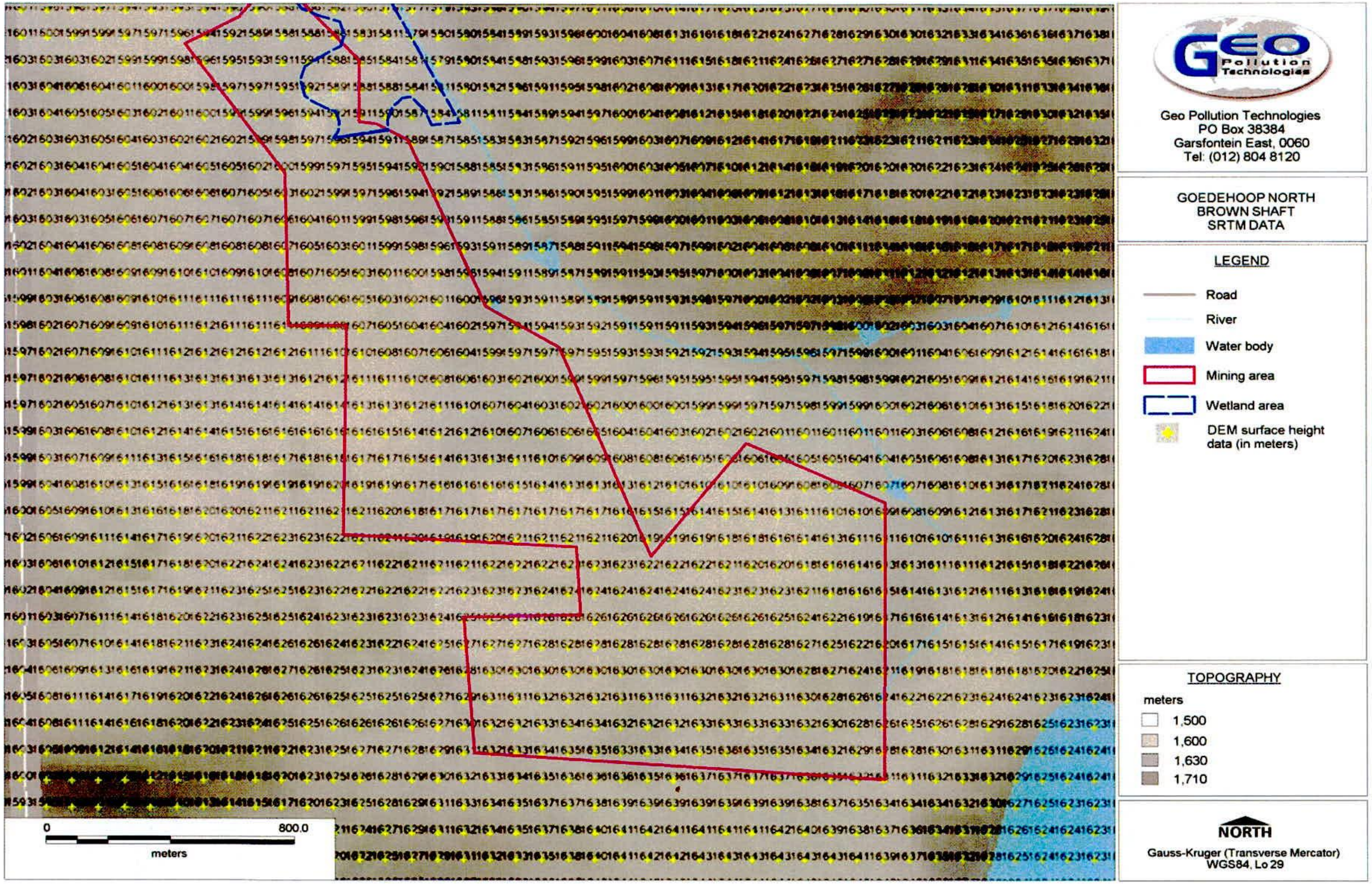

Figure 12: STRM Elevation Points

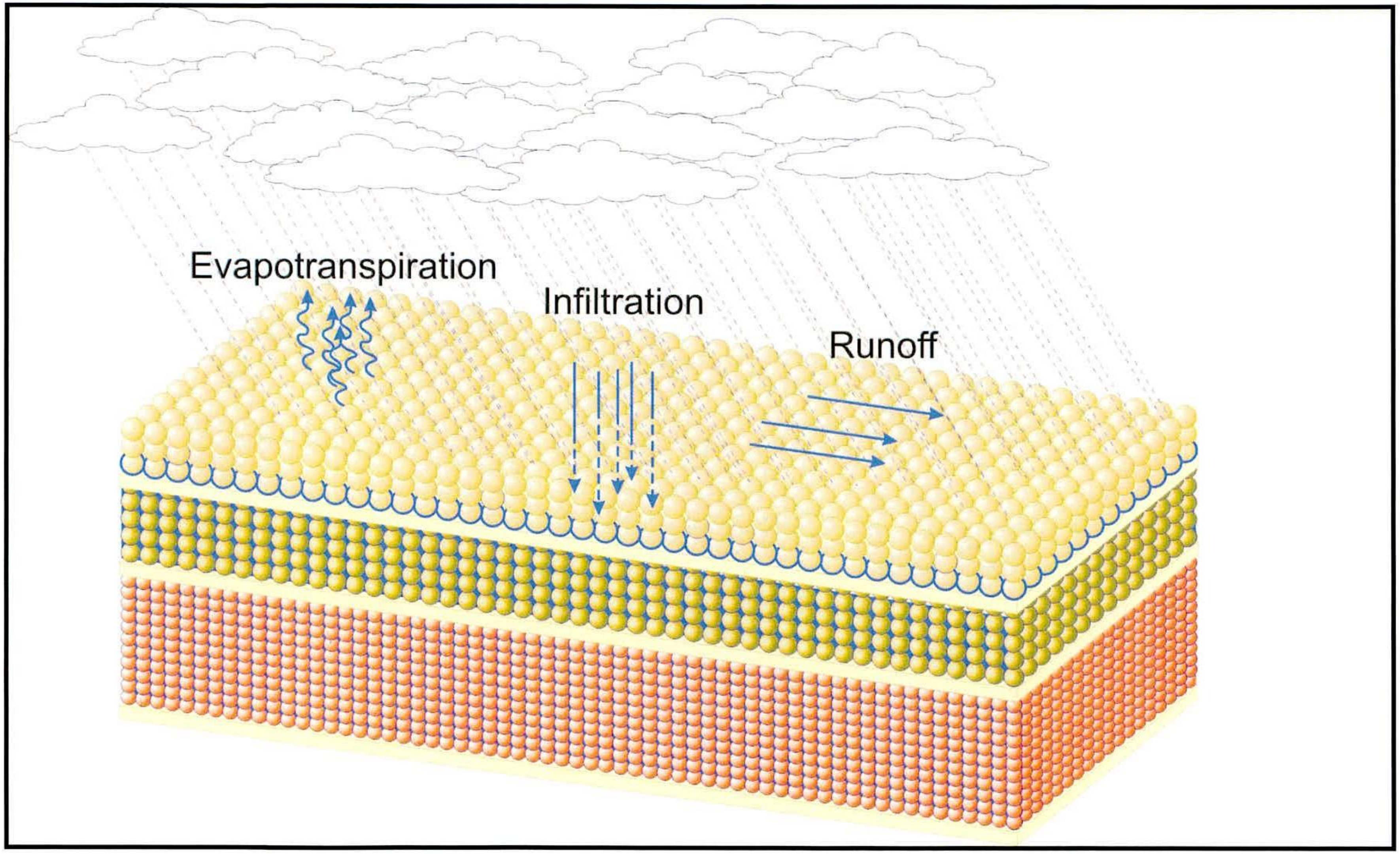

Figure 13: Conceptual Numerical Model

The following assumptions and simplifications were made in constructing the conceptual model, as illustrated in Figure 13 above:

- The upper completely weathered aquifer perched in the bedrock is mostly unsaturated. It is thus not an important part of the hydrogeological system in this area, and it has not been modelled as a separate component. It is very thin in comparison to the fractured bedrock aquifer and of little consequence at the depth of mining. It has thus been grouped into the upper layer of the model.
- The bedrock has been modelled as three layers of decreasing hydraulic conductivity and specific yield. Fractures in bedrock close up at depth, which result in a lowering of the hydraulic conductivity[10].
- It is generally acknowledged and confirmed by the mining experience that only the upper 30 meters of the Ecca contains significant groundwater[11]. Thus, an upper model layer of 30 meters were created, followed by two more layers of 30 and 40 metres thickness respectively; a total of 100 metres. The hydraulic parameters were allowed decreased by an order of magnitude over these layers[12]
- No provision has been made for the lower Pretoria Group as a separate unit, as neither its vertical position nor properties are known with any certainty. However, at depth secondary porosity due to bedrock fracturing is more important than the original bedrock properties. It can thus reasonably be assumed that the hydraulic properties are reasonable similar to that of the fractured Ecca rock.
- The local effect of discontinuities, such as faults, fractures and intrusions, has been disregarded. The exact location and characteristics of these structures are unknown and will be difficult and expensive to determine, if at all possible. Besides, on a large enough scale the effect of these structures become less important and can be considered as part of the homogeneous aquifer, as described in paragraph 7.1.2. Although the coal seam could have a somewhat higher hydraulic conductivity than the surrounding bedrock, it has not been modelled as separate layer. It would require extensive pump testing to determine the hydraulic properties; and its effect on groundwater flow is expected to relatively unimportant as it has been (or will be) extensively mined, it has not been included in this study.

