- Longitudinal dispersion of 50m.
- Ratio of transverse to dispersion = 0.1.
- Ratio of vertical to longitudinal dispersion = 0.01.

- It was furthermore assumed that no pollution could migrate to the surrounding aquifer before the post-mining water level has not recovered, as negative water level gradients will prohibit any movement of groundwater from the mining void.
- The calculated water levels as simulated for the post-mining scenario were used as hydraulic heads in the mass transport model.

This methodology was selected to provide worst-case scenario results within the limitations of homogeneous assumptions, which is consistent with the approach followed with the remainder of the report.

7.4 Model runs

The calibrated model as described above was used to estimate the impact of the proposed mining on the groundwater quality and quantity. Models ran and assumptions made, were the following:

7.4.1 Pre-Mining

This scenario represents the current situation. This scenario, and the assumptions made for modelling purposes, was described in detail in the previous two paragraphs, and the reader is referred to these sections for detail.

7.4.2 During Mining

This model represents the groundwater situation during mining of the proposed underground. For the purposes of this model a worst-case scenario was assumed, namely that the whole underground will be dewatered during the mining period. A constant head was thus imposed on the mining area at the anticipated floor.

7.4.3 Post Mining

This models the post-mining scenario, assuming that the most likely recharge over the rehabilitated mining area will be four times higher than the natural recharge. This amounts to a recharge of about 20% of rainfall, which is probably a realistic, if not worst case scenario[17].

7.5 Limitations of the modelling exercise

The modelling was done within the limitations of the scope of work of this study and the 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. Especially the assumption that a fractured aquifer will behave as a homogeneous porous medium can lead to error. However, on a large enough scale (bigger than the REF, Representative Elemental Volume) this assumption should old reasonable well.

[17] Grobbelaar, R et al: Long-Term Impact of Intermine Flow from Collieries in the Mpumalanga Coalfields, Sept 2004. Institute for Groundwater Studies, University of the Free State, Bloemfontein RSA.

8 GEOHYDROLOGICAL IMPACTS

It is the aim of this chapter to assess the likely hydrogeological impact that the proposed mining of the Brown Shaft 2 underground might have on the receiving environment. The typical mining stages that will be considered in this section are:

- Construction Phase: Start-up of mining operations at the specific site before actual mining operations commences.
- Operational Phase: The conditions expected to prevail during the mining of the new underground.
- Decommissioning Phase: The closing of mining operations, site clean-up and rehabilitation of the mining area.
- Post-mining Phase: This relates to the steady-state conditions following closure of the underground. A period will be considered after which it is assumed that impacts will steadily decrease and start returning to normal.

8.1 Construction phase

8.1.1 Impacts on Groundwater

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.

With the exception of lesser oil and diesel spills, there are also no activities expected that could impact on regional groundwater quality. This phase should thus cause very little additional impacts in the groundwater quality. It is expected that the current status quo will be maintained.

8.1.2 Groundwater Management

In the event of groundwater encountered during the adit development, precementation can and should be used to restrict inflow thereby negating excessive drawdown.

As only diesel and oil spills have been identified as potential groundwater pollutants during this phase, measures to prevent and contain such spills should be introduced. The following is suggested:

- 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.
- 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.

8.2 Operational Phase

The operational phase is interpreted as the active mining of the proposed Brown Shaft 2 underground. It is inevitable that these effects will impact on the groundwater regime. The potential impacts that will be considered are the groundwater quantity and quality.

8.2.1 Impacts on Groundwater Quantity

During the operational phase, it is expected that the main impact on the groundwater environment will be de-watering of the surrounding aquifer. Water entering the mining pit will have to be pumped out to enable mining activities. This will cause a lowering in the groundwater table in and adjacent to the mine.

The dewatering of the aquifer has been calculated for the underground using the calibrated numerical model as described above. A worst-case scenario has been modelled, assuming that all undergrounds 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 Figure 19 as contours of drawdown. It follows from this figure 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. The details of this boreholes are:

BH NO.	OWNER	USE
BH5	Bank Colliery	Not in use
Farm	Danie Pienaar	Not in use

It must again be stressed that structures of preferred groundwater flow have not been modelled. If such a structure is dewatered through mining, any boreholes drilled into the structure might be seriously affected. These effects cannot be predicted with the current knowledge, and can only be established through continuous groundwater level monitoring.

It is also possible to calculate the inflow into the undergrounds from the flow budget for the finite difference cells assigned as drains in a MODFLOW model. In the case of model prepared for this project, the computed inflow to the underground was calculated in the order of 300 m^3/day.

Direct recharge from rainfall will add to these volumes. The amount of direct recharge will depend on the season as well as the details of the mining plans and storm water management. It is suggested that this is calculated as part of the surface water study.

It must be cautioned that these calculations have been done using simplified assumptions of homogeneous aquifer conditions. The reality could deviate substantially from this and the model should thus be updated as more information becomes available.

8.2.2 Impacts on Wetland/Streams

Due to the depth of mining varying between 40 to 60 meters below surface the effect of the underground mining on surface receptors such as wetlands is difficult to determine. The reason for this is that in most cases deep underground coal mines act as confined man-made aquifers. This is based on the assumption there are no vertical fractures linking shallower aquifers and surface water receptors with the aquifer. Thus any dewatering in a confined aquifer is unlikely to affect wetlands or surface water receptors. However underground mining has the potential to affect the base flow of the wetlands close to the underground mining area if well connected through a network of preferential pathways (semi-confined to unconfined aquifers).

Although not shown the underground mining area closest to the wetland could have an impact as dewatering during the start of mining will be in close proximity to the wetland. As the underground mine moves further south away from the wetland the dewatering impact should be less prominent.

8.2.3 Cumulative Effects

The cumulative drawdown of all previous mining in addition to the proposed new underground was unable to calculate due to the lack of data. It is recommended that a regional study be conducted taking in consideration all neighbouring mine dewatering.

8.2.4 Impacts on Groundwater Quality

The flow in the aquifer will be directed towards the undergrounds during this stage of mining. The exposed coal seams will be above groundwater level, and very little groundwater pollution is thus expected.

8.2.5 Groundwater Management

A substantial drop in groundwater level is not expected. However, as a drawdown of 5 metres and more is needed to seriously affect the yield of boreholes, a negative quantity impact on one current private groundwater users (Farm borehole owned by Mr. Danie pienaar) are predicted.

It is nevertheless important to monitor static groundwater levels as well as flow in the wetland on a quarterly basis in all boreholes within a zone of two kilometres surrounding the underground to ensure that any deviation of the groundwater flow from the idealised predictions is detected in time and can be acted on appropriately. Preferred flow structures (dykes, sills, faults, etc) have not been included in the model due to the unknown hydraulic characteristics, and these structures could alter the actual effects considerably.

If it can be proven that the mining operation is indeed affecting the quantity of groundwater available to certain users, the affected parties should be compensated. This may be done through the installation of additional boreholes for water supply purposes, or an alternative water supply.

It is also recommended that the development of the adit and start of mining take place within the dry months (May to August) to limit the effects of dewatering on the seasonal shallow perched aquifer that might develop as result of rainfall. This shallow perched aquifer is thought to be major contributor of water to the wetlands.

Although little or no groundwater contamination is expected during this stage due to the cone of depression, it is nevertheless also recommended that groundwater quality be monitored on a quarterly basis. This is essential to provide a necessary database for future disputes.

Water samples must be taken from all the monitoring boreholes by using approved sampling techniques and adhering to recognised sampling procedures. Samples should be analysed for both organic as well as inorganic pollutants, as mining activity often lead to hydrocarbon spills in the form of diesel and oil. At least the following water quality parameters should be analysed for:

- Major ions (Ca, K, Mg, Na, SO4, NO3, Cl, F)
- pH
- Electrical Conductivity (EC),
- Total Petroleum Hydrocarbons (TPH)
- Total Alkalinity

These results should be recorded on a data sheet. It is proposed that the data should be entered into an appropriate computer database and reported to the Department of Water Affairs and Forestry.

Please note that in terms of the National Water Act, 1998 (Act No. 36 of 1998 Government Notice 704) no mine (opencast or underground) or mine activity may be established within the 1:50 year flood-line or within a horizontal distance of 100m from any watercourse or estuary, whichever is the greatest.

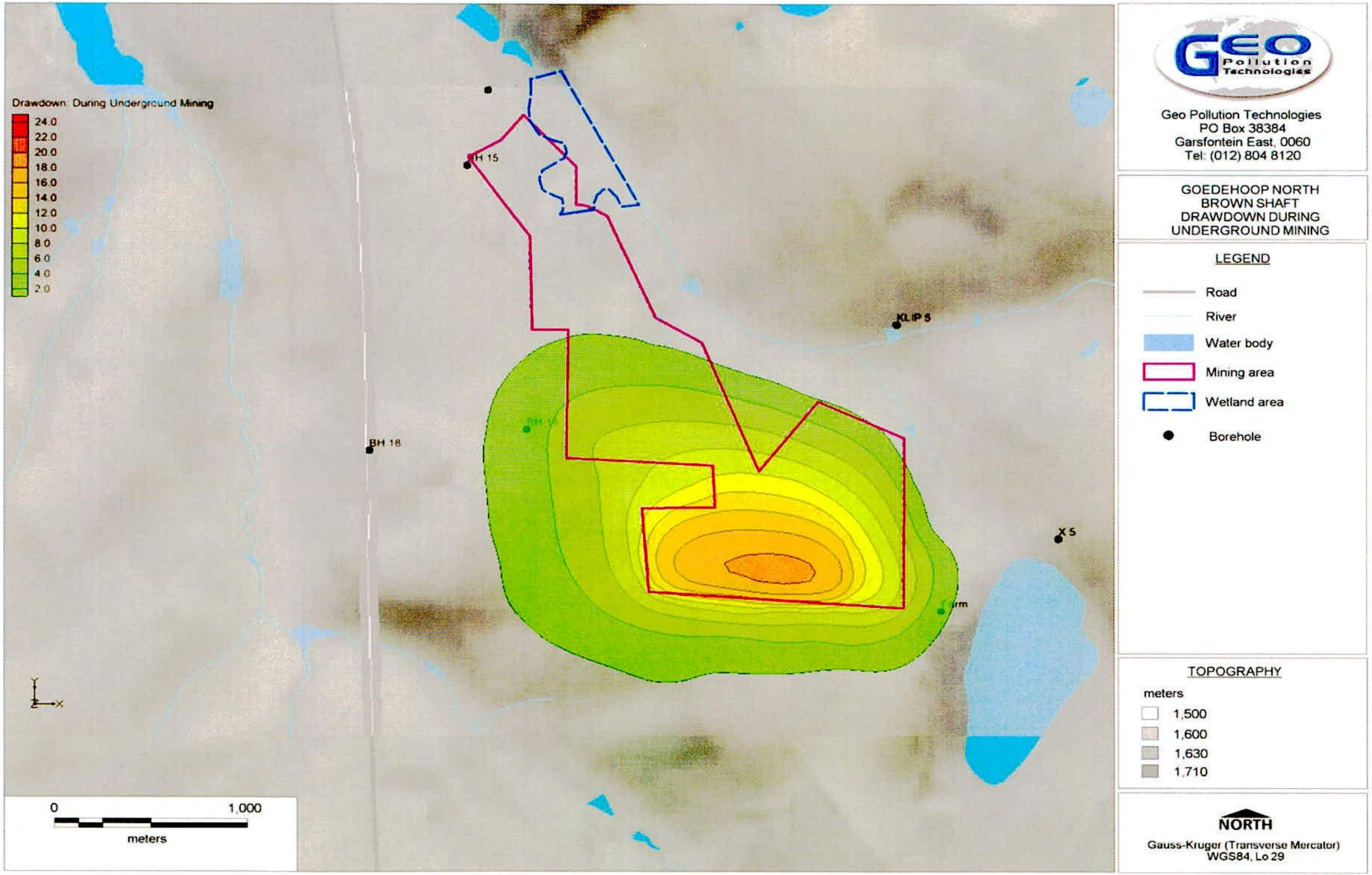

Figure 19: Groundwater Drawdown during Mining

8.3 Decommissioning Phase

During this phase of mining it is assumed that dewatering of the colliery will be ceased. The groundwater regime will return to a state of equilibrium once mining has stopped and the removal of water from the mining void has been discontinued.

The rate of recovery is expected to be in the order of twenty years following termination of dewatering, as shown in the figure below.

8.3.1 Groundwater Management

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. This will prevent any subsidence which can have an impact on the flow within the wetland.

8.4 Post-mining Phase

This phase of the mining process is the period following the completion of mining and rehabilitation of the Brown Shaft 2 underground. The following possible impacts were identified at this stage:

- 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.
- Groundwater within the underground(s) is expected to deteriorate due to acid mine drainage and other chemical interactions between the geological and the groundwater regimes. The resulting groundwater pollution plume will commence with downstream movement.

These impacts are discussed separately below and the significance of each impact is discussed.

8.4.1 Groundwater Quantity

The underground 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 the underground, in contrast to the gradient that existed previously.

The end result of this will be a permanent lowering of the groundwater level in the higher topographical area and a rise in lower lying areas. As illustrated in Figure 20 below, it is predicted that the groundwater will rise up to five metres in the north section of the underground.

Inspection of the predicted post mining groundwater levels indicates that decanting would probably not occur as illustrated in **Error! Reference source not found.**. However as mining progress and mining plans is finalised, this prediction must be confirmed.

8.4.2 Groundwater Quality

Once the normal groundwater flow conditions have been re-instated, polluted water can migrate away from the underground mining areas. As some coal and discards could remain in the underground, this outflow might be contaminated as a result of acid or neutral mine drainage. As sulphate is normally a significant solute in such drainage, it has been modelled as a conservative (non-reacting) indicator of mine drainage pollution. A starting concentration of 2 000 mg/litre has been assumed as a worst case scenario, based on past experience in the area and measured values in the study area.

Estimating the potential impacts on the receiving environment through modelling of the solute transport was therefore important and the results are described in this paragraph.

The migration of contaminated water from the mining area has been modelled as described, and the results are presented in Figure 21 in terms of the extent of the pollution plume 10, 20, 40 and 80 years after the pit has been closed. Experience has shown that the plume stagnates after about 80 years, and no further movement after such time is expected.

As stated previously, the results must be viewed with caution as a homogeneous aquifer has been assumed. Heterogeneities in the aquifer are unknown and the effect of this cannot be predicted. Furthermore, no chemical interaction of the sulphate with the minerals in the surrounding bedrock has been assumed. As there must be some interaction and retardation of the plume, this prediction will represent a worst-case scenario.

Within the limitations of the abovementioned assumptions, it can be estimated from these figures that:

- 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 area 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 is known from experience and other related studies that over time and especially in underground mines which induce a reducing environment that water quality will gradually improve and return to background water qualities within several years[18]. This is as a result of the depletion of geochemical interactions.

8.4.3 Cumulative Effects

As the proposed underground mine is surrounded by historic underground mined areas, cumulative effects are a possibility. However cumulative impact prediction was not part of the scope of work for this study.

8.4.4 Groundwater Management

The recharge into the rehabilitated underground is a very important variable in solute transport, and thus the rate of movement of the pollution originating from the underground mine. Rehabilitation measures must therefore be directed to decrease recharge into the underground.

In conclusion, the following measures are recommended:

- The final mine topography should be engineered such that runoff is directed away from the rehabilitated area.
- Mining should remove all coal and as little as possible should be left in the underground mining area.
- 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.

