
**AIR QUALITY IMPACT ASSESSMENT:
WEST CLIFF MINE SURFACE GAS DRAINAGE PROJECT**

17 October 2007

*Prepared for
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*On behalf of
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by

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1. INTRODUCTION

This report has been prepared by Holmes Air Sciences for Olsen Environmental Consulting (Olsen) on behalf of BHPBilliton-Illawarra Coal (BHPBIC). As part of the ongoing operations of the West Cliff Mine, BHPBIC plans to implement a program to extract gas from the goaf area remaining after longwall extraction has occurred. The goaf area is defined as the void left after extraction in an underground mine has finished. The gas extraction program is referred to as the West Cliff Mine Surface Gas Drainage Project (the "Project") and Olsen are preparing the Environmental Assessment (EA). The purpose of this report is to quantitatively assess the air quality impacts of the Project.

The assessment is based on the use of a computer-based dispersion model to predict odour and dust concentrations in the vicinity of proposed activities. The dispersion model predictions have been compared to relevant air quality criteria to assess the impacts on existing air quality.

The assessment follows the conventional procedures outlined by the NSW Department of Environment and Climate Change (DECC) in their document titled "Approved Methods for the Modelling and Assessment of Air Pollutants in NSW" (DEC, 2005).

In summary, the report provides information on the following:

- Proposed surface gas drainage activities;
- Air quality criteria relevant for the Project;
- Meteorological and climatic conditions in the area;
- Existing air quality;
- Emissions to air, including odour and dust; and
- Dispersion modelling, results and interpretation.

2. LOCAL SETTING AND PROJECT DESCRIPTION

Figure 1 shows the location of the study area, including the locations of the West Cliff Colliery and proposed West Cliff Area 5 Surface Goaf Wells. Land use in the study area consists of agricultural land uses (grazing and farming), scattered residential properties and the town of Appin. Local topography (see **Figure 2**) shows that the area comprises rolling hills.

BHPBIC are proposing to extract gas from the goaf area remaining after longwall mining has occurred. Gas will be transferred to the surface via a cased borehole installed prior to mining. Once at the surface, the gas will either be flared or vented to atmosphere.

The Project involves the installation and operation of 17 boreholes in Longwall Panels 32 to 34 of the West Cliff Mine. The location of the boreholes are shown in **Figure 3**. Nearest privately-owned residential properties to the boreholes are also indicated in **Figure 3**.

Each borehole installation can be summarised as follows:

- Borehole installation with appropriate drilling equipment and fit-out to enable gas extraction;
- Gas extraction and ventilation facility; and
- Gas flaring equipment located at a safe distance from the ventilation points.

A mobile gas extraction plant will be used at each borehole site, consisting of equipment mounted on an 18-wheel semi-trailer. There will be an on-board diesel-powered generator (175 kVA) to generate the power necessary to operate the equipment.

A 9 m high vent stack will be used when flaring is not occurring, or when flares are located remote to the mobile plant. Extracted goaf gas will be directed to the flare units and/or the local or remote vent stack.

Gas extraction will occur at each borehole over a 7 week period. Gas flows are predicted to be of the order of 700 litres per second (L/s) at start-up, and decaying to 200 L/s by week 7. Flaring units will be used when appropriate and possible which can process up to 300 L/s.

A schematic of a mobile goaf plant is shown in **Figure 4**.

The potential air quality impacts of the Project are identified as follows:

- Odour from the gas vent stacks;
- Dust generated during the borehole construction phase; and
- Pollutant emissions from the diesel generator.

The items listed above are the focus of this air quality assessment.

3. AIR QUALITY CRITERIA

3.1 Odour

This section evaluates odour in terms of measurement and air quality criteria that relate to odour. There is still considerable debate in the scientific community about appropriate odour criteria as determined by dispersion modelling.

3.1.1 Measurement of Odour

Odour is measured using panels of people who are presented with samples of odorous gas diluted with decreasing quantities of clean odour-free air. The panellists then note when the smell becomes detectable. Odour in the air is then quantified in terms of odour units which is the number of dilutions required to bring the odour to a level at which 50% of the panellists can just detect the odour. This process is known as olfactometry.