7.1.3 Fixed Aquifer Parameters

Although the most relevant aquifer parameters are optimised by the calibration of the model (paragraph 7.2), many parameters are calculated and/or judged by conventional means. The following fixed assumptions and input parameters were used for the numerical model of this area:

- Recharge = 0.0001 m/d. This value was calculated using the RECHARGE program[13] (Table 9 below) and amounts to about 5% of annual rainfall. Please note that this is not effective recharge, as evapotranspiration was also modelled as discussed below. The result will thus be higher recharge in high topographical areas and lower recharge where the water table is shallow, similar to the conditions in nature.

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[10] Barnes, S. L. et al: Coal Mine Drainage Prediction and Pollution Prevention in Pennsylvania. Pennsylvania Department of Environmental Protection

[11] Hodgson, F. D. I. et al: Investigation of Water decant from the Underground Collieries in Mpumalanga, With Special Emphasis on Predictive Tools and Long-Term Water Quality Management, August 2007. Institute for Groundwater Studies, University of the Free Satate, Bloemfontein RSA.

[12] Gerrit van Tonder, Yongxin Xu: RECHARGE program to Estimate Groundwater Recharge, June 2000. Institute for Groundwater Studies, Bloemfontein RSA.

[13] Gerrit van Tonder, Yongxin Xu: RECHARGE program to Estimate Groundwater Recharge, June 2000. Institute for Groundwater Studies, Bloemfontein RSA.

- Maximum Evapotranspiration = 0.005 m/d. This value is based on the E-pan evaporation data for this area[14] as discussed in Table 1 . Note that this rate of evapotranspiration is used by the modelling software only if the groundwater should rise to the surface. For the groundwater level between the surface and the extinction depth, the evapotranspiration is calculated proportionally. Below the extinction depth the evapotranspiration is assumed to be zero.

- Evapotranspiration Extinction Depth = 2 m. This depth relates to the expected average root depth of plants in this area.

- The specific storage over the area was taken as 0.000001. This is a typical value for fractured bedrock.

- Horizontal Hydraulic Permeability of the bedrock = 0.1 m/d, declining with depth by an order of magnitude at the third layer due to decreasing weathering of the bedrock and increased pressure that tend to close fractures, as described in paragraph 7.1.2 (Conceptual Model). This value was subsequently adjusted during calibration of the model, as described below.

- Hydraulic Permeability of the mined out and rehabilitated underground areas = 100 m/d. This is more than two orders of magnitude larger than the pre-mining conditions, and typical that of a sandy gravel. It is also the highest value that could be used without creating numerical instability due to too large permeability differences in neighbouring cells.

- Hydraulic Permeability of the layer containing the underground mined areas = 100 m/d, with a vertical hydraulic anisotropy (Kh/Kv) = 1 000 to ensure that vertical hydraulic conductivity between layers does not exceed 0.01 m/d.

- The layer thickness of the underground mined areas has been increased to 30 metres to ensure a large enough transmissivity without using a too large hydraulic conductivity that could destabilize the numerical model.

- Vertical Hydraulic Anisotropy (KH/KV) of the bedrock= 10. By nature of the pronounced horizontal layering, this value is commonly used in the Karoo sedimentary layers.

- Vertical Hydraulic Anisotropy (KH/KV) of the backfilled underground= 1, as no post mining horizontal layering is anticipated.

- The effective porosity value was taken as 0.05, declining gradually with depth to 0.01 at a depth of 100 metres. This value could not be determined directly and were taken as typical of the fractured bedrock.

- Longitudinal dispersion was taken as 50 metres, which is about 10% of expected plume dimensions, as recommended in various modelling guidelines.

- Transverse and vertical dispersion was taken as 10 metres and 1 metre respectively to reflect the stratification of the bedrock.

- A value of 1.0e-6 m2/day/m2 was used for drain conductance. This value was calibrated during a previous modelling study in the area[15], with measured groundwater levels above the mined areas.