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[18] Dynamic Model of Long Term Geochemical Evolution of Mine Water after Mine Closure and Flooding. IMWA Conference Proceedings 2009, J. Zeman, M. Černík And I. Šupíková

- The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the undergrounds.
- 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.

The sampling methods and substances to be sampled for are similar to those recommended in the previous paragraph.

Figure 20: Change in Groundwater Levels Post Mining

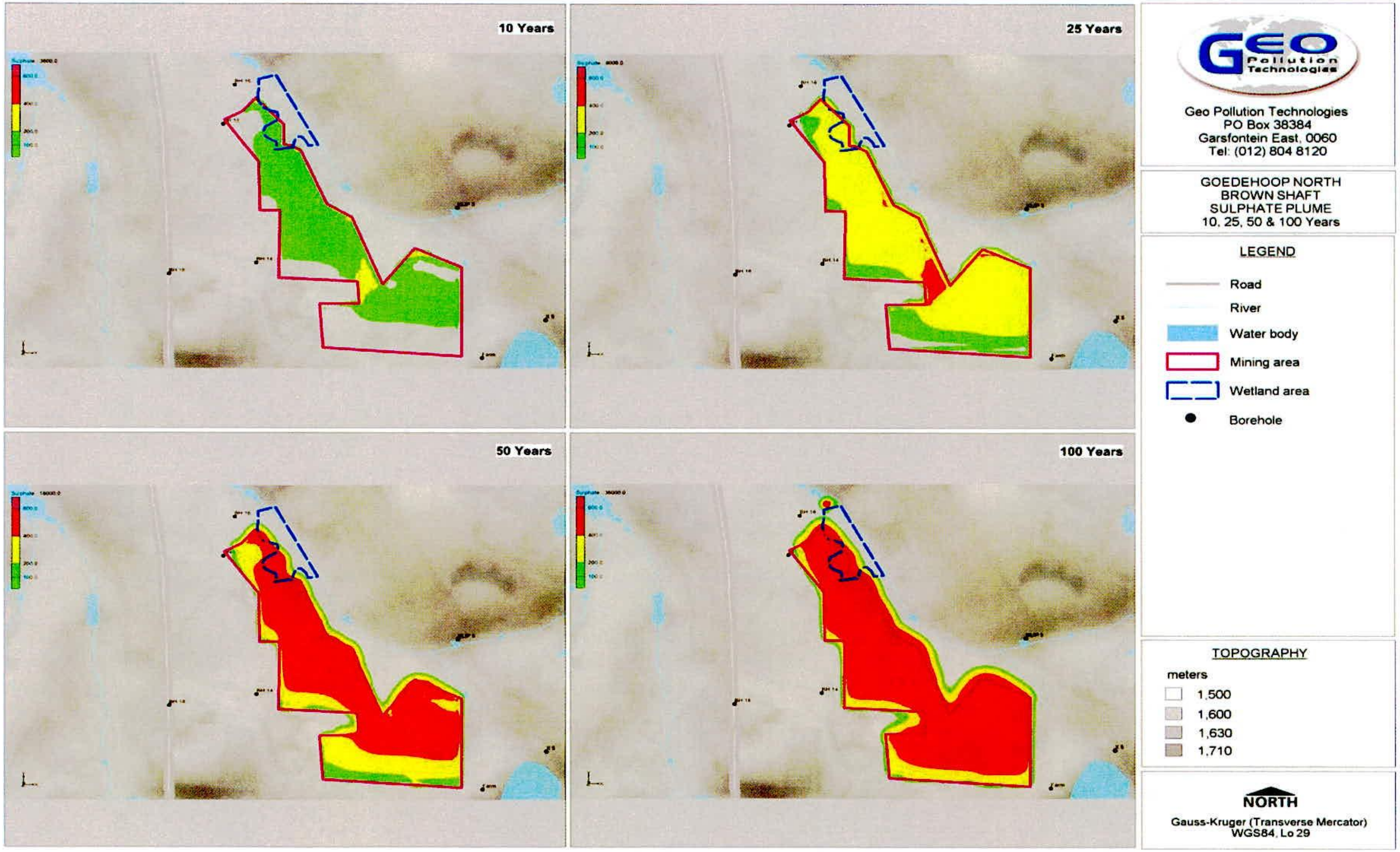

Figure 21: Plume Migration

9 GROUNDWATER MONITORING SYSTEM

9.1 Groundwater Monitoring Network

The main purpose of monitoring is as follows:

- To establish the baseline environmental conditions before the commencement of mining (for new excavations, or for extensions to, or deepening of, existing excavations).
- To fill in gaps in the knowledge of the hydrogeology and hydrology of a operation and its surrounding area. In other words, to improve the conceptual model by reducing the uncertainty.
- To provide the data necessary to undertake water balance for the mine, for example by measuring abstraction and discharge quantities and qualities, and water usage within the operation.
- To demonstrate compliance with conditions attached to relevant abstraction licences or discharge consents.
- To trigger mitigation measures or temporary cessation of dewatering, if the water level in a receptor (such as a wetland) falls below an agreed threshold, for example.

Furthermore DWAF (1998) states that "A monitoring hole must be such that the section of the groundwater most likely to be polluted first is suitably penetrated, to ensure the most realistic monitoring result.

The penultimate point, on optimising the monitoring system, is sometimes forgotten when concentrating on environmental issues and compliance with licences and consents. Operating costs can be reduced significantly by adjusting the operating system in response to good quality monitoring data.

9.1.1 Source, plume, impact and background monitoring

A groundwater monitoring system has to adhere to the criteria mentioned below. As a result the system should be developed accordingly. The groundwater monitoring network should contain monitoring positions which can assess the groundwater status at certain areas. The boreholes can be grouped classification according to the following purposes:

- **Source monitoring** - monitoring boreholes are placed close to or in the source of contamination to evaluate the impact thereof on the groundwater chemistry.
- **Plume monitoring** - monitoring boreholes are placed in the primary groundwater plume's migration path to evaluate the migration rates and chemical changes along the pathway.
- **Impact monitoring** - monitoring of possible impacts of contaminated groundwater on sensitive ecosystems or other receptors. These monitoring points are also installed as early warning systems for contamination break-through at areas of concern.
- **Background monitoring** - background groundwater quality is essential to evaluate the impact of a specific action/pollution source on the groundwater chemistry.

9.2 System Response Monitoring Network

Groundwater levels - the response of water levels to abstraction are monitored. Static water levels are also used to determine the flow direction and hydraulic gradient within an aquifer. Where possible all of the above mentioned borehole's water levels need to be recorded during each monitoring event.

9.3 Monitoring frequency

In the operational phase and closure phase, quarterly monitoring of groundwater quality and groundwater levels is recommended. Quality monitoring should take place before after and during the wet season, i.e. during September and March. It is important to note that a groundwater-monitoring network should also be dynamic. This means that the network should be extended over time to accommodate the migration of potential contaminants through the aquifer as well as the expansion of infrastructure and/or addition of possible pollution sources.

9.4 Monitoring Parameters

The identification of the monitoring parameters is crucial and depends on the chemistry of possible pollution sources. They comprise a set of physical and/or chemical parameters (e.g. groundwater levels and predetermined organic and inorganic chemical constituents). Once a pollution indicator has been identified it can be used as a substitute to full analysis and therefore save costs. The use of pollution indicators should be validated on a regular basis in the different sample position. The parameters should be revised after each sampling event; some metals may be added to the analyses during the operational phase, especially if the pH drops.

9.4.1 Abbreviated analysis (pollution indicators)

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
  - pH, EC
- Laboratory analyses:
  - Major anions and cations (Ca, Na, Cl, SO4)
  - Other parameters (EC)

9.4.2 Full analysis

Physical Parameters:

- Groundwater levels

Chemical Parameters:

- Field measurements:
  - pH, EC
- Laboratory analyses:
  - Anions and cations (Ca, Mg, Na, K, NO3, Cl, SO4, F, Fe, Mn, Al, & Alkalinity)
  - Other parameters (pH, EC, TDS)
  - Petroleum hydrocarbon contaminants (where applicable, near workshops and petroleum handling facilities)
  - Sewage related contaminants (E.Coli, faecal coliforms) in borehole in proximity to septic tanks or sewage plants.

9.5 Monitoring Boreholes

Provisional positions for monitoring boreholes have been chosen taking existing boreholes and the predicted spread of pollution into account. The boreholes and surface monitoring sampling positions are depicted in Table 11 and Figure 22

However, there could be structures such as intrusive dykes and/or fractures and faults in the areas downstream of the undergrounds. To ensure that monitoring boreholes correctly monitor such preferred groundwater flow structures, it is **essential** that the presence of these structures be determined by geophysical means. Both magnetic and electromagnetic geophysical traverses must be completed downstream of the mining areas and other potential pollution sources and boreholes sited by a qualified hydrogeologist before mining commence.

Should it be found any of the new monitoring boreholes is severely polluted at any time after mining closure, this would be an indication that the mitigation measures were not adequately enforced and that emergency procedures must be implemented to prevent permanent damage to the Spookspruit and wetland. Such measures would entail the construction of pump and treat system(s) and or emergency interception trenches. At such stage, further monitoring boreholes will also have to be drilled between the underground and the Spookspruit to monitor progression or stagnation of the pollution plume.

However, such actions will be very costly and adequate mitigation measures during and post mining, as recommended earlier in this report, cannot be over-emphasised.

Table 11: Proposed Monitoring Boreholes

Sample ID	Latitude	Longitude	Property	Owner	Current Water level	Use	Monitoring
BH 14	-25.99621	29.48936	Wolvenfontein 471 JS	Bank Colliery	5.37	Not in use	Source/Plume/Impact
BH 15	-25.98255	29.48617			8.78	Not in use	Plume/Impact
BH 16	-25.97866	29.48723			13.13	Not in use	Plume/Impact
BH 18	-25.99733	29.48113			13.435	Not in use	Background
Farm	-26.00554	29.51077	Wolvenfontein 471 JS	SIS Farming (Danie Pienaar)	No access	Not in use	Impact
KLIP 5	-25.99071	29.50839	Wolvenfontein 471 JS	SIS Farming (Danie Pienaar)	4.31	Not in use	Background
X 1	-25.96968	29.49443	Bankfontein 340 JS	Mining area	0	Not in use	Background
X 2	-25.97428	29.48454		Mining area	0	Not in use	Background
MON1	To be sited						Source/Plume/Impact
MON2							Source/Plume/Impact
MON3							Source/Plume/Impact
MON4							Source/Plume/Impact

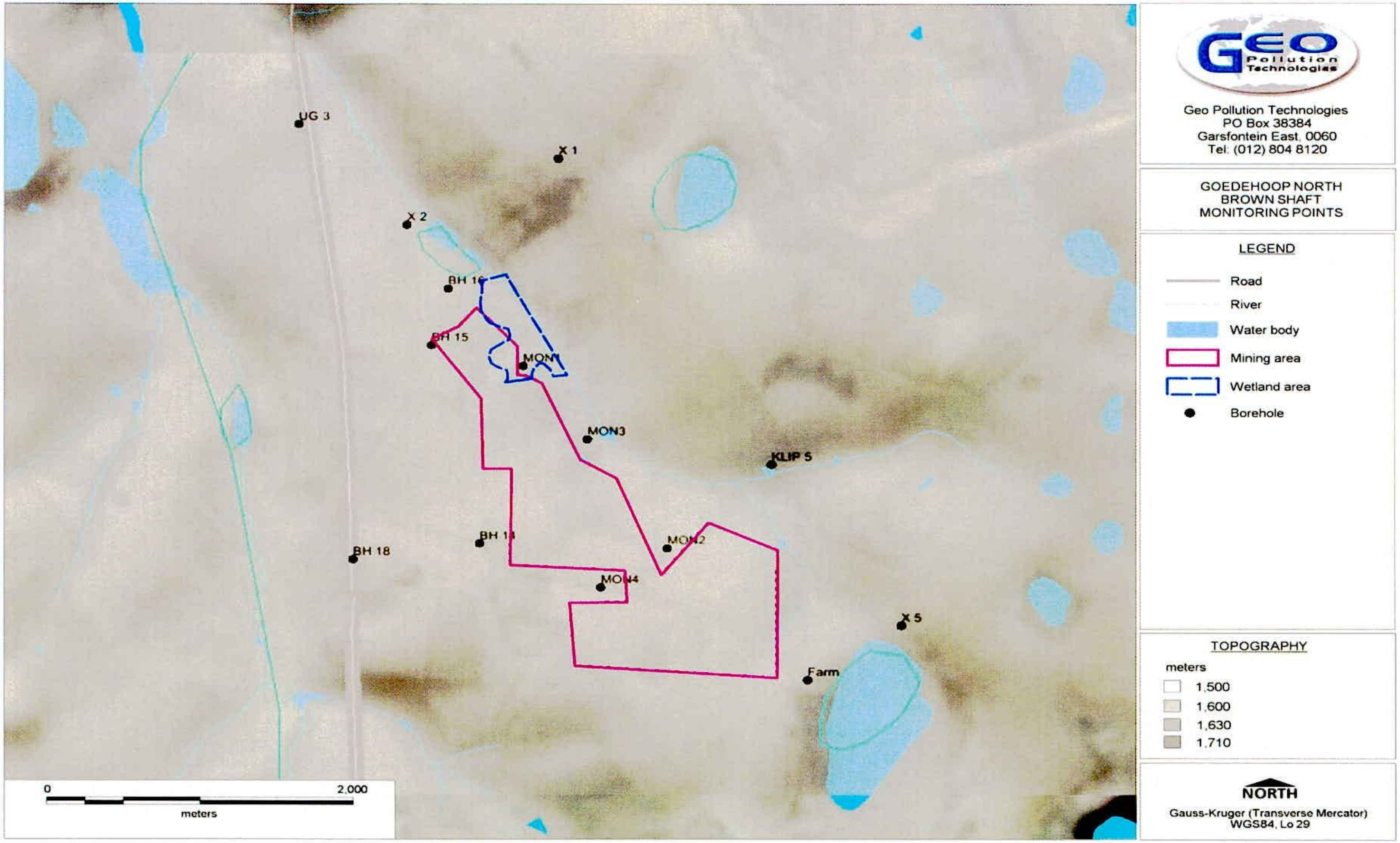

Figure 22: Monitoring Boreholes

10 GROUNDWATER ENVIRONMENTAL MANAGEMENT PROGRAMME (EMP)

The table summarised all the groundwater related EMP's and should be implemented during the various phases of mining. The EMP's were developed in accordance with the DWA Best Practice Guideline series.

Table 12: Groundwater Related EMP

Activity/phase	Aspect	Impact	Actions/Mitigations
Construction Phase	Dewatering of shallow aquifers. Deterioration of groundwater quality.	Drawdown	• In the event of groundwater encountered during the adit development, precementation should be used to restrict inflow negating excessive drawdown. • 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.
		Oil, diesel and chemical spills from machinery	• 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 • Store all potential sources in secure facilities with appropriate storm water management, ensuring contaminants are not released into the environment.
		Contamination potential of mine material exposed during mine construction	• Ensure that the appropriate design facilities (berms, storm water channels etc.) are constructed before constructing the coal handling facilities and adit(s). • Implement the EMP's of other environmental related aspects, including pollution prevention and impact minimisation. • Groundwater monitoring boreholes should be sited with the aid of geophysics at designated positions based on final infrastructure layout, to comply with the design requirements of a groundwater monitoring system, as recommended. • Groundwater monitoring boreholes should be installed to comply with the minimum requirements as set by governmental guidelines.