Olfactometry can involve a “forced-choice” end point or a “free choice” endpoint. The “forced-choice” method is where panellists identify from multiple sniffing ports, the one port where odour is detected, regardless of whether they are sure they can detect odour. The “free choice” endpoint is a “yes/no” decision where panellists are required to say whether or not they can detect odour from one sniffing port. Forced-choice olfactometry generally detects lower odour levels than free choice olfactometry.

In both the “forced-choice” and “free choice” cases, odorous air is presented to the panellists in increasing concentrations. For the forced-choice method, where there are multiple ports for each panellist, the concentration is increased until all panellists consistently distinguish the port with the sample from the blanks. For a yes/no olfactometer (which has only one sniffing port) one method used is to increase the concentration of odour in the sample until all panellists respond. The sample is then shut off and once all panellists cease to respond, the sample is introduced again at random dilutions and the panellists are asked whether they can detect the odour.

There are variations in the literature in the terminology for odour thresholds. The DECC has used the definition of the **detection** threshold as the lowest concentration which will elicit a response, but where the panellist is essentially guessing correctly. This corresponds to the first end point in the forced-choice olfactometry method. The odour **recognition** threshold is, by definition, the minimum concentration at which the panellist is certain they can detect the odour. This is also referred to as the certainty threshold and is the second endpoint in forced-choice olfactometry and similar to the first end point in yes/no olfactometry.

An Australian Standard (AS/NZS 4323.3.2001) for olfactometry has been developed which is consistent with the European Standard, CEN. This enables results between laboratories to be more uniform. These standards have adopted the certainty threshold as the odour standard and referencing this to a concentration of butanol (40 ppb). The odour levels referred to in this report are the certainty odour levels (odour detected by 50% of panellists using the recognition threshold).

As with all sensory methods of identification there is variability between individuals. Consequently the results of odour measurements depend on the way in which the panel is selected and the way in which the panel responses are interpreted. The process by which these imprecise measurements are translated into regulatory criteria is still being refined. However, the DECC has recently published a Technical Framework for the assessment of odour from stationary sources, which includes recommendations for odour criteria (DEC, 2006). These are explained below and have been used for this assessment.

3.1.2 Odour Criteria

The determination of air quality criteria for odour and their use in the assessment of odour impact is recognised as a difficult topic in air pollution science. The topic has received considerable attention in recent years and the procedures for assessing odour impacts using dispersion models have been refined considerably.

The DECC has in recent times refines odour criteria and the way in which they should be applied with dispersion models to assess the likelihood of nuisance impact arising from the emission of odour. However, as discussed above these procedures are still being developed and odour criteria are likely to be revised in the future.

There are two factors that need to be considered:

1. what "level of exposure" to odour is considered acceptable to meet current community standards in NSW and
2. how can dispersion models be used to determine if a source of odour meets the criteria which are based on this acceptable level of exposure.

The term "level of exposure" has been used to reflect the fact that odour impacts are determined by several factors. The most important factors (the so-called **FIDOL** factors) are:

- the **F**requency of the exposure
- the **I**ntensity of the odour
- the **D**uration of the odour episodes
- the **O**ffensiveness of the odour, and
- the **L**ocation of the source

In determining the offensiveness of an odour it needs to be recognised that for most odours the context in which an odour is perceived is also relevant. Some odours, for example the smell of sewage, hydrogen sulfide, butyric acid, landfill gas etc., are likely to be judged offensive regardless of the context in which they occur. Other odours such as the smell of jet fuel may be acceptable at an airport, but not in a house, and diesel exhaust may be acceptable near a busy road, but not in a restaurant.

In summary, whether or not an individual considers an odour to be a nuisance will depend on the FIDOL factors outlined above and although it is possible to derive

formulae for assessing odour annoyance in a community, the response of any individual to an odour is still unpredictable. Odour criteria need to take account of these factors.

The DECC Technical Framework includes some recommendations for odour criteria. The criteria have been refined by DECC to take account of population density in the area. **Table 1** lists the odour certainty thresholds, to be exceeded not more than 1% of the time, for different population densities.