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[14] http://www.dwaf.gov.za/hydrology

[15] Geo Pollution Technologies, 2005. Geohydrological Report for the Proposed New Blackwattle Opencast Coal Mine on the Middelburg Town and Townlands 287 JS, Mpumalanga. Report number: BLW/06/149

Table 9: Recharge Calculation

Method	Recharge (mm/a)	%
Soil information	45.4	6.9
Geology	21.1	3.2
Vegter	45.0	6.8
Acru	35.0	5.3
Harvest Potential	25.0	3.8
Average	34.3	5.2

7.2 Construction of the model

Construction of the numerical model consists of selecting natural boundaries for the model, discretisation of this area in finite elements, and calibration against measured groundwater levels and/or flow.

7.2.1 Model Boundaries and Discretisation

Boundaries for the numerical model have to be chosen where the groundwater level and/or groundwater flow is known. The most obvious locations are zero flow conditions at groundwater divides, while groundwater levels are known at prominent perennial dams and rivers connected to the groundwater.

To simulate the groundwater conditions in and around the proposed mining area, the aquifer as described below has been modelled. Boundaries were chosen so as to include the area where the groundwater pollution plume could reasonably be expected to spread and simultaneously be far enough removed from mining boundaries not to be affected by groundwater abstraction in the mine.

Wherever practical, natural topographical water divides has been used as a no-flow boundaries, assuming that the groundwater elevation follows the topography. To the north and south, water divides served as no-flow boundaries. The Spookspruit has been selected as the western boundary and the Woes-Alleenspruit to the east, as groundwater would be expected to flow towards and parallel to a stream without crossing it.

These boundaries resulted in a modelled area of about 2 to 12 km around the proposed mining area, which is considered far enough for the expected groundwater effects not to be influenced by boundaries.

The modelling area was discretizised by a 190 by 160 grid, refined at the mining areas as depicted in Figure 15 below, resulting in finite difference elements of about 50 by 50 meters at the mining areas and up to 500 meters at the edges of the model. All modelled features, like mining areas etc., are sizably larger than these dimensions, and the grid is thus adequate for the purpose. Nevertheless, the total amount of active cells over all layers added up to more than 80 000, resulting in a large model.

7.2.2 Calibration of the Model

Based on the depths of nine boreholes within a 1km measured during the hydrocensus, the numerical model could be calibrated using this data. Most data is concentrated around the area of the proposed mining area, and the calibration is thus mainly applicable to the area in the immediate vicinity of the proposed underground. The model was optimised manually with the main aim to fit the hydraulic parameters to the boreholes closest to the proposed underground, as shown below in Figure 17 below.

A reasonably good fit was obtained as can be visualised through the vertical bars in Figure 17 (calibration interval = 10 metres, that is about 10% of altitude differences over the modelled area). The final optimised parameters were:

- Horizontal hydraulic conductivity Layer1= 0.03
- Horizontal hydraulic conductivity Layer2= 0.003
- Horizontal hydraulic conductivity Layer3= 0.0003
- Horizontal hydraulic conductivity Layer4= 0.0003

All other parameters were unchanged, with values as listed in the above paragraph "Flow Model Set-Up".