Operational Phase	**Groundwater quantity- lowering of groundwater table**	Impact on water supply of groundwater users surrounding mine	• Monitor static groundwater levels on a quarterly basis in all boreholes as well as wetland flow within a zone of one to two kilometres surrounding the undergrounds to ensure that any deviation of the groundwater flow from the idealised predictions is detected in time and can be reacted on appropriately. • If it can be proven that the mining operation is indeed affecting the quantity of groundwater available to certain users, the affected parties should be compensated. This may be done through the installation of additional boreholes for water supply purposes, or an alternative water supply. • The numerical model should be updated during mining by using the measured water ingress, water levels, mining and geophysics information to re-calibrate and refine the impact prediction

Operational Phase	**Groundwater quantity- lowering of groundwater table**	Potential impact on base flow of streams/wetlands	• It is recommended that the development of the adit and start of mining take place within the dry months (May to August) to limit the effects of dewatering on the seasonal shallow perched aquifer that might develop as result of rainfall. • Various options should be investigated such as if clean discharge is available to be pumped back into the wetland. • Keep a buffer distance of at least 150m from the edge of the wetland • Another very important aspect to consider is the layout and order of the underground cuts. The best possible scenario for minimising impacting on the wetland/stream is to start the boxcut parallel to the wetland/stream and at the farthest point from the wetland. In such a mining scenario the impact on the wetland will be delayed to the latest possible time before closure of the underground.

	Groundwater quality - Contamination of groundwater	Deterioration of groundwater quality down gradient of the mining operations	• Groundwater quality must be monitored on a quarterly basis as mention in section 9. • The monitoring results must be interpreted annually by a qualified hydrogeologist and the monitoring network should be audited annually to ensure compliance with regulations. • Numerical groundwater model must be updated by calibrating the model with monitoring data. • Pollution control dams should be lined to prevent ingress of contamination • Mine sections should be sealed where possible during mining to reduce the contact of water and air with remaining sulphides. • Install water collection and pumping systems within the mining areas capable of rapidly pumping water out, so minimising contact of water the geochemically reactive material. • Assess the impact of the neighbouring mines on this colliery and vice versa. This is best done by pooling measured groundwater data to update and expand the current numerical model • Kinetic testing of the pillar material should be conducted to aid in the prediction of post mining geochemical conditions. • Process water must be stored in a lined pollution control dam and the processing areas should be designed to prevent standing water. • Clean and dirty water systems should be separated.

Operational Phase	**Groundwater quality - Contamination of groundwater**	Oil, diesel and chemical spills/leaks from machinery and storage facilities	• 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 • Store all potential sources in secure facilities with appropriate storm water management, ensuring contaminants are not released into the environment.
		Sewage related groundwater contamination	• Sewage effluent emanating from latrines or ablution blocks should be treated to acceptable levels before discharge into the environment

Decommissioning and post mining Phase	**Groundwater quantity - change in groundwater level**	Decant volume	• 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. • All sulphate containing waste material should be stored underground and flooded as soon as possible to exclude oxygen. • Treatment of the decant may be viable, however all passive methods should be investigated first during the operational phase of the mine • Major underground fractures encountered while mining must be sealed by grouting, both on inflow and outflow areas
		Potential (positive) impact on base flow of streams-(not predicted)	
	Groundwater quality - Contamination of groundwater	Deterioration of groundwater quality down gradient of the mining operations due to plume movement	• A pollution control dam could be used to intercept polluted seepage water. This should be considered if it is found that the wetlandis indeed negatively affected by pollution. Regular sampling of the streams and wetland is essential to decide on this option if needed. • Implement as many closure measures during the operational phase, while conducting appropriate monitoring programmes to demonstrate actual performance of the various management actions during the life of mine. • All mined areas should be flooded as soon as possible to minimise oxygen from reacting with the remaining pyrite. • Mining should remove all coal from the undergrounds and separate acid forming and non-acid forming material. Deposit acid forming material at the base of the pit. • The final backfilled underground topography should be engineered such that runoff is directed away from the underground areas. • The final layer (just below the topsoil cover) should be as clayey as possible and compacted if feasible, to reduce recharge to the undergrounds. • Quarterly groundwater sampling must be conducted to establish a database of groundwater quality to assess plume movement trends. • Audit the monitoring network annually.

Decommissioning and post mining Phase	**Groundwater quality - Contamination of groundwater**	Contaminants emanating from historic Oil, diesel and chemical spills and facilities	• Remove or remediate areas of hydrocarbon contaminated soils by following a risk based approach, take action if a negative risk is found. A risk assessment should be conducted by a qualified hydrogeologist.

All phases	**Groundwater management**		• All the monitoring data needs to be collated and analysed on at least a bi-annual basis and included in management reports. This information will also be required by government departments (Department of Water Affairs, Department of Environmental Affairs) for compliance monitoring. • After 2 years from start of mining, the monitoring information collated should be used to update the groundwater flow and geochemical models. These models should thereafter be updated so that sufficient mitigation measures can be implemented. Management and mitigation plans should be continuously adapted using the monitoring data.
Closure Phase	**Groundwater management**		• A detailed mine closure plan should be prepared during the operational phase, including a risk assessment, water resource impact prediction etc. as stipulated in the DWA Best Practice Guidelines. • The implementation of the mine closure plan, and the application for the closure certificate can be conducted during the decommissioned phase.

11 CONCLUSIONS AND RECOMMENDATIONS

This section will briefly summarise the current groundwater conditions in the area of the proposed underground, the expected impacts of the mine on the groundwater and the recommendations to minimise the effect of mining on the groundwater.

11.1 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 site.

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 concentration was 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.

11.2 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 underground 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 are made:

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 updated.
- 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 within a 50-100 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 is known from experience and other related studies that over time and especially in underground mines which induce a reducing environment that water quality will gradually improve and return to background water qualities within several years . This is as a result of the depletion of geochemical interactions. 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.

11.3 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.

11.3.1 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.

11.3.2 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:

- The final mine topography should be engineered such that runoff is directed away from the rehabilitated area.
- 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.
- 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.
- Leaving a final void in the underground areas must be investigated. Once final mining plans are available, it will be essential to model this option.

- 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.

11.3.3 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.

11.3.4 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 geophysical 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 be done on available core logs to determine the acid generation capacity of the rocks

Appendix 6

Ambient Air Quality Impact Study in Support of the Access Brown Shaft II Project Area

TITLE AND DESCRIPTIVE ABSTRACT

GEOVICON ENVIRONMENTAL

REPORT 0612-P002C-GEO

AMBIENT AIR QUALITY IMPACT STUDY IN SUPPORT OF THE BROWN SHAFT II PROJECT OF GOEDEHOOP COLLIERY

This report documents the results and findings of an air quality impact investigation pertaining to the utilisation of coal reserves by Anglo Coal on the farm Wolvenfontein 471 JS in the Mpumalanga Province.

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TECHNICAL VERIFICATION

All results and related data have been obtained through careful and precise execution of recognised methods of evaluation and are related only to the scope of work covered in this report and of prevailing conditions at the time of the assessment. The opinions and interpretations are embraced through judgment, discernment and comprehension to the best of available knowledge.

Fieldwork and report compilation performed by:

[signature]	21 November 2012
Uno Neveling M.Sc.	Date

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1. *INTRODUCTION*

1.1. TERMS OF REFERENCE

Environmental and Health Risk Consulting was retained by Geovicon Environmental to perform an ambient air quality impact assessment in support of the proposed Brown Shaft II Project of Goedehoop Colliery.

The project is situated approximately 23km south of Middelburg and 30km east south-east of Emalahleni within the Steve Tshwete Municipality, one of six Local Municipalities comprising the Nkangala District Municipality.

The scope of this study was based on specific conditions outlined by Mr R Bate of Geovicon Environmental.

The objectives of this study were to describe the ambient emissions from the coal mining process and to assess the impact on the health of the receiving community. The findings of the study are aimed at providing Anglo Coal, the Mpumalanga Provincial Government Department of Agriculture and Land Administration and other stakeholders with scientific data required in terms of present and future air quality management systems.

The inclined shaft for the underground mining operation will be situated on the farm Wolvenfontein 471JS.

Potential sensitive receptors associated with this project include commercial establishments and residential dwellings near the mining operation.

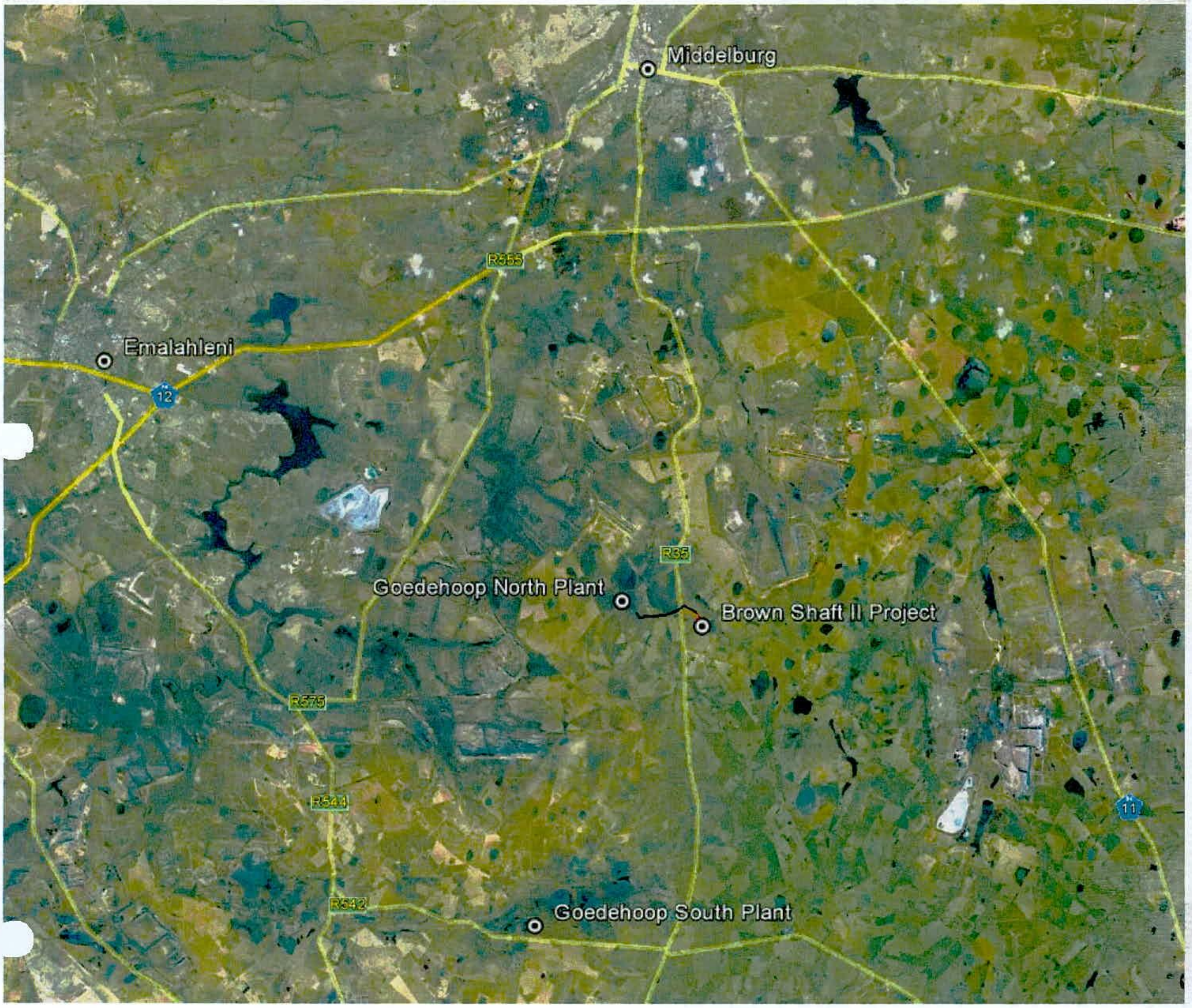


Figure 1: Location of the Brown Shaft II Project

The assessment of the potential air quality impact associated with the Brown Shaft II Project considered the following terms of reference:

- A review of the legislative framework, ambient air quality standards and guidelines as well as relevant health criteria (Chapter 2).
- A process description and baseline emission inventory (Chapter 3).

- A description of the local climate and meteorology (Chapter 3).
- An overview of available data on criteria air pollutant concentrations in the area (Chapter 4).
- Assessment of the potential for human health and environmental impacts based on comparisons of modelled pollutant concentrations with relevant guidelines and standards (Chapter 4).
- Assessment of the incremental contribution of the process and the cumulative outcome on selected future air quality parameters in the study area (Chapter 4).

1.2. METHODOLOGICAL OVERVIEW

The establishment of an emissions inventory formed the basis for assessing the impact from the project. The inventory comprised the identification of sources of emission and the quantification of each source's contribution to ambient air concentrations. In the emissions inventory, dispersion simulation and impact assessment, reference was made to routine emissions from production and support processes.

Process emission rates were obtained from emission factors which associate the quantity of a pollutant to the activity associated with its release. Due to the absence of locally generated emission factors, use was made of the comprehensive set of emission factors published by the United States Environmental Protection Agency (US-EPA) in its AP-42 document *Compilation of Pollution Emission Factors*.

The simulation of emissions was performed through the application of the ISC-AERMOD View Model. AERMOD is a steady-state plume model, applicable to rural and urban areas, flat and complex terrain, surface and elevated releases, and multiple sources (including, point, area and volume sources). In the stable boundary layer (SBL), the concentration distribution is assumed to be Gaussian in both the vertical and horizontal. In the convective boundary layer (CBL), the horizontal distribution is assumed to be Gaussian, but the vertical distribution is described with a bi-Gaussian probability density function. Additionally, in the CBL, AERMOD treats "plume lofting," whereby a portion of plume mass, released from a buoyant source, rises to and remains near the top of the boundary layer before becoming mixed into the CBL. AERMOD also tracks any plume mass that penetrates into elevated stable layer, and then allows it to re-enter the boundary layer when and if appropriate.

Ambient pollutant concentrations were simulated to ascertain highest daily and annual averaging levels to facilitate comparisons with air quality guidelines.

1.3. KEY FINDINGS

The study, aimed at describing emissions from coal mining operations at the Brown Shaft II Project of Goedhoop Colliery near Middelburg, concludes the following:

- Suspended particulates account for most emissions from the process with PM_{10} being the criteria pollutant of consequence.
- Dispersion of particulate emissions from the process was modelled using the ISC-AERMOD View model based on the standard Gaussian solution.
- The results present the spectrum from maximum ground level concentration to maximum impact area, and accounts for daily and annual reference periods.
- Ground level concentrations were predicted for atmospheric conditions based on local meteorological data for the period June 2007 to May 2012.
- Nuisance dust from construction operations will probably exceed the residential action level up to a distance of 400m downwind of operations. The receivers of concern are the commercial/residential dwellings at the R35/Bank Road intersection.
- During normal operations dust deposition rates as high as 1 100mg/m^2/day are predicted on-site, during extreme pollution episodes associated with dry and windy spells. Vehicles entering and leaving the mine will always be the most visible sources of pollution.
- It is unlikely that nuisance dust emanating from the project will have negative long term health impacts on people residing in the study area.
- PM_{10} concentrations are likely to remain below the 24-hour and annual AQA limits during the operational phase of the project.
- Maximum daily concentrations as high as 118µg/m^3 could occur within the shaft area boundary.
- Annual PM_{10} concentrations will remain below the current background levels at the nearest sensitive receivers.