The difference between odour criteria is based on considerations of risk of odour impact rather than differences in odour acceptability between urban and rural areas. For a given odour level there will be a wide range of responses in the population exposed to the odour. In a densely populated area there will therefore be a greater risk that some individuals within the community will find the odour unacceptable than in a sparsely populated area.

The criteria assume that 7 odour units at the 99th percentile would be acceptable to the average person, but as the number of exposed people increases there is a chance that sensitive individuals would be exposed. The criterion of 2 odour units at the 99th percentile is considered to be acceptable for the whole population.

Table 1 : DECC odour assessment criteria

Population of affected community	Odour performance criteria (nose response odour certainty units at the 99 th percentile)
Rural single residence (≤ 2)	7
~10	6
~30	5
~125	4
~500	3
Urban (>2000) and/or schools and hospitals	2

It is common practice to use dispersion models to determine compliance with odour criteria. This introduces a complication because Gaussian dispersion models are only able to directly predict concentrations over an averaging period of 3-minutes or greater. The human nose, however, responds to odours over periods of the order of a second or so. During a 3-minute period, odour levels can fluctuate significantly above and below the mean depending on the nature of the source.

To determine more rigorously the ratio between the one-second peak concentrations and three-minute and longer period average concentrations (referred to as the peak-to-mean ratio) that might be predicted by a Gaussian dispersion model, the DECC (then EPA) commissioned a study by Katestone Scientific Pty Ltd (see **Katestone 1995** and **1998**). This study recommended peak-to-mean ratios for a range of source types. The ratio is also dependent on atmospheric stability and the distance from the source. A summary table of these ratios is presented in **Appendix A**.

The DECC Technical Framework (DEC, 2006) takes account of this peaking factor and the criteria shown in **Table 1** are based on nose-response time.

3.2 Dust

Table 2 and **Table 3** summarise the air quality assessment criteria for dust concentration and deposition. The air quality criteria relate to the total dust burden in the air and not just the dust from the project. In other words, some consideration of background levels needs to be made when using these criteria to assess impacts. The estimation of appropriate background levels will be discussed further in **Section 4.3**.

Table 2 : DECC criteria for particulate matter concentrations

Pollutant	Criteria	Averaging period	Agency
Total suspended particulate matter (TSP)	90 µg/m ³	Annual mean	National Health & Medical Research Council
Particulate matter < 10 µm (PM ₁₀)	50 µg/m ³	24-hour maximum	DECC
	30 µg/m ³	Annual mean	DECC long-term reporting goal
	50 µg/m ³	(24-hour average, 5 exceedances permitted per year)	National Environment Protection Council

In addition to health impacts, airborne dust also has the potential to cause nuisance impacts by depositing on surfaces. **Table 3** shows the maximum acceptable increase in dust deposition over the existing dust levels. The criteria for dust fallout levels are set to protect against nuisance impacts (DEC, 2005).

Table 3 : DECC criteria for dust fallout

Pollutant	Averaging period	Maximum increase in deposited dust level	Maximum total deposited dust level
Deposited dust	Annual	2 g/m ² /month	4 g/m ² /month

3.3 Oxides of Nitrogen

The key product of combustion from the diesel-powered generator will be oxides of nitrogen (NO_x). NO_x is comprised of nitric oxide (NO) and nitrogen dioxide (NO₂) however NO is much less harmful to humans than NO₂ and is not generally considered a pollutant with health impacts at the concentrations normally found in urban environments. **Table 4** shows the DECC air quality assessment criteria for NO₂. The air quality criteria relate to the total burden of NO₂ in the air and not just that from the sources being modelled.

Table 4 : DECC criteria for nitrogen dioxide

Pollutant	Criterion*	Averaging period	Agency
Nitrogen dioxide (NO ₂)	0.12 ppm or 246 µg/m ³	1-hour maximum	DECC
	0.03 ppm or 62 µg/m ³	Annual mean	DECC

* ppm = parts per million.

4. EXISTING ENVIRONMENT

This section describes the dispersion meteorology, local climatic conditions and existing air quality in the Project area.

4.1 Dispersion Meteorology

The Gaussian dispersion model used for this assessment (AUSPLUME) requires information about the dispersion characteristics of the area. In particular, data are required on wind speed, wind direction, atmospheric stability class¹ and mixing height². Suitable meteorological data are available from a weather station operated by the DECC at Appin. The station was approximately three kilometres to the south of the Project area but has since been decommissioned.