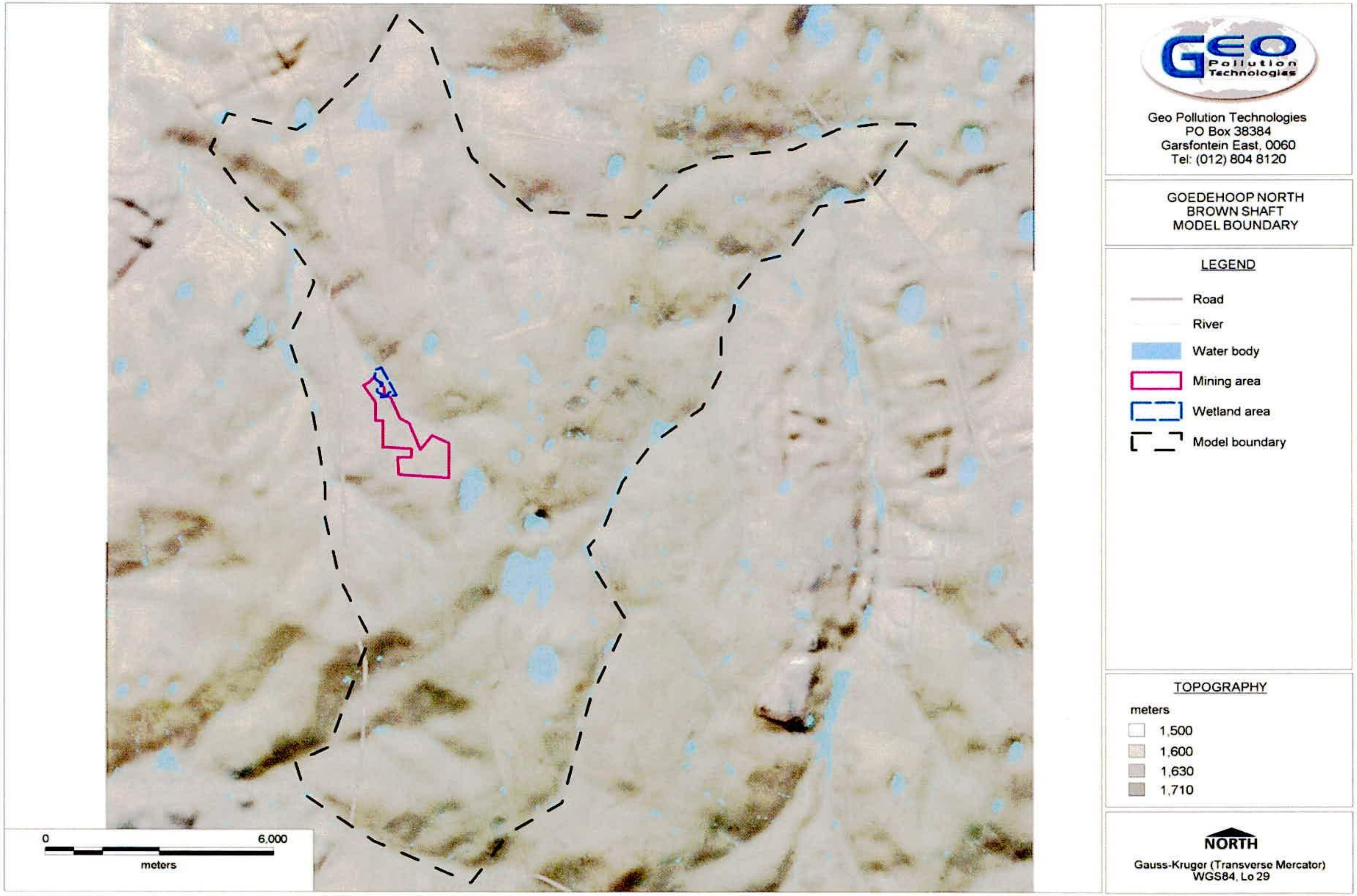

Figure 14: Model Boundaries

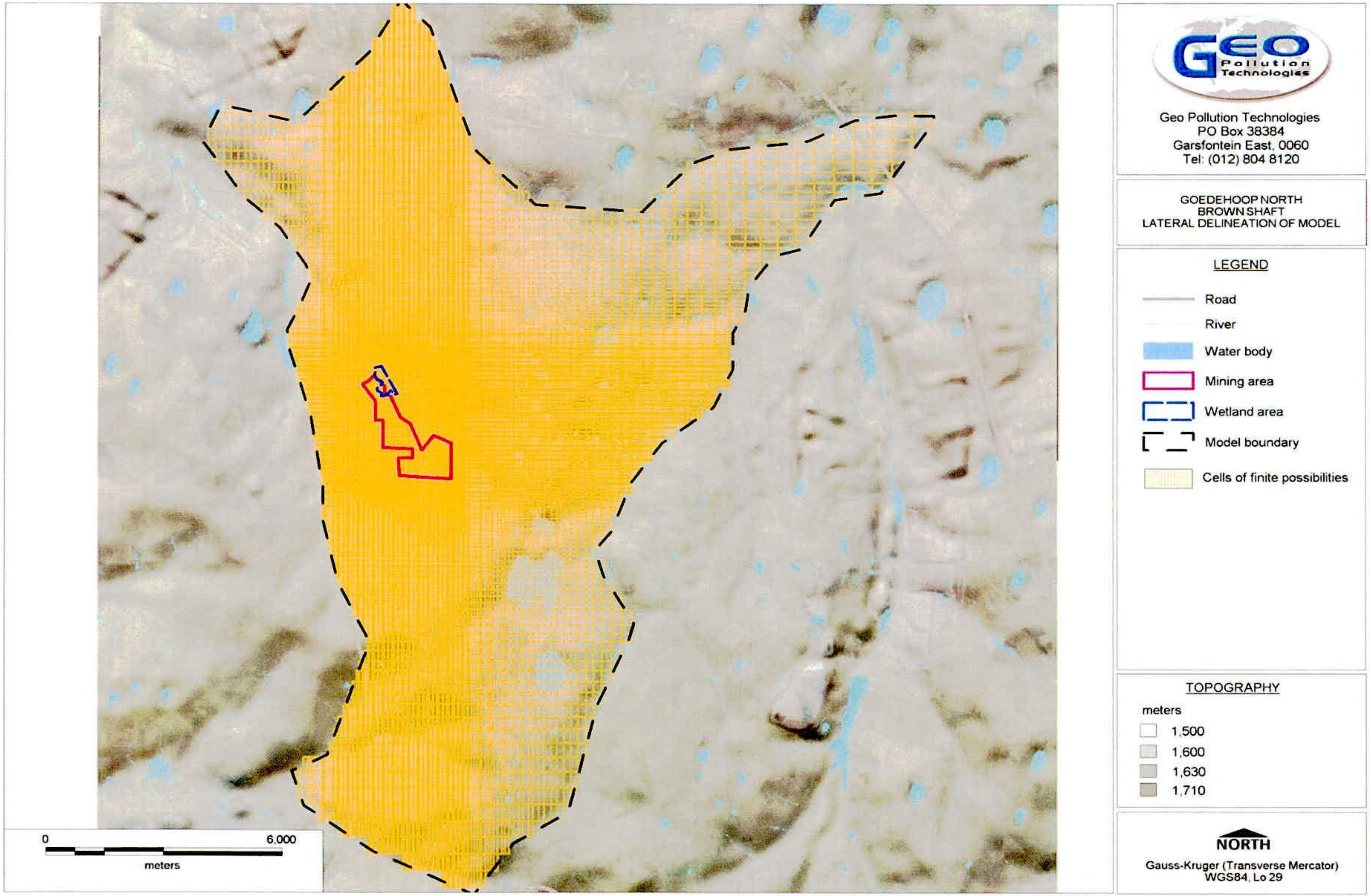

Figure 15: Lateral Delineation of the Regional Model

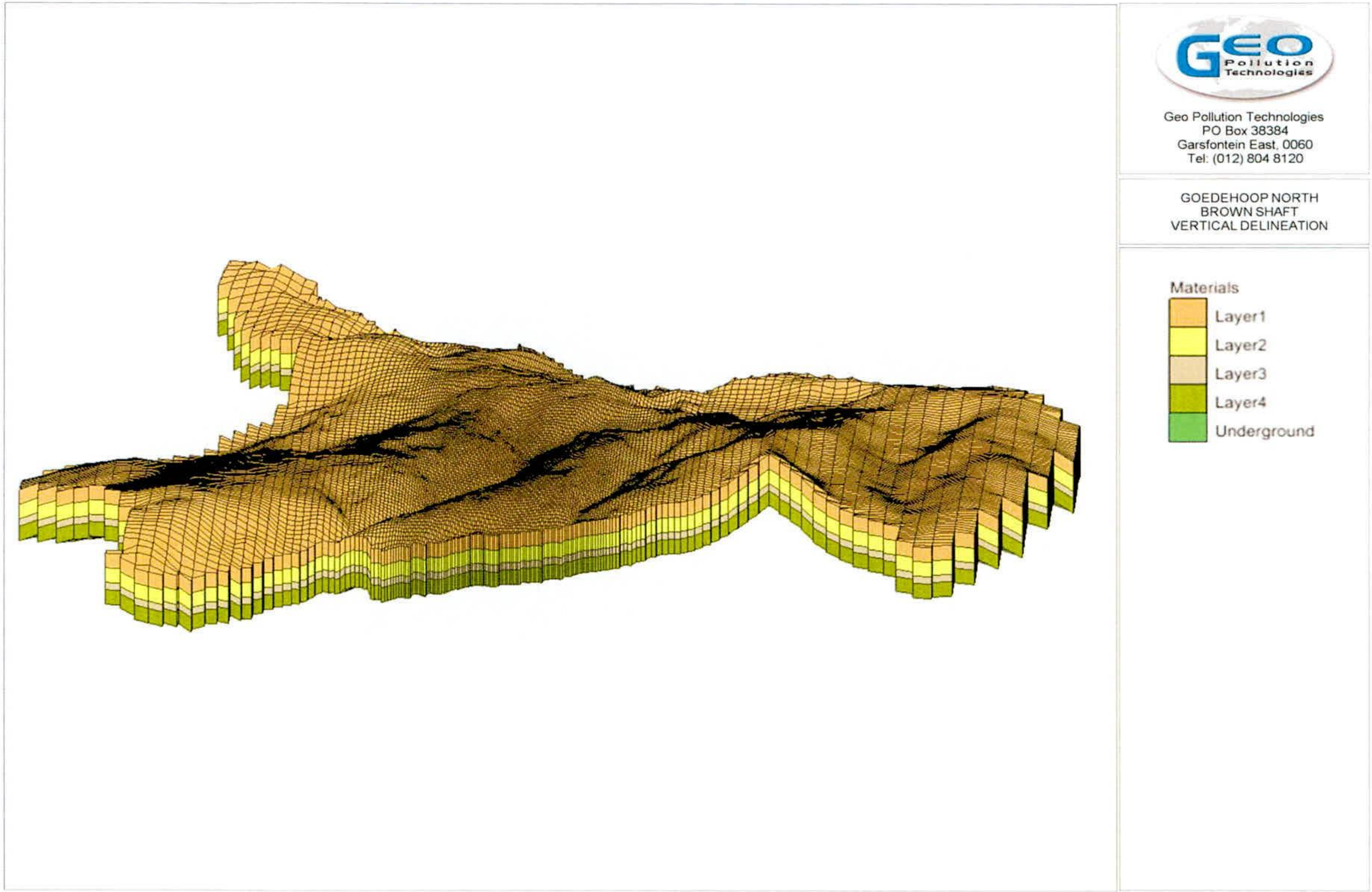

Figure 16: Vertical Delineation of the Modelled Area

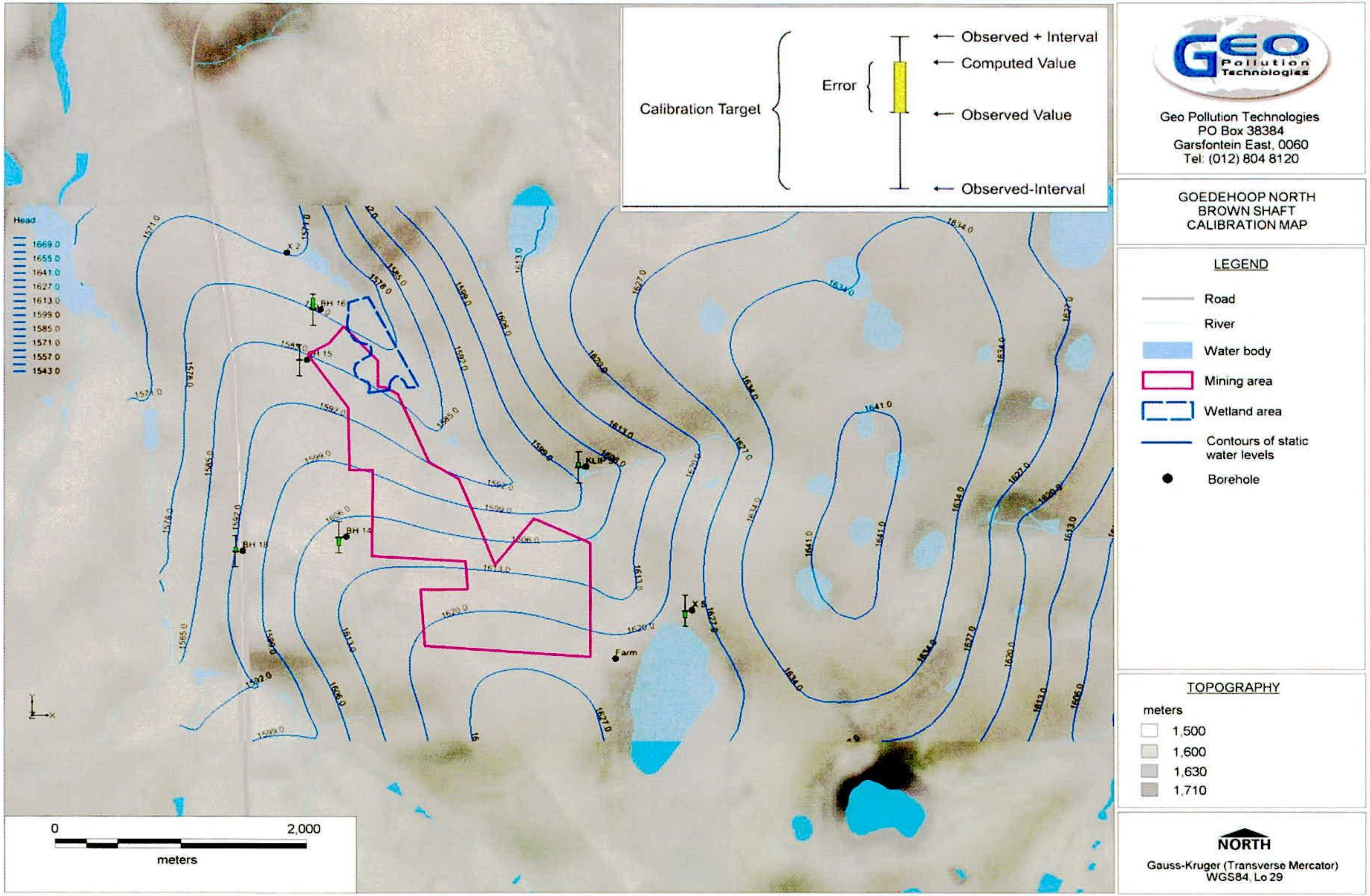

Figure 17: Calibration of the Numerical Model

Table 10: Calibration Statistics

Item	Value
Mean Residual (Head)	-0.772949218
Mean Absolute Residual (Head)	3.979085285
Root Mean Squared Residual (Head)	4.529280144

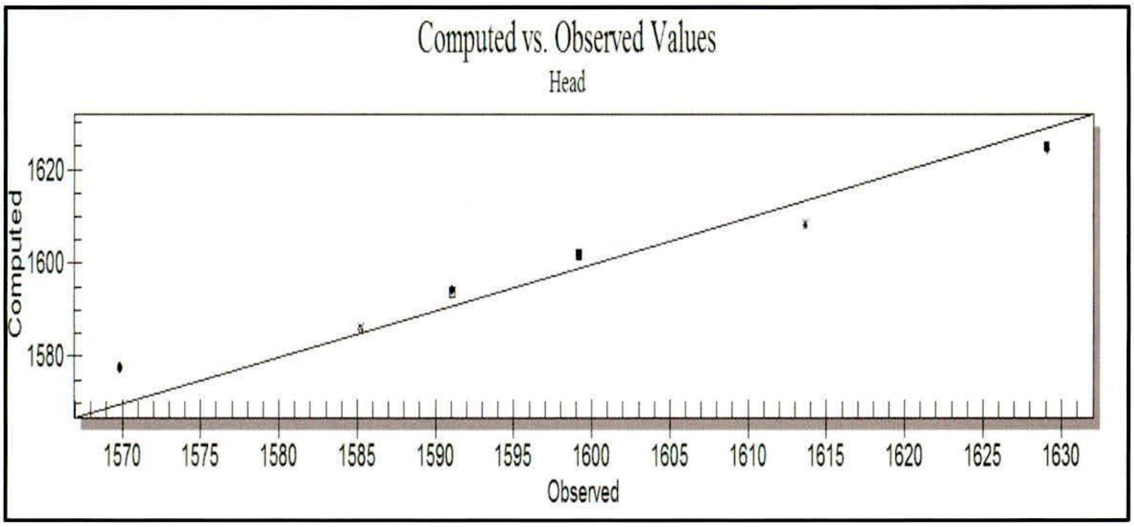