- Air quality management during the operational phase of the mine should focus on all residences within a radius of 1 kilometre from the mining operation.
- The impact assessment considered the cumulative effects on air quality caused by the aggregate of past and present actions in the area.
- Modelling predictions are based on emission reduction factors ranging from 70% to 90% for selected activities. Implementation of a combination of control measures in a focused approach will see a further reduction in the predicted impact area.
- Source monitoring should be used in combination with modelling to assess the effectiveness of control measures at the receiving environment.
- Strict monitoring of ambient air quality will assist effective air quality management and open communication to all stakeholders.

2. *AIR QUALITY ASSESSMENT CRITERIA*

2.1. AIR QUALITY DESCRIPTORS

The following words or expressions form the basis of the Act, existing guidelines and SANS standards and will be used in this report-

a) **acceptable** to the authority administering this standard or to the parties concluding the purchase contract, as relevant.

b) **air pollution** means any change in the composition of the air, caused by smoke, soot, dust (including fly ash), cinders, solid particles of any kind, gases, fumes, aerosols and odorous substances.

c) **air quality standard** comprises limit values based on health risk or environmental risk (or both) and associated averaging periods indicative of exposure durations, in addition to the following criteria:
   - monitoring and data management protocols for air quality assessment and reporting;
   - permissible frequencies of exceeded limit values within defined time frames; and
   - time frames for achieving compliance in non-attainment areas

d) **agglomeration** area with a population of 250 000 or more inhabitants or, where the population is less than 250 000 inhabitants, a population density per square kilometre that justifies the need for ambient air quality to be assessed and managed.

e) **alert threshold** level beyond which there is a risk to human health from brief exposure and for which priority action is required.

f) **ambient air** means outdoor air in the troposphere, excluding work places, were air quality is determined in accordance with SANS 1929:2005.

g) **assessment** method used to measure, calculate, predict or estimate the level of a pollutant in the ambient air.

h) **assessment threshold**
   - **lower assessment threshold** level below which modelling or objective estimation techniques alone may be used to assess ambient air quality; and

- **upper assessment threshold** level above which monitoring is mandatory, and below which a combination of measurements and modelling techniques may be used to assess ambient air quality.

i) **atmospheric emission** or **emission** means any emission or entrainment process emanating from a point, non-point or mobile source that result in pollution.

j) **national** authority national authority responsible for air quality.

k) **provincial authority** provincial government department tasked with air quality management under the National Environmental Management: Air Quality Act.

l) **local authority** local government department tasked with air quality management under the National Environmental Management: Air Quality Act.

m) **averaging period** over which average value is determined.

n) **level** concentration of a pollutant in ambient air or the deposition thereof over a given time.

o) **limit value** level fixed on the basis of scientific knowledge, with the aim of avoiding, preventing or reducing harmful effects on human health or the environment as a whole (or both), to be attained within a given period and not to be exceeded once attained.

p) **margin of tolerance** percentage of the limit value by which this value may be exceeded, subject to the conditions laid down in SANS 69:2004.

q) **natural events** geothermal activities, bush fires, high winds or the atmospheric re-suspension or transport of natural particles from dry regions.

r) **pollutant** substance introduced directly or indirectly by man into the ambient air and likely to have harmful effects on human health or the environment as a whole (or both).

s) **priority area** identified and proclaimed as a priority area by the Minister of Environmental Affairs and Tourism or any member of the executive committee (MEC), by notice in the Gazette and after consultation with relevant stakeholders, where he/she is of the opinion that:
   - ambient air quality limits or values are being, or are likely to be exceeded; or
   - any other harmful situation exists; and
   - the limits or values being exceeded are causing, or may cause, a significant negative impact on the environment or health.

t) **PM10** particulate matter which passes through a size-selective inlet with a 50% efficiency cut-off at 10μm aerodynamic diameter.

u) **target value** level fixed with the aim of avoiding more long-term harmful effects on human health and the environment as a whole, to be attained where possible over a given period.

v) **zone** area designated by the national authority in which limit values for a specific pollutant are exceeded owing to the concentrations of that pollutant in ambient air due to natural sources.

2.2. MINISTRY OF ENVIRONMENTAL AFFAIRS AND TOURISM

The exclusive use of source-based controls (e.g. emission limits) as an air quality management tool has been found to have important short-comings. Emission limits do not take the unique characteristics of the receiving environment into account, such as the dispersion potential, existence of other sources, existing ambient pollutant concentrations, and the sensitivity of the receiving environment. Such limits therefore provide no insurance that ambient air quality objectives will be achieved and that there will be no adverse effects on human health and welfare.

There is a strong shift from air pollution control based exclusively on source-based methods (e.g. emission limits) to air quality management based on an effects-based approach (e.g. air quality objectives). An effects-based approach requires the setting of ambient air quality guidelines and standards. Ambient air quality guidelines and standards are laid down by various countries, including South Africa, for the regulation of air concentrations of various criteria pollutants (e.g. sulphur dioxide, particulate matter, nitrogen oxides and lead). Such ambient guideline and standards define satisfactory air quality to ensure human health and welfare, thus providing objectives for air quality management.

Air quality guidelines and standards are fundamental to effective air quality management, providing the link between the source of atmospheric emissions and the receptor. These guideline values indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout the individual's entire lifetime. Air quality guidelines and standards are normally given for specific averaging periods, i.e. the duration over which the standard or guideline is applicable. Generally, five averaging periods are applicable, namely an instantaneous peak, 1-hour average, 24-hour average, 1-month average and annual average.

DEAT have brought into effect the National Environmental Management: Air Quality Act (Act No. 39 of 2004, AQA) on 11 September 2005 as part of a broad programme of air quality management reform.

The publication in May 2000 of government's Integrated Pollution and Waste Management Policy (IP & WM Policy) marked a turning point for pollution and waste governance in South Africa. The National Air Quality Management Plan (NAQMP), borne from the IP & WM Policy, has as its definition AQA.

Government's vision with respect to the NAQMP is that the programme will develop, implement and maintain an air quality management regime that contributes to sustainable development and a measurable improvement in the quality of life of all, by harnessing the energy and commitment of all South Africans for the effective prevention, minimisation and control of atmospheric pollution.

DEAT is responsible for establishing a national framework for achieving the objectives of AQA, which includes –

a) mechanisms, systems and procedures to attain compliance with ambient air quality standards;
b) mechanisms, systems and procedures to give effect to the Republic's obligations in terms of international agreements;
c) national norms and standards for the control of emissions from point and non-point sources;
d) national norms and standards for air quality monitoring;
e) national norms and standards for air quality management planning;
f) national norms and standards for air quality information management; and
g) any other matter which the Minister considers necessary for achieving the objectives of the Act.

The establishment of national ambient air quality standards is achieved through AQA and the South African Bureau of Standards (SABS) standard setting initiative. Schedule 2 (Section 63) of AQA pertaining to ambient air quality standards is summarised in **Table 1** below.

Table 1:

Ambient air quality standards – DEA

(@ 25°C and 101.3 kPa)

Substance	Time-weighted average (µg/m³)				
	10-minutes	1-hour	8-hour	24-hour	Annual
Ozone (O_3)	n.a.	n.a.	120[1]	n.a.	n.a.
Nitrogen dioxide (NO_2)	n.a.	200[2]	n.a.	n.a.	40
Sulphur dioxide (SO_2)	500[3]	350[2]	n.a.	125[4]	50
Lead (Pb)	n.a.	n.a.	n.a.	n.a.	0.5
Particulate matter (PM_{10})	n.a.	n.a.	n.a.	120[4] 75[4]*	50 40*
Particulate matter ($PM_{2.5}$)	n.a.	n.a.	n.a.	65[4] 40[4]** 25[4]***	25 20** 15***
Carbon monoxide (CO)	n.a.	30 000[2]	10 000[1]	n.a.	n.a.
Benzene (C_6H_6)	n.a.	n.a.	n.a.	n.a.	10 5*

Note:

µg/m³	:	microgram per cubic meter air
DEA	:	Department of Environmental Affairs
1	:	Not to be exceeded more than 11 times per annum.
2	:	Not to be exceeded more than 88 times per annum.
3	:	Not to be exceeded more than 526 times per annum.
4	:	Not to be exceeded more than 4 times per annum.
5	:	Not to be exceeded more than 4 times per annum.
*	:	All standards are to be complied with immediately. Standards indicated with one asterisk are to be complied with as from 1 January 2015. Standards with two asterisks are to be complied with as from 1 January 2016. Standards with three asterisks are to be complied with as from 1 January 2030.

2.3. SOUTH AFRICAN BUREAU OF STANDARDS

South African National Standard SANS 69:2009 "Framework for setting and implementing national ambient air quality standards" defines the basic principles of a strategy to:

a) define and establish objectives for ambient air quality in South Africa designed to avoid, prevent or reduce harmful effects on human health and the environment as a whole, taking into account technical, economic, social, political, and strategic considerations;
b) assess the ambient air quality within provinces and within metropoles and towns on the basis of common methods and criteria;
c) establish adequate databases of ambient air quality at local government level that is consolidated on a national basis and that assists with prioritisation on local and national levels;
d) report air quality information to the public, particularly in instances where air pollution levels can be harmful; and
e) endeavour to preserve ambient air quality where it is good and improve it in other cases, compatible with sustainable development.

This standard support the establishment and implementation of a system of multiple levels of air quality objectives, including limit values and associated time frames for attainment, target values and alert thresholds.

In order to take into account the actual levels of a given pollutant when setting limit values and the time needed to implement measures for improving the ambient air quality, the national authority may also make provision for temporary margins of tolerance.

The system of air quality objectives intended for implementation in South Africa is modelled on the tiered or banded approach applied by the European Community. The exceeding of thresholds therefore does not result in litigation, as in the United States of America, but rather in the initiation of more intensive air quality management planning. The banded approach also encourages the management of air pollution to the lowest levels which can cost-effectively be met while compatible with sustainable development objectives, rather than ensuring that pollution levels stay just below the relevant threshold.

An updated edition of SANS 1929:2005 "Ambient air quality – Limits for common pollutants", SANS 1929:2009, was published for comment in October 2008. This standard gives limit values for common pollutants to ensure that the negative effects of such pollutants on human health are prevented or reduced. Limit values given in this standard are expressed for common pollutants as are the margins of tolerance, compliance time frames and permissible frequencies by which the limit values may be exceeded.

It is recognised that, although national limit values laid down primarily aim at the protection of human health, these limit values might be revised in future to address other components of the environment such as vegetation and ecosystems.

Concentrations shall be expressed at a standardised temperature of 25°C and a pressure of 101.3kPa. Where test methods are specified, any other method which can be demonstrated to give equivalent results may be used.

Dust deposition

The four-band scale which should be used in the evaluation of dust deposition is given in **Table 2** and target, action and thresholds are indicated in **Table 3**.

An enterprise may submit a request to the authorities to operate within band 3 (action band), as specified in **Table 2**, for a limited period, provided that this is essential in terms of the practical operation of the enterprise (for example the final removal of a tailings deposit) and provided that an appropriate control technology is applied for the duration. No margin of tolerance will be granted for operations that result in dust deposition rates which fall within band 4 as specified in **Table 3**.

Dust depositions that exceed the specified rates but can be shown to be the result of some extreme weather or geological event shall be discounted for the purpose of enforcement and control. Such event might typically result in excessive dust deposition rates across an entire metropolitan region, and not be localised to a particular operation. Natural seasonal variations, for example, the naturally windy months each year, will not be considered extreme events for this definition.

Table 2:

Four-band scale evaluation criteria for dust deposition – SANS 1929:2009

Band number	Band description	Dust deposition rate, *D* ($mg/m^2/day$)	Comment
1	Residential	$D < 600$	Permissible for residential and light commercial.
2	Industrial	$600 < D < 1\,200$	Permissible for heavy commercial and industrial.
3	Action	$1\,200 < D < 2\,400$	Requires investigation and remediation if two sequential months lie in this band, or more than three occur in a year.
4	Alert	$2\,400 < D$	Immediate action and remediation required following the first incidence of the dust deposition rate being exceeded. Incident report to be submitted to the relevant authority.

Notes:
D : Dust deposition rate in milligram per square metre per day over a 30-day averaging period

Table 3:

Target, action and alert thresholds for dust deposition – SANS 1929:2009

Level	Dust deposition rate, *D* ($mg/m^2/day$)	Averaging period	Comment
Target	300	Annual	No comment.
Action residential	600	30 days	Three within any year, no sequential months.
Action industrial	1 200	30 days	Three within any year, not sequential months.
Alert threshold	2 400	30 days	None. First incidence of dust deposition being exceeded requires remediation and compulsory report to the relevant authorities.

Notes:
D : Dust deposition rate in milligram per square metre per day over a 30-day averaging period

The reference method for measuring dustfall shall be ASTM D 1739.

2.4. HIGHVELD PRIORITY AIRSHED

The overarching constitutional right to an environment that is not harmful to health or well-being is captured in the objectives of the National Environmental Management: Air Quality Act (No. 39 of 2004) (NEMAQA). Importantly, the promulgation of NEMAQA marked a turning point in the approach to air pollution control and governance in South Africa, introducing the philosophy of Air Quality Management, in line with international policy developments and the environmental right, i.e. Section 24 of the Constitution (Act No. 108 of 1996). The focus shifted from source control to management of pollutant levels in the ambient environment. Numerous tools and instruments are incorporated into the NEMAQA, including the establishment of Priority Areas approach (Sections 18 to 20) of the NEMAQA in so-called "hot-spot" areas where ambient air quality standards are exceeded or may be exceeded. This important air quality management tool has three strategic drivers:

i. It effectively allows for the concentration of limited air quality management capacity (human, technical and financial) for dealing with acknowledged problem areas in order to obtain measurable air quality improvements in the short-, medium- and long-term;
ii. It prescribes a cooperative governance regime by effectively handing-up air quality management authority to the tier of government that can provide leadership and coordination; and
iii. It allows for cutting edge air quality management methodologies that take into account all contributors to the air pollution problem, i.e. "air-shed" air quality management.

The Highveld area in South Africa is associated with poor air quality and elevated concentrations of criteria pollutants occur due to the concentration of industrial and non-industrial sources. The Minister of Environmental Affairs therefore declared the Highveld Priority Area (HPA) on 23 November 2007. As the area declared overlaps provincial boundaries, the Department of Environmental Affairs (DEA) functions as the lead agent in the management of the priority area and is required in terms of Section 19(1) of the NEMAQA to develop an AQMP for the priority area.

The Highveld Priority Area covers 31 106 km^2, including parts of Gauteng and Mpumalanga Provinces, with a single metropolitan municipality, three district municipalities, and nine local municipalities (see **Figure 2** below).