DECC have specified the requirements for meteorological data that are used for air dispersion modelling in their *Approved Methods* (DEC, 2005). The requirements are as follows:

- Data must span at least one year;
- Data must be 90% complete; and
- Data must be representative of the area in which emissions are modelled.

The Appin data included hourly records of temperature, wind speed, wind direction and sigma-theta (the standard deviation of the horizontal wind direction) and have been processed into a form suitable for the AUSPLUME dispersion model. The data were collected in 1995 and there were 8,112 hours available which represents a 93% data recovery.

Figure 5 shows the annual and seasonal wind roses from the Appin site. In 1995, winds were predominantly from the south-southeast and this wind direction is present in all seasons. Annually, calm conditions (winds less than or equal to 0.5 m/s) were measured for 3.4% of the time.

As described above, to use the wind data to assess dispersion, it is necessary to also have available data on atmospheric stability. A stability class was assigned to each hour of the meteorological data using sigma-theta according to the method

¹ In dispersion modelling, stability class is used to categorise the rate at which a plume will disperse. In the Pasquill-Gifford stability class assignment scheme, as used in this study, there are six stability classes A through to F. Class A relates to unstable conditions such as might be found on a sunny day with light winds. In such conditions plumes will spread rapidly. Class F relates to stable conditions, such as occur when the sky is clear, the winds are light and an inversion is present. Plume spreading is slow in these circumstances. The intermediate classes B, C, D and E relate to intermediate dispersion conditions.

² The term mixing height refers to the height of the turbulent layer of air near the earth's surface into which ground-level emissions will be rapidly mixed. A plume emitted above the mixed-layer will remain isolated from the ground until such time as the mixed-layer reaches the height of the plume. The height of the mixed-layer is controlled mainly by convection (resulting from solar heating of the ground) and by mechanically generated turbulence as the wind blows over the rough ground.

recommended by the US EPA (US EPA, 1986). Table 5 shows the frequency of occurrence of the stability categories expected in the area.

The most common stability class was determined to be D class. This suggests that the dispersion conditions are such that air emissions disperse rapidly for a significant proportion of the time.

Table 5 : Frequency of occurrence of stability classes in the study area

Stability Class	Appin, 1995 (%)
A	9.4
B	5.5
C	11.4
D	44.5
E	15.1
F	14.1
Total	100

Mixing height was determined using a scheme defined by Powell (1976) for day-time conditions and an approach described by Venkatram, (1980) for night-time conditions. These two methods provide a good estimate of mixing height in the absence of upper air data.

Joint wind speed, wind direction and stability class frequency tables for the Appin 1995 data are provided in Appendix B. The Appin data are considered to satisfy the requirements of the DECC.

4.2 Local Climatic Conditions

The Bureau of Meteorology (BoM) also collects climatic information in the vicinity of the study area. The closest BoM station to the Project site is Picton, located approximately 15 km to the west. A range of climatic information collected from Picton are presented in Table 6 (Bureau of Meteorology, 2007).

Temperature and humidity data consist of monthly averages of 9 am and 3 pm readings. Also presented are monthly averages of maximum and minimum temperatures. Rainfall data consist of mean monthly rainfall and the average number of rain days per month.

Table 6 : Climate information for Picton

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mean 9 am dry-bulb temperature (deg C)	21.7	21.4	19.9	16.8	12.2	9.4	7.7	10.4	14	17.4	18.9	20.9	15.9
Mean 3 pm dry-bulb temperature (deg C)	26.1	25.7	24.5	22.5	18.3	15.7	15.6	16.2	19	21.3	23	25.4	21.1
Mean daily maximum temperature (deg C)	29.3	28.6	27	23.7	20.2	17.3	16.8	18.2	21.4	24	26.3	28.5	23.4
Mean daily minimum temperature (deg C)	15.2	15.4	13.1	9.2	5.7	3.2	1.7	2.9	5.2	8.8	11.5	14	8.8
Mean rainfall (mm)	88.2	87.8	88.6	69.9	58.1	65.1	51	45.1	44.8	65.7	71.8	70.1	806
Mean number of rain days	9.4	9.3	9.8	7.7	7	7.4	6.5	6.9	7.4	8.7	8.7	8.6	97.4

Climate averages for Station: 'PICTON COUNCIL DEPOT' [068052], Commenced: 1880; Last record: 2007. Latitude (deg S): -34.17; Longitude (deg E): 150.61; State: NSW. Source: **Bureau of Meteorology (2007)** website.