Figure 18: Calibration Graph for the Numerical Model

7.3 Solute Transport Model

The migration rate of a pollution plume was estimated by means of the numerical mass transport model MT3DMS as described in the introduction to this section. Advection and hydrodynamic dispersion are the two main processes that control contaminant transport through a porous medium. Advection is the flow component, while hydrodynamic dispersion refers to mechanical dispersion and molecular diffusion.

The same input parameters as previously stated for the flow modelling were chosen for the numerical model. In addition, the following assumptions were made for the transport modelling:

- The total and effective porosity values of the aquifer was taken as 0.05 (5%), decreasing to 0.01 (1%) at depths of 100m. These are estimated reasonable values for the fractured bedrock, decreasing by the square root of the hydraulic conductivity16.
- Only sulphate was considered for solute transport calculations as it is the main chemical of concern in coal mining.
- An initial concentration of 2000 mg/litre was assumed for the sulphate levels in the flooded undergrounds. This value is based on typical values at various studies in the Witbank coal fields. This is probably an overestimation, and should present a worst case scenario.
- It was assumed that the sulphate will behave as a conservative tracer, that is no decay and no retardation of contaminates occur while the plume is migrating.
- Only advection and hydrodynamic dispersion was therefore modelled, assuming:

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[16] Institute for Groundwater Studies, University of the Free State. Class notes