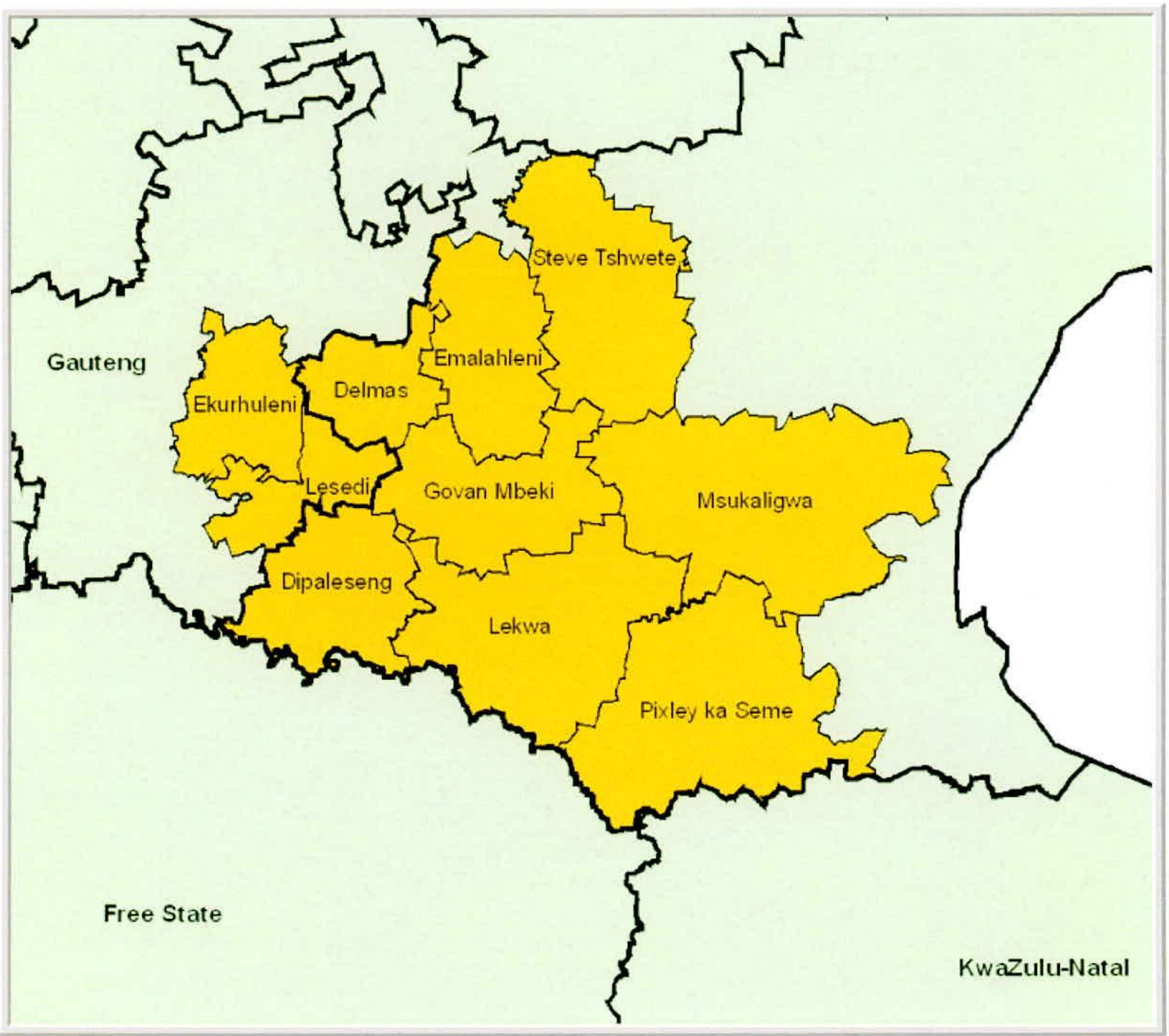


Figure 2: Locality of the Highveld Priority Area (from AQMP for the HPA, DEA 2010)

The baseline assessment for the HPA made a succinct presentation of the major issues to be addressed. Concerns have been highlighted in the areas of ambient air quality, technology and capacity. These issues will be carried forward into the strategy analysis and management planning stages of the AQMP development. The Logical Framework Approach workshop will assist in developing these aspects of the AQMP, where stakeholders will work towards the interventions to be implemented in the HPA.

3. *BACKGROUND*

3.1. PROCESS

Anglo Coal intends to mine coal from the Brown Shaft II Project using underground mining techniques. The Life of Mine (LOM) is 5 years at a rate of 2 000 000 tons of coal per annum.

Run-of-mine coal will be beneficiated at the Goedehoop North Plant. An overland conveyer system will link the Brown Shaft II Project with existing operations.

The following activities were considered as part of this investigation:

a) Construction phase;
b) Operational phase; and
c) Decommissioning.

Figure 3 on the next page contains the surface infrastructure plan for the Brown Shaft II Project.

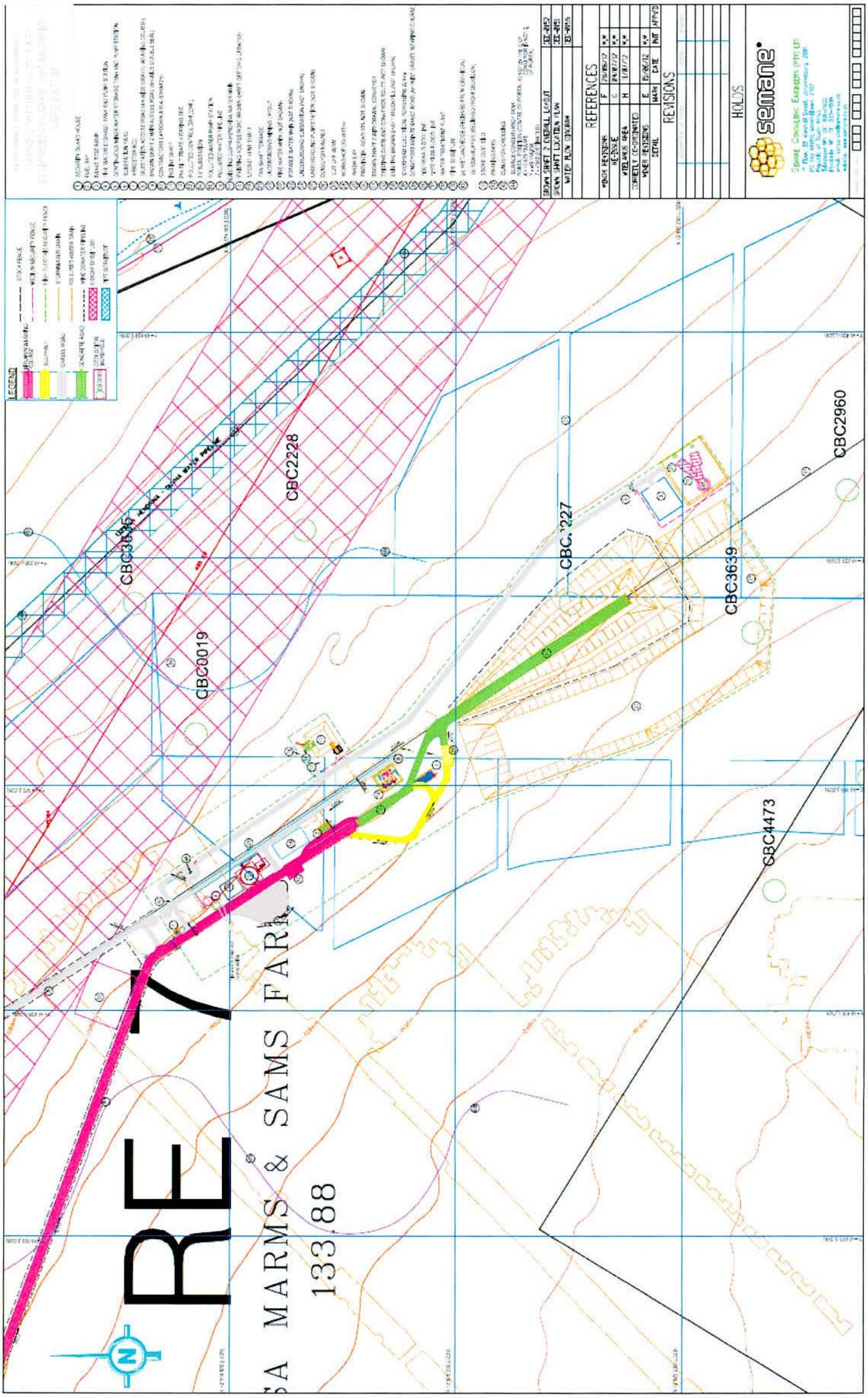
<u>**Construction Phase:**</u>

Construction of access and ventilation shafts. This would involve the following actions:

- Removal of vegetation,
- Stripping of topsoil and subsoil,
- Drilling and blasting of hard overburden to construct the incline shaft.

Construction of access roads and overland conveyor. This would involve the following actions:

- Removal of vegetation,
- Stripping of topsoil,
- Use of subsoil to construct haul roads, and
- Compaction and grading of surfaces.



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Stockpiling of topsoil. This would involve the following actions:

- Separate stockpiling of topsoil and subsoil.
- Separate stockpiling of carbonaceous overburden and non-carbonaceous overburden.
- Stockpiling of carbonaceous overburden on prepared stockpiling areas.

Construction of water management infrastructure. This would involve the following actions:

- Removal of vegetation,
- Stripping of topsoil and subsoil,
- Excavation of diversion trenches,
- Utilisation of subsoil to construct isolation and diversion berms,
- Construction of the pollution control dam,
- Compaction of surfaces,
- Laying down of lining materials, where applicable, and
- Construction of silt and oil traps.

Construction of Access Control and Offices (including ablution facilities). This would involve the following actions:

- Removal of vegetation,
- Stripping of topsoil and subsoil,
- Excavations for, and construction of, building foundations,
- Compaction of surfaces,
- Temporary storage of building materials,
- Construction of buildings,
- Excavation for, and installation of, underground domestic wastewater storage tanks.

Construction of Workshops. This would involve the following actions:

- Removal of vegetation,
- Stripping of topsoil and subsoil,
- Compaction of surfaces,
- Temporary storage of building materials,
- Construction of foundations and buildings,

- Construction of paved / tarred / cemented surfaces, particularly for vehicle maintenance and hazardous / contaminating substance storage areas,
- Construction of washbays.
- Excavation for, and installation of, underground domestic wastewater storage tanks.

Construction of a power supply system.

Operational Phase:

This phase begins when the first load of coal is removed from the ground and ends when the last load coal is removed from the ground.

Underground mining. This would involve the following actions.

- The Bord-and-pillar method will be used where the coal seam is mined out in a checker board pattern, leaving square pillars of coal for roof support.
- Access shaft operation to transport employees and material to and from underground mining areas
- Operation of ventilation shafts to ensure good quality air to all employees working underground.

Use and maintenance of access and service roads.

Operation and maintenance storm water and pollution control measures.

Utilisation of Access Control and Offices (all including ablution facilities).

Utilisation of Workshop. This involves the following actions:

- Utilisation of paved / tarred surfaces for vehicle maintenance areas,
- Utilisation of washbays, and
- Storage and disposal of waste (domestic).

Decommissioning Phase:

This phase begins when the last load of coal is removed from the ground and ends when the mine receives a Closure certificate from the Department of Minerals and Resources (DMR). During this phase, rehabilitation will continue to take place.

Rehabilitation of all remaining surface areas directly affected by mining activities. This would involve the following actions:

- Backfilling of final void with overburden (unless the voids are required for long term water management purposes),
- Compaction of backfilled void,
- Distribution and shaping of subsoil and topsoil, and
- Seeding of landscaped areas.

Ripping up of redundant access and service roads (dependent on the rehabilitation plan and the agreed upon post-closure end land-use).

Removal of all redundant surface water management measures (berms and trenches) (dependent on the rehabilitation plan and the agreed upon post-closure end land-use).

Continued implementation of the long-term water management strategy.

Removal of all redundant infrastructure (dependent on the rehabilitation plan and the agreed upon post-closure end land-use).

Monitoring and maintenance of all environmental aspects as committed to in the approved Environmental Management Program (EMP).

Rehabilitation of all surface areas indirectly affected by mining activities, such as subsided areas.

3.2. EMISSIONS INVENTORY

Construction

Heavy construction is a source of dust emissions that may have substantial temporary impact on local air quality. Building and road construction are two examples of construction activities with high emissions potential. Emissions during the construction of a building or road can be associated with land clearing, drilling and blasting, ground excavation, cut and fill operations (i.e., earth moving), and construction of a particular facility itself. Dust emissions often vary substantially from day to day, depending on the level of activity, the specific operations, and the prevailing meteorological conditions. A large portion of the emissions results from equipment traffic over temporary roads at the construction site.

The temporary nature of construction differentiates it from other fugitive dust sources as to estimation and control of emissions. Construction consists of a series of different operations, each with its own duration and potential for dust generation. In other words, emissions from any single construction site can be expected (1) to have a definable beginning and an end and (2) to vary substantially over different phases of the construction process. This is in contrast to most other fugitive dust sources, where emissions are either relatively steady or follow a discernable annual cycle. Furthermore, there is often a need to estimate area-wide construction emissions, without regard to the actual plans of any individual construction project.

The quantity of dust emissions from construction operations is proportional to the area of land being worked and to the level of construction activity. By analogy to the parameter dependence observed for other similar fugitive dust sources, one can expect emissions from heavy construction operations to be positively correlated with the silt content of the soil (that is, particles smaller than 75 micrometers [μm] in diameter), as well as with the speed and weight of the average vehicle, and to be negatively correlated with the soil moisture content.

Fugitive dust sources

Significant atmospheric dust arises from the mechanical disturbance of granular material exposed to the air. Dust generated from these open sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream. Common sources of fugitive dust include unpaved roads, agricultural tilling operations, aggregate storage piles, material handling and heavy construction operations.

From the time a mining area is disturbed until new vegetation emerges, all disturbed areas are subject to wind erosion.

For the above sources of fugitive dust, the dust-generation process is caused by 2 basic physical phenomena:

1. Pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.).
2. Entrainment of dust particles by the action of turbulent air currents, such as wind erosion of an exposed surface by wind speeds over 19 kilometers per hour (km/hr) (5.3 m/s).

The impact of a fugitive dust source on air pollution depends on the quantity and drift potential of the dust particles injected into the atmosphere. In addition to large dust particles that settle out near the source (often creating a local nuisance problem), considerable amounts of fine particles also are emitted and dispersed over much greater distances from the source.

The potential drift distance of particles is governed by the initial injection height of the particle, the terminal settling velocity of the particle, and the degree of atmospheric turbulence. Theoretical drift distance, as a function of particle diameter and mean wind speed, has been computed for fugitive dust emissions. Results indicate that, for a typical mean wind speed of 16 km/hr (4.4 m/s), particles larger than about 100 µm are likely to settle out within 6 to 9 meters (20 to 30 feet) from the edge of the road or other point of emission. Particles that are 30 to 100 µm in diameter are likely to undergo impeded settling. These particles, depending upon the extent of atmospheric turbulence, are likely to settle within a few hundred feet from the source. Smaller particles, particularly TSP and PM-10, have much slower gravitational settling velocities and are much more likely to have their settling rate retarded by atmospheric turbulence.

Dust emissions may be generated by wind erosion of open aggregate storage piles and exposed areas within an industrial facility. These sources typically are characterized by nonhomogeneous surfaces impregnated with non-erodible elements (particles larger than approximately 1 centimeter in diameter). Field testing of coal piles and other exposed materials using a portable wind tunnel has shown that (a) threshold wind speeds exceed 5 meters per second (m/s) at 15 cm above the surface or 10 m/s at 7 m above the surface, and (b) particulate emission rates tend to decay rapidly (half-life of a few minutes) during an erosion event. In other words, these aggregate material surfaces are characterized by finite availability of erodible material (mass/area) referred to as the erosion potential. Any natural crusting of the surface binds the erodible material, thereby reducing the erosion potential.

Vehicle transport emissions

When a vehicle travels an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed.

The quantity of dust emissions from a given segment of unpaved road varies linearly with the volume of traffic. Field investigations also have shown that emissions depend on source parameters that characterize the condition of a particular road and the associated vehicle traffic. Characterization of these source parameters allow for "correction" of emission estimates to specific road and traffic conditions present on public and industrial roadways.