Temperature data show that January is typically the warmest month with a mean daily maximum of 29.3°C. July is the coldest month with a mean daily minimum of 1.7°C.

Rainfall data collected at Picton show that March is the wettest month with a mean rainfall of 89 mm over 10 rain days. Annually the area experiences, on average, 806 mm of rain.

4.3 Existing air quality

The DECC have previously operated an air quality monitoring station at Appin which measured NO₂. **Table 7** shows the measured NO₂ concentrations for the most recent year of data available (1997).

Table 7 : Monitoring of nitrogen dioxide at Appin in 1997

Month	Measured NO ₂ concentration (µg/m ³)	
	Maximum 1-hour average	Average
Jan-97	55	6
Feb-97	35	10
Mar-97	53	8
Apr-97	78	12
May-97	66	8
Jun-97	90	12
Jul-97	62	8
Aug-97	49	8
Sep-97	53	6
Oct-97	53	10
Nov-97	33	8
Dec-97	70	10
Maximum	90	-
Average	-	9
DECC criteria	246	62

Source: EPA quarterly air quality monitoring reports for 1997 (EPA, 1997)

The monitoring data show that the area experiences NO₂ concentrations below the DECC ambient air quality criteria. The maximum 1-hour average NO₂ concentration in 1997 was 90 µg/m³ and the annual average was 9 µg/m³.

There are no known air quality monitoring stations close to the study area that can be used to determine the existing particulate matter concentrations. The DECC operate an extensive air quality monitoring network in NSW however their closest rural monitoring station to the site would be Macarthur (Campbelltown), approximately 20 km to the north.

Existing annual average PM₁₀ concentrations for the Appin area are estimated to be of the order of 15 µg/m³. The 24-hour average PM₁₀ concentrations will be highly variable and, in many parts of NSW, it is common for the DECC's 50 µg/m³ criteria to be exceeded on several occasions each year due to widespread events such as bushfires or dust storms.

5. ESTIMATED EMISSIONS

As discussed in **Section 1**, the potential air quality impacts of the Project are identified as follows:

- Odour from the gas vent stacks;
- Dust generated during the borehole construction phase; and
- Pollutant emissions from the diesel generator.

For stack sources, the AUSPLUME dispersion model requires information on the source location, the source height, internal source tip diameter, temperature of emissions, exit velocity of emissions and the mass emission rate of the pollutants to be assessed. Temperature, exit velocity and mass emission rates can be provided to the model as hourly records for an entire year (variable emissions) or as constant emissions.

Table 8 outlines the stack characteristics and emissions that were used as input into AUSPLUME.

Emissions from the diesel-powered generator were estimated using the National Pollutant Inventory (NPI) Emission Estimation Technique Manual for Combustion Engines (**NPI, 2003**). It was assumed that the generator is classed as an uncontrolled stationary diesel engine.

There are limited odour emission data from gas extraction vents associated with underground mining operations. EML Air Pty Ltd were however commissioned by BHPBIC to measure odour emission rates from the Dendrobium underground mine ventilation shaft (**Holmes Air Sciences, 2005**). The measured odour emission rate was 4,600 ou.m³/s and while this may not be representative of the odour in the gas extraction vents, it provides an indicative estimate for the purposes of this assessment.

There will also be emissions of NO_x from the flares however these emissions are difficult to quantify, due to the nature of the testing conditions. NPI reports (**NPI, 2005**) an emission factor of 1.5 kilograms of NO_x per tonne of methane throughput which is less than 0.2 g/s assuming the maximum flare capacity of 300 L/s (total gas). This mass emission rate is lower than the mass emission rate from the diesel-powered generator and the NO_x emissions from the flares have not been modelled