Dust emissions from unpaved roads have been found to vary directly with the fraction of silt (particles smaller than 75 micrometers in diameter) in the road surface materials.

Other variables are important in addition to the silt content of the road surface material. For example, at industrial sites, where haul trucks and other heavy equipment are common, emissions are highly correlated with vehicle weight.

Emission factors

Data for this investigation were obtained from a number of sources within the Office of Air Quality Planning and Standards (OAQPS) of the United States Environmental Protection Agency. The AP-42 background files located in the Emission Factor and Inventory Group (EFIG) were reviewed for information on the industry, processes, and emissions.

National Pollution Inventory series document *Emission Estimation Technique Manual for Mining* published by the Australian Government Department of Sustainability, Environment, Water, Population and Communities was also used to supplement the study. **Table 4** below summarizes the emission factors and emission rates for the Brown Shaft II Project.

Table 4a:

Brown Shaft II Project – Emission factors

Activity	Emission factor	
	TSP	**PM10**
1. Construction and pre-mining:		
a. Fugitive emissions [a]	2.69 Mg/hectare/year	1.40 Mg/hectare/year
2. Underground mining:		
a. ROM coal conveying to North Plant [b]	0.003 kg/Mg	0.00014 kg/Mg
b. All underground activities [b]	1.156 mg/m^3	0.404 mg/m^3
3. Auxiliary equipment:		
a. Toyota LDV 2.5 D-4D [c]	1.26 kg/VKT	0.39 kg/VKT

Notes:

a : US EPA, AP42, Volume I, 5 Edition, Chapter 13.2/11.9.
b : Australian Government, Emission Estimation Technique Manual for Mining, Version 3.
c : US EPA, AP42, Volume I, 5 Edition, Chapter 13.2.
Average vehicle weight of 1 530kg and average road silt content 13.6%.

Table 4b:

Brown Shaft II Project – Emission rates

Activity	Emission Control Factor (%) [b]	Emission rate (g/s) [a]	
		TSP	PM10
1. Construction and pre-mining:			
a. Fugitive emissions [b]	No control	0.383	0.199
3. Underground mining:			
a. ROM coal conveying to North Plant [c]	75%	0.394	0.018
b. All underground activities [d]	99%	0.231	0.081
6. Auxiliary equipment:			
a. Toyota LDV 2.5 D-4D [e]	75%	0.729	0.226

Notes:

a	:	Emission rate in gram per second.
b	:	Construction footprint area of 4.5ha
c	:	ROM of 170 000 tons/month, two transfer stations
d	:	Stack height of 5m, flow rate of 200 m^3/s and temperature of 25°C
e	:	100km/day for LDVs,

3.3. METEOROLOGY

The macro-ventilation characteristics of a region are determined by the nature of the synoptic systems that dominate the circulations of the region, and the nature and frequency of occurrence of alternative systems and weather perturbations over the region. Meso-scale processes affecting the dispersion potential include thermo-topographically induced circulations, the development and dissipation of surface inversions, and the modification of the low-level wind field and stability regime by urban areas.

Atmospheric processes at meso-scale were taken onto account in the characterisation of the atmospheric dispersion potential of the study area. Reference was made to hourly average meteorological data recorded by the South African Weather Service in Emalahleni, modelled to the site of the Brown Shaft II Project. Parameters that need to be taken into account in the characterisation of meso-scale ventilation potentials include wind speed, wind direction, extent of atmospheric turbulence, ambient air temperature and mixing depth.

Summary of Climatic Region H - The Highveld

The South African Weather Service has partitioned the country into 15 climatic regions. This division is based firstly on geographic considerations, more specifically the prominent mountain ranges (great escarpment) which after constitutes the main climatic divides, besides also other features such as rivers and political boundaries; secondly, on the interior plateau, use has been made of the change from BW to BS and from BS to C climates according to the Köppen classification.

The average annual precipitation in the Highveld region varies from about 900mm on its eastern border to about 650mm in the west. The rainfall is almost exclusively due to showers and thunderstorms and falls mainly in summer (85% of annual rainfall), from October to March, the maximum fall occurring in January. Heavy falls of 125 to 150mm occasionally fall in a single day. The annual average number of thunderstorms is 75. These storms are often violent with severe lightning and strong gusty south-westerly winds and are sometime accompanied by hail. The region has the highest hail frequency in South Africa; about 4 to 7 occurrences can be expected annually in one spot.

Average daily maximum temperature is roughly 27°C in January and 17°C in July but in extreme cases these may rise to 30°C and 26°C respectively. Average daily minima range from about 13°C in January to 0°C in July, whereas extremes can sink to 1°C and -13° respectively. The period during which frost is likely to form lasts on the average for about 120 days from May to September.

Air temperature is important, both for determining the effect of plume buoyancy (the larger the temperature difference between the plume and the ambient air, the higher the plume is able to rise), and determining the development of mixing and inversion layers.

Surface wind field

Dispersion comprises vertical and horizontal components of motion. The wind field largely determines the horizontal dispersion of pollution in the atmospheric boundary layer. The wind speed determines both the distance of downwind transport and the rate of dilution as a result of plume stretching. The generation of mechanical turbulence is similarly a function of the wind speed, in combination with the surface roughness. The wind direction and the variability in wind direction, determine the general path pollutants will follow, and the extend of cross-wind spreading.

In the study area, the mean daytime surface winds are predominantly northwesterly as a result of the prevalent anticyclonic circulation, with easterly winds being the next most frequent. In the winter, the frequency of southwesterly winds increases because of the passage of cyclonic westerly waves. Light topographically induced winds from the eastern sector are common at night. The so-called Escarpment Breeze that develops at night under weak pressure gradients is up to 1 000m deep.

Winds are mostly light except during thunderstorms. Very occasionally tornadoes do occur. Sunshine duration in summer is about 60% and in winter about 80% of the possible.

An annual average surface wind speed of 2.8m/s was recorded from 1 June 2007 to 31 May 2012.

Period, diurnal, and seasonal wind roses for the period 1 June 2007 to 31 May 2012 are presented in **Figure 4**. Wind roses comprise 16 spokes, which represents the directions from which winds blew during the period. The colours used in the wind roses reflect the different categories of wind speeds. The dotted circles provide information regarding the frequency of occurrence of wind speed and direction categories. The value given in the centre of the circle describes the frequency with which calms occurred, i.e. periods during which the wind speed was below 1m/s.

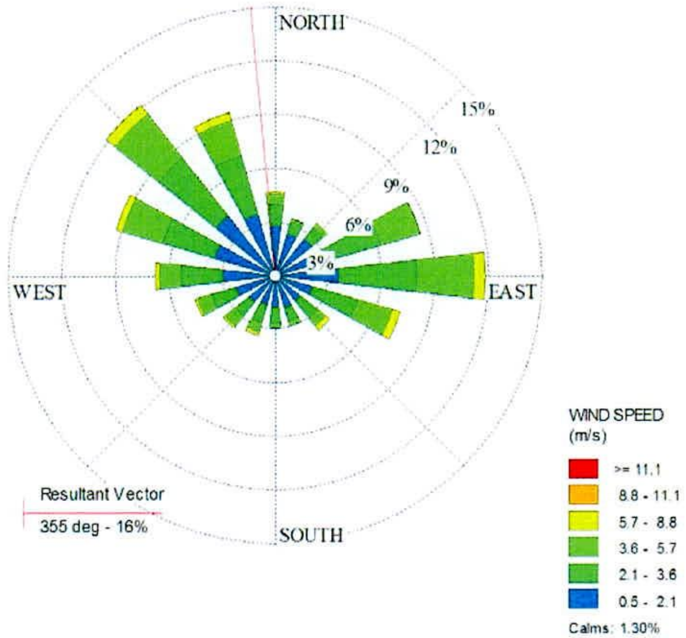

Figure 4a: Period wind rose

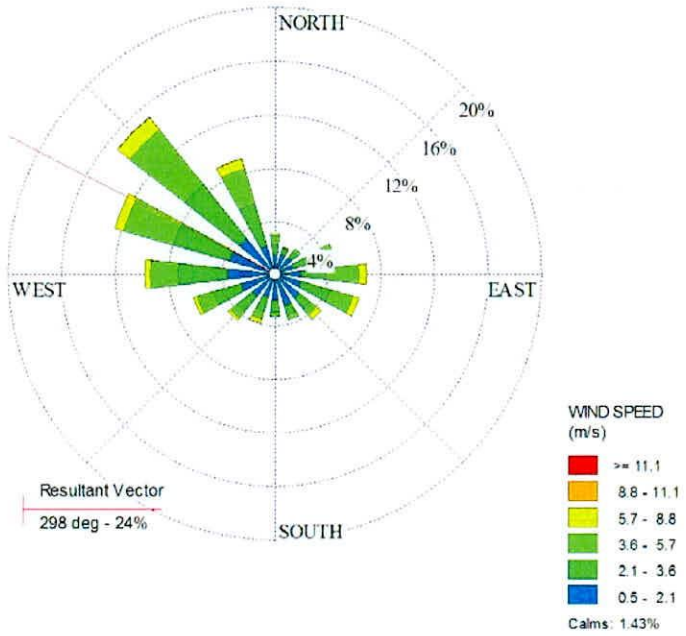

Figure 4b: Day-time wind rose

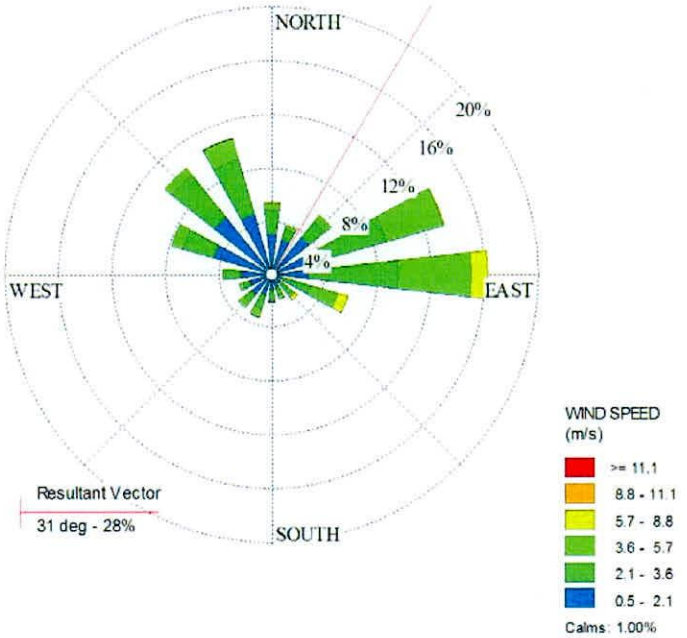

Figure 4c: Evening wind rose

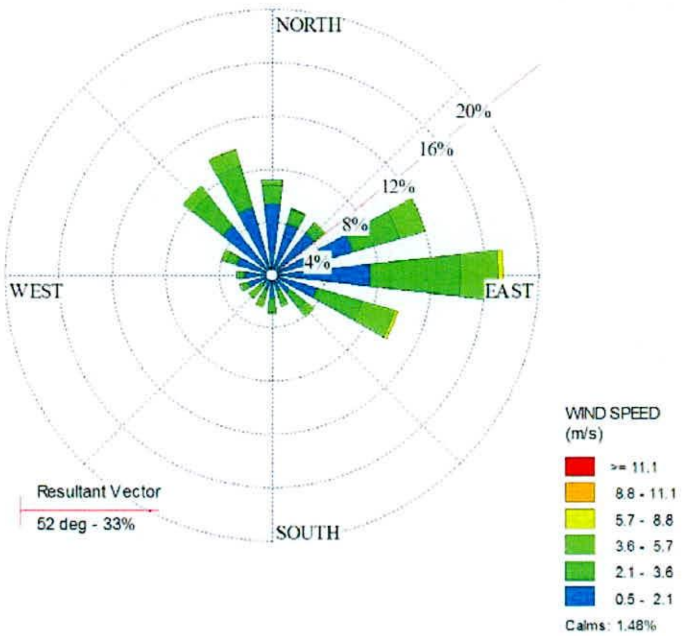

Figure 4d: Night-time wind rose

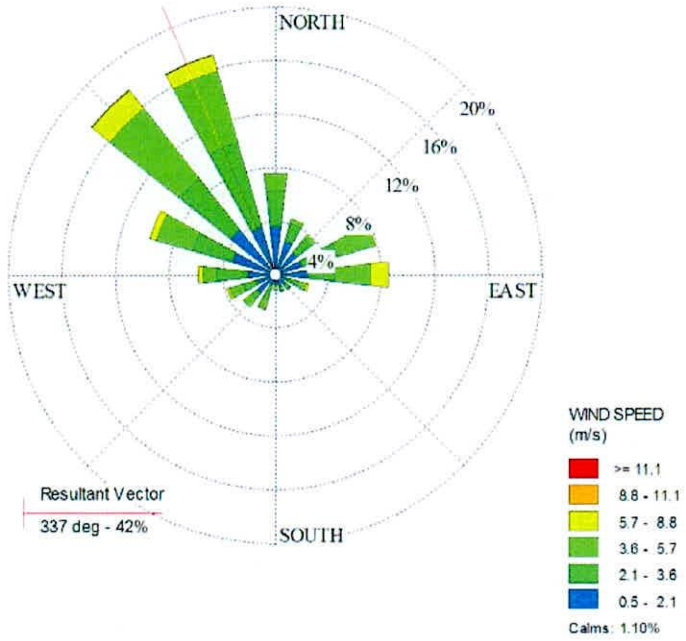

Figure 4e: Spring wind rose

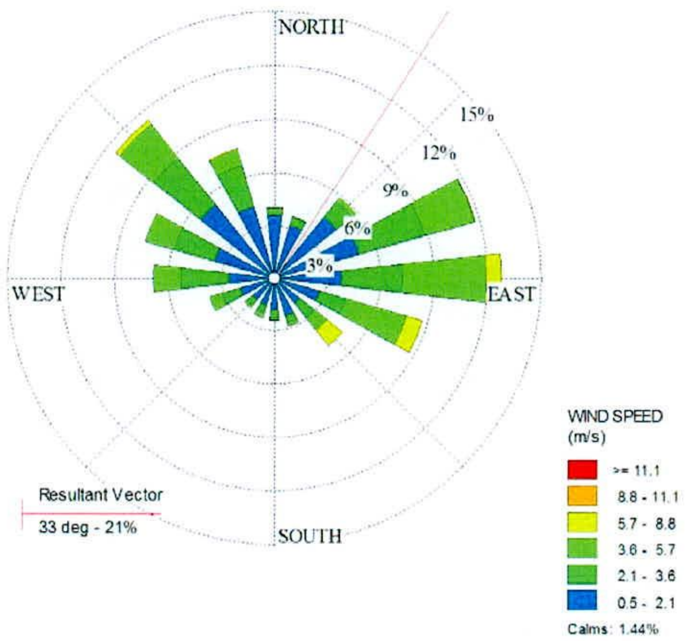

Figure 4f: Summer wind rose

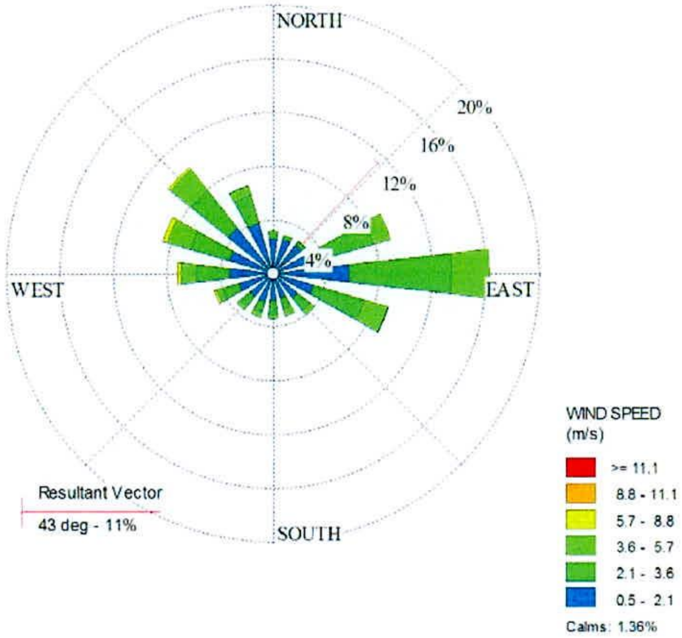

Figure 4g: Autumn wind rose

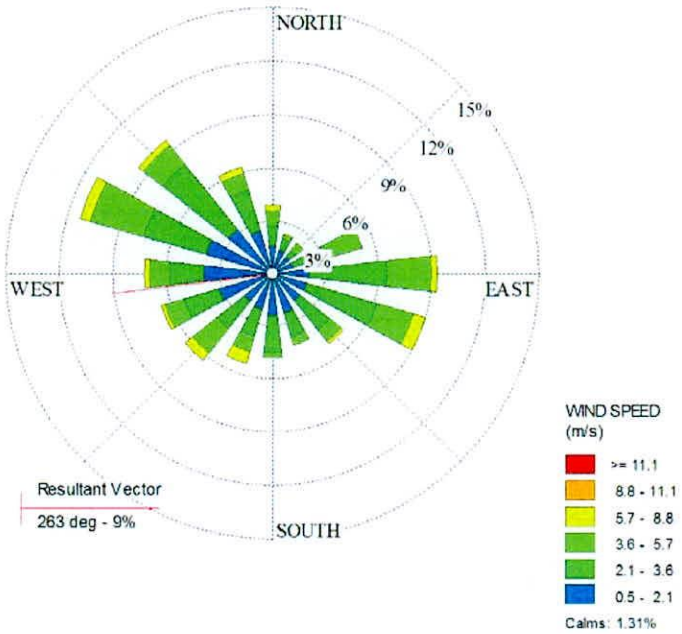

Figure 4h: Winter wind rose

Mixing height and atmospheric stability in the HPA

The high frequency of anticyclonic circulation and associated subsidence in the upper air reaches a maximum in winter. The subsidence is conducive to the formation of elevated temperature inversions throughout the year with a frequency of 60% and winter base height of about 1 300 and 2 600 m AGL in summer.

Stable and clear conditions are ideal for the formation of surface temperature inversions at night. The winter inversions in the HPA region vary in strength from 5°C to 7°C and in depth from 300 to 500m AGL. These inversions occur between 80 and 90% of winter nights, varying in n strength from 3°C to 11°C and from 100 m to 400 m in depth. Inversions of more than 10°C occur more than 25% of winter nights. In summer, the surface inversions are weaker and seldom exceeded 2°C in strength. The maximum midday mixing depths vary between 1 000m and 2 000m AGL in winter and may exceed 2 500m in summer.

The presence of subsidence induced semi-permanent absolutely-stable layers at approximately 800 hPa (about 350 m AGL) and 500 hPa (about 3500 m AGL) were shown to extend over the southern African sub-continent. The vertical transport of aerosols between the surface and the tropopause is controlled by these stable layers. Aerosols typically accumulate below the base of the respective layers and in turn, the layers promote transport of the aerosols at their respective levels. Trajectories pass through different height levels, but become trapped between absolutely-stable layers.

Atmospheric transport into and out of the HPA

Considerable research effort has focused on the meteorological circulation responsible for the accumulation and recirculation of pollutants in the HPA region. Westerly ventilation (WV) of the HPA region occurs mostly during winter with the passage of westerly waves across or south of the subcontinent. The westerly airflow over the HPA region is warm, dry and relatively free of pollutants as it originates from a source-free area. The easterly ventilation (EV) originates with a strongly ridging (or budding) anticyclone up the east coast, resulting in an onshore flow and easterly winds over the HPA. The ridging anticyclone to result in a recirculation path that loops to the north of the

HPA in winter (see **Figure 5**) and to the east and south of the HPA region in summer due to the seasonal north-south shift of the anticyclonic high-pressure belt.

Four major transport pathways exist to the HPA region in the lower troposphere. The most frequently occurring transport mode is from the Atlantic Ocean, occurring 43% of times. Transport from the Indian Ocean (26%) and from the African continent (25%) account for half of the transport to the HPA region. Regional-scale advection exclusively over southern Africa accounts for less than 10% of the transport. Air from the south and central Atlantic reaching the HPA region is likely to be free of industrial pollutants, while African transport may carry pollutants from central and southern Africa, particularly industrial pollutants from the Zambian copper-belt, from biomass burning in winter, and Aeolian dust.

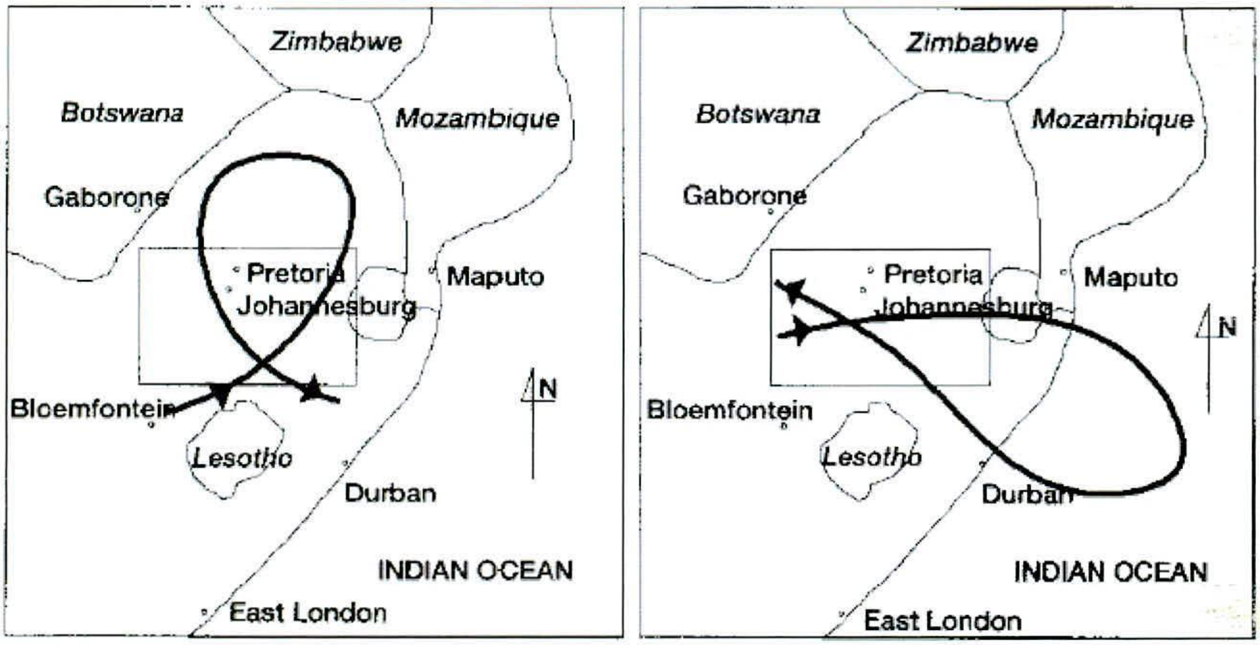

Figure 5: Characteristic wind paths during strong anticyclonic ridging in from May to June (left) and August to April (right) (from Air Quality Management Plan for the HPA, DEA 2010)

Significant seasonal variation exists in the transport of air to the HPA region. Noteworthy is the high percentage of Indian Ocean transport (51%) in summer and by contrast, the high percentage of Atlantic transport (51%) in winter. The sub-continental scale recirculation does not vary much with season.

There are two main transport modes out of the HPA region, direct and re-circulated transport. In the direct transport mode (45%), material is transported out of the HPA region with little decay in a westerly (to the Indian Ocean), easterly (to the Atlantic Ocean), northerly (to the south Indian Ocean, or southerly (equatorial Africa) transport mode. The second mode is re-circulated transportation where material re-circulates over the subcontinent towards the point of its origin, on a regional or sub-continental scale (33%). The overall re-circulating time ranges from 2 to 9 days, depending on the scale of the re-circulation.

Approximately 41% of all air transported from the HPA region affects countries bordering South Africa through either direct or re-circulated transport. Transport to Mozambique occurs more than 35% of the time, and more than 30% of the time to Botswana. Transport to Swaziland, Namibia and Zimbabwe is between 15% and 23% with less to other southern African countries.

HPA meteorology and air quality

The predominant anticyclonic circulation over the HPA, particularly in winter, results in light winds, clear skies and the development of surface temperature inversions at night that persist well into the morning. The mechanisms to disperse pollutants that are released at or near ground level into this stable atmosphere are typically weak. Pollutants tend therefore to accumulate near their source or to travel under the light near-surface drainage winds. Relatively high ambient concentrations may occur especially at night and in the morning when the surface inversions are strongest. This meteorology is particularly relevant to low-level industrial stacks, domestic fuel burning and motor vehicles.

During the day, surface warming induces the break-up of the surface inversion and promotes convection, which enhances the dispersion the nigh-time pollution build-up. Convection, on the other hand, may bring emissions from taller stacks down to ground level, so-called fumigation, that result in episodes of high ambient pollutant concentrations.

Immediately above the surface inversion, the low-level jet (LLJ), a strong nocturnal wind system, provides an effective mechanism to transport pollutants from taller stacks away from their source. The LLJ occurs over the much of the HPA at night and is stronger and more persistent in winter.

Westerly flow into the HPA is associated with the introduction of clean, mostly maritime, air. Hence, ambient air quality improves with the passage of wintertime westerly waves over the HPA and ambient pollutant concentrations decrease. Convective summer showers and thundershowers wash pollutants out of the atmosphere on a relatively local scale, while widespread convective rain activity can reduce ambient pollutant concentrations on a larger scale.

Pollutants released in the HPA do not only affect the HPA. Easterly airflow associated with a ridging Indian Ocean Anticyclone results in recirculation over the subcontinent. Pollutants emitted in the HPA are recirculated at different spatial and temporal scales depending on the strength of the ridging anticyclone. The recirculation may be limited to the HPA for a few days only or for a number of days of resulting in increases in ambient pollutant concentrations. Recirculation on larger spatial scales may transport pollutants emitted in the HPA well beyond its boundaries and into neighbouring municipalities and even across international borders.

3.4. TOPOGRAPHY AND LAND USE

The topography of the study area is relatively flat with undulating plains, isolated hills and rocky ridges or outcrops. There are no significant topographical features.

The Brown Shaft II Project exists entirely in the Grassland Biome ecosystem, but as with virtually all ecosystems in South Africa, it has been modified or transformed by human activities. These include cultivation for commercial crops or subsistence agriculture; livestock; the invasive spread of alien plants; urbanisation and settlements; the impoundment of rivers; mining; transportation and industrialisation.

4. *AIR QUALITY IMPACT ASSESSMENT*

4.1. EXISTING AIR QUALITY

The outdoor sources of air pollution resulting from human activities comprise three broad categories.

Stationary sources, which can be subdivided into; rural area sources, e.g. agriculture, mining and quarrying and industrial point and area sources, e.g. manufacturing of chemicals, non-metallic mineral products, basic metal industries and power generation.

Community sources, e.g. heating of homes and buildings, municipal waste and sewage sludge incinerators, fireplaces, cooking facilities, laundry services and cleaning plants.

Mobile sources, such as combustion-engine vehicles, e.g. light duty petrol-powered cars, light and heavy-duty diesel-powered vehicles, motorcycles, aircraft and line sources such as fugitive emissions from vehicle traffic.

Air pollutants are traditionally classified into suspended particulate matter (dusts, fumes, mists and smokes), gaseous pollutants (gases and vapours) and odours.

Particulate matter suspended in air includes total suspended particles (TSP), PM_{10} (SPM with a aerodynamic diameter of less than 10μm), $PM_{2.5}$ (SPM with a aerodynamic diameter of less than 2.5μm), fine and ultra fine particles, diesel exhaust, coal fly-ash, mineral dusts (e.g. coal, asbestos, limestone and cement), metal dusts and fumes (e.g. zinc, copper, iron, lead), acid mists (e.g. sulphuric acid), fluoride particles, paint pigments, pesticide mists, carbon black, oil smoke and many others.

Gaseous pollutants include sulphur compounds (e.g. sulphur dioxide and sulphur trioxide), carbon monoxide, nitrogen compounds (e.g. nitric oxide, nitrogen oxide and ammonia), organic compounds (e.g. hydrocarbons, volatile organic compounds, polycyclic aromatic hydrocarbons and halogen derivatives, aldehydes etc.), halogen compounds (e.g. HF and HCl) and odorous substances.

Secondary pollutants may be formed from gaseous pollutants by thermal, chemical or photochemical reactions. For example, by thermal action sulphur dioxide can be oxidised to sulphur trioxide which, dissolved in water, gives rise to the formation of sulphuric acid mist. Photochemical reactions between nitrogen oxides and reactive hydrocarbons can produce ozone, formaldehyde and peroxyacetyl nitrate; reactions between hydrochloric acid and formaldehyde can form bischloromethyl ether.

While some odours are known to be caused by specific chemical agents such as hydrogen sulphide, carbon disulphide and mercaptans, others are difficult to define chemically.

The main source of information on air pollution in developing countries is the Air Management Information System (AMIS) set up the World Health Organisation (WHO). AMIS is based on voluntary reporting of data by municipalities of the WHO member states. The AMIS core data base collects information on annual (arithmetic) mean and high (95-, 98-) percentiles of daily mean concentrations of SO_2, NO_2, O_3, CO, SPM, lead and other potentially monitored compounds in more than 100 cities. In principle data from three types of monitoring stations are stored: 'industrial' reflecting levels in areas affected by emissions from industry, 'city centre/commercial' reflecting levels mostly affected by traffic and 'residential' which should reflect the lowest level of population exposure.

Highveld Priority Area Air Quality

The state of ambient air quality in the HPA has been the subject of investigation and monitoring for more than 30 years in step with the growing power generation industry, mining and other industrial sectors such as the petrochemical and metallurgical sectors. The state of air quality in the Highveld region is described in the Air Quality Baseline Assessment for the Highveld Priority Area (DEA, 2010).

The total annual emissions of PM_{10} on the HPA is estimated at 279 630 tons, of which approximately half is attributed to dust entrainment on mine haul roads. The emission of PM_{10} from the primary metallurgical industry accounts for 17% of the total emission, with 12% of the total from power generation. By contrast, power generation contributes 73% of the total estimated NO_x emission of 978 781 tons per annum and 82% of the total estimated SO_2 emission of 1 622 233 tons per annum.

Industrial sources in total are by far the largest the contributor of emissions in the HPA, accounting for 89% of PM_{10}, 90% of NO_x and 99% of SO_2.

Major sources in the HPA are grouped into the following categories:

1. Power Generation
2. Coal Mining
3. Primary Metallurgical Operations
4. Secondary Metallurgical Operations
5. Brick Manufacturers
6. Petrochemical Industry
7. Ekurhuleni Industrial Sources (excluding the above)
8. Mpumalanga Industrial Sources (excluding the above)
9. Agricultural operations (seasonal)

Parts of the HPA experience relatively good air quality, but generally ambient air quality in the HPA is poor and eight extensive areas occur where ambient SO_2, PM_{10} and O_3 concentrations exceed air quality standards. These "hotspots" are illustrated in **Figure 6** by the number of modelled exceedences of the 24-hour SO_2 and PM_{10} standards.

The air quality hotspots result mostly from a combination of emissions from the different industrial sectors and residential fuel burning, with motor vehicle emissions, mining and cross-boundary transport of pollutants into the HPA adding to the base loading.

Available monitoring data confirms that the areas of concern are in the vicinity of Kendal, Witbank, Middelburg, Secunda, Ermelo, Standerton, Balfour, and Komati where exceedences of ambient SO_2 and PM_{10} air quality standards occur.

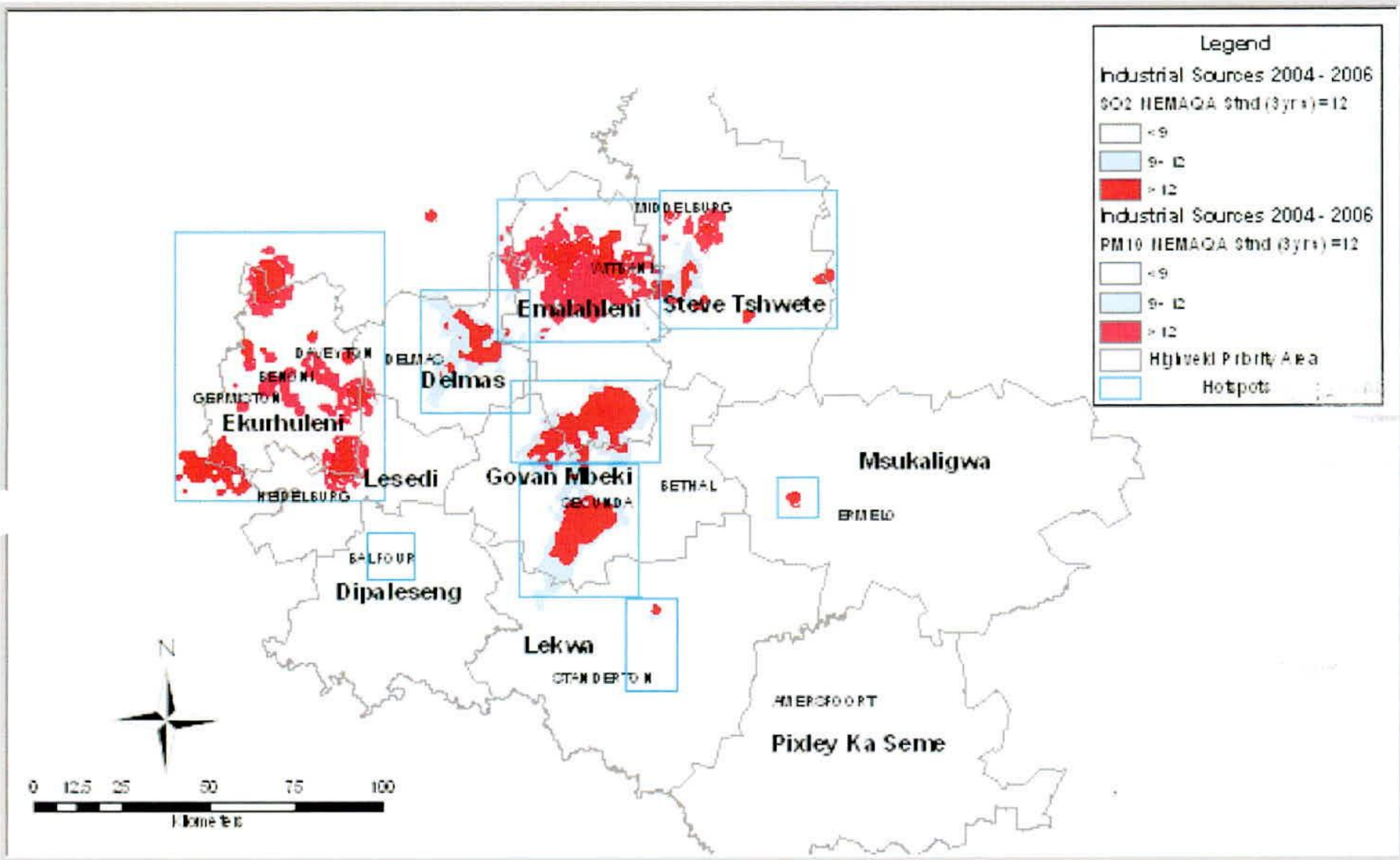

Figure 6: Modelled frequency of exceedence of 24-hour ambient SO_2 and PM_{10} standards and the 1-hour NO_2 standard in the HPA, indicating the air quality Hot Spot areas (from Air Quality Management Plan for the HPA, DEA 2010)

The effects of poor dispersion conditions in the winter are evident throughout the monitoring record for all pollutants, resulting in greater frequency of exceedences of the standards. PM_{10} displays this seasonal trend most strikingly, showing a sharp contrast between wintertime peaks and summer minimum values at monitoring sites. Seasonal trends are clearly observed for O_3 in the monitoring record, as springtime peaks are easily identified. Monitoring data show CO and benzene to be within acceptable limits at the new sites. Trends in pollutant concentrations, based on current data, cannot be conclusively identified, marred in particular by poor data collection.

Exceedences of ambient air quality standards present situations where potential impacts on human health can occur. Ambient monitoring and dispersion modelling have identified eight areas on the HPA where ambient concentrations of PM_{10}, SO_2 or NO_2 exceed the ambient standards. Exposure may be high where these exceedences coincide with populated areas and the risks to human health may be significant.

It is important to note that the air pollutants of concern in the Nkangala Municipality are PM_{10}, SO_2 and NO_2. Since particulate matter is the only significant pollutant likely to be emitted from the Brown Shaft II Project, it will be the focus of the remainder of this discussion.

Particulate Matter

In Western Europe and North America efforts to control emissions of particulate matter have generally resulted in positive trends. In many cities the annual ambient average concentrations of PM_{10} are in the range of 20 to 50µg/m^3.

However, annual average concentrations in some cities in Eastern Europe and in most developing countries can be well above 100µg/m^3.

Daily average PM_{10} concentration data for Hendrina are depicted in **Figure 7** on the following page. This monitoring station is approximately 30km due south east of the study area and is the nearest PM_{10} monitoring station providing credible data.

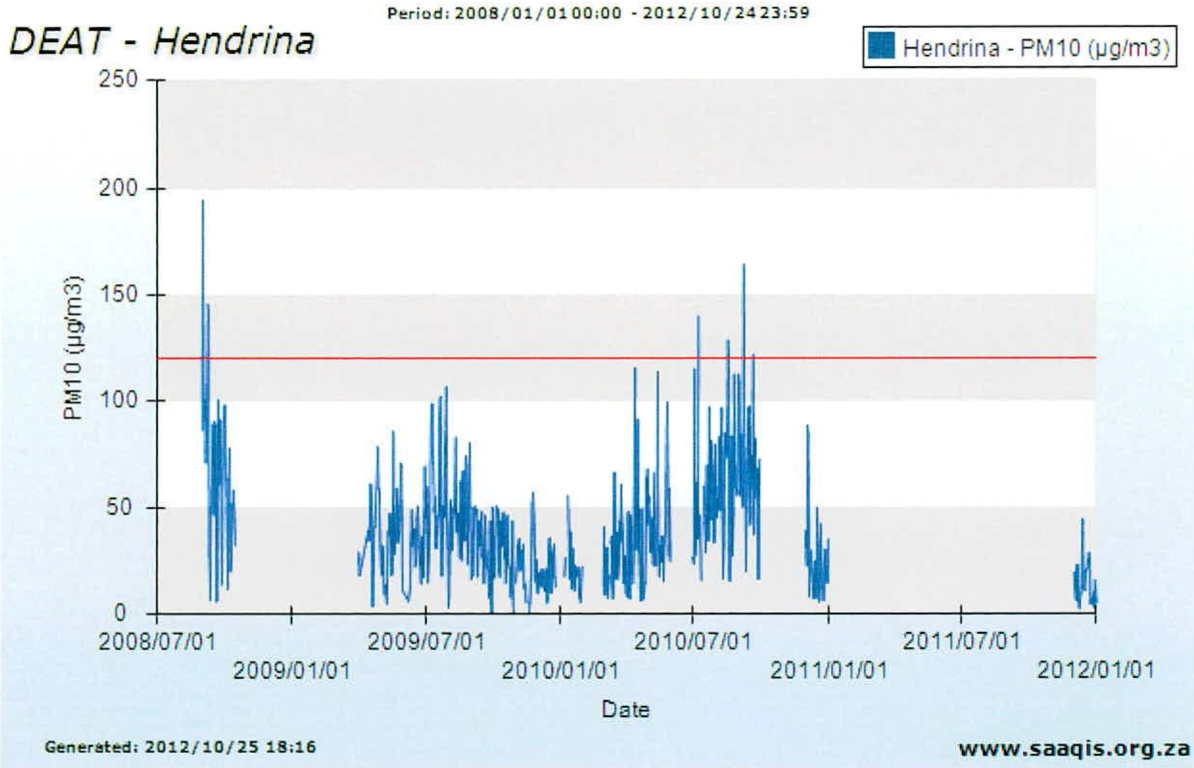

Figure 7: Monitored 24-hour ambient PM_{10} concentrations at Hendrina for 2010 and 2011 (SAAQIS, DEA 2010)

Particulate matter (PM) is a broad term used to describe the fine particles found in the atmosphere, including soil dust, dirt, soot, smoke, pollen, ash, aerosols and liquid droplets. The most distinguishing characteristic of PM is the particle size and the chemical composition. Particle size has the greatest influence on the behaviour of PM in the atmosphere with smaller particles tending to have longer residence times than larger ones. PM is categorized, according to particle size, into TSP, PM_{10} and $PM_{2.5}$.

Total suspended particulates (TSP) consist of all sizes of particles suspended within the air smaller than 100 micrometres (µm). TSP is useful for understanding nuisance effects of PM, e.g. settling on houses, deposition on and discolouration of buildings, and reduction in visibility.

PM_{10} describes all particulate matter in the atmosphere with a diameter equal to or less than 10µm. Sometimes referred to simply as coarse particles, they are generally emitted from motor vehicles (primarily those using diesel engines), factory and utility smokestacks, construction sites, tilled fields, unpaved roads, stone crushing, and burning of wood. Natural sources include sea spray, windblown dust and volcanoes. Coarse particles tend to have relatively short residence times as they settle out rapidly and PM_{10} is generally found relatively close to the source except in strong winds.

$PM_{2.5}$ describes all particulate matter in the atmosphere with a diameter equal or less than 2.5µm. They are often called fine particles, and are mostly related to combustion (motor vehicles, smelting, incinerators), rather than mechanical processes as is the case with PM_{10}.

$PM_{2.5}$ may be suspended in the atmosphere for long periods and can be transported over large distances.

Fine particles can form in the atmosphere in three ways: when particles form from the gas phase, when gas molecules aggregate or cluster together without the aid of an existing surface to form a new particle, or from reactions of gases to form vapours that nucleate to form particles.

Particulate matter may contain both organic and inorganic pollutants. The extent to which particulates are considered harmful depends on their chemical composition and size, e.g. particulates emitted from diesel vehicle exhausts mainly contain unburned fuel oil and hydrocarbons that are known to be carcinogenic. Very fine particulates pose the greatest health risk as they can penetrate deep into the lung, as opposed to larger particles that may be filtered out through the airways' natural mechanisms.

In normal nasal breathing, particles larger than 10µm are typically removed from the air stream as it passes through the nose and upper respiratory airways, and particles between 3µm and 10µm are deposited on the mucociliary escalator in the upper airways. Only particles in the range of 1µm to 2µm penetrate deeper where deposition in the alveoli of the lung can occur.

Coarse particles (PM_{10} to $PM_{2.5}$) can accumulate in the respiratory system and aggravate health problems such as asthma. $PM_{2.5}$ which can penetrate deeply into the lungs, are more likely to contribute to the health effects (e.g. premature mortality and hospital admissions) than coarse.

People with existing health conditions such as cardiovascular disease and asthmatics, as well as the elderly and children, are more at risk to the inhalation of particulates than normal healthy people.

Mortality outcomes calculated for South African urban areas estimate that outdoor air pollution caused 3.7% of total mortality from cardiopulmonary disease in adults aged 30 years and older, 5.1% of mortality attributable to cancers of the trachea, bronchus, and lung in adults, and 1.1% of mortality from acute respiratory infections in children under 5 years of age.

4.2. DISPERSION SIMULATION

Dilution of air contaminants in the atmosphere is an important process in preventing undesirable levels of pollutants in the ambient air. Atmospheric dispersion of air contaminants is the result of ventilation, atmospheric turbulence and molecular diffusion. However, gaseous and particulate air contaminants are primarily dispersed into the ambient air through wind action and atmospheric turbulence, much of it on the micro scale level. Depending on the relevant environmental and adiabatic lapse rates, various plume formation can be predicted. These include, looping, neutral, coning, fanning, lofting, fumigating and trapping.

Moisture content and form in the atmosphere can have a profound effect upon the air quality. The presence and amount of water vapour in the atmosphere affects the amount of solar radiation received and reflected by the earth.

Several dispersion models have been developed and are the mathematical description of the meteorological transport and dispersion of air contaminants. In order to describe the position of the place where the concentration of contaminants will be estimated, relative to both the source and the ground, a standard Cartesian (x, y, z) co-ordinate system is used in which:

- the physical source is located at the origin,
- the x-axis lies along the mean wind direction,
- x is the distance from the source,
- y is the lateral distance from the mean wind direction,
- z is the height above ground level,

- h is the physical height of the source,
- Δh is the additional height by which the plume rises due to its buoyancy and/or momentum,
- $H = h + \Delta h$ is the effective (plume) height of the release, and
- u is the mean wind speed at plume height.

Most models in use today assume Gaussian distribution of emission pollutants, horizontally and vertically downwind of the source. With the assumption that the distributions in the y and z directions are normal with a standard deviation of σ_i, the concentration of a gas or aerosol (<20μm diameter particles) can be calculated at ground level for a distance downwind of the source:

$$C_{x,y} = \frac{Q}{\pi u \sigma_z \sigma_y} \exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]$$

where $C_{x,y}$ = pollutant concentration in g/m^3 with a maximum ground level concentration where $\sigma_z = 0.707H$,

Q	=	pollutant emission rate in g/s
π	=	constant pi = 3.14159
u	=	mean wind speed in m/s
σ_y	=	standard deviation of horizontal plume concentration at distance x in m,
σ_z	=	standard deviation of vertical plume concentration at distance x in m,
exp	=	base of natural logarithm = 2.71828183
H	=	effective stack height in m,
x	=	downwind distance along plume mean centreline from point source in m, and
y	=	crosswind distance from centreline of plume in m

The Gaussian equation contains explicit references to y and z, and also implicit references to x (since σ_y and σ_z are themselves functions of x). Empirical studies resulted in graphs where values for these constants could be obtained for different Pasquill stability categories. However, these graphs were inaccurate by nature and equations for the variation of σ_y and σ_z with stability class have been developed and are shown in the table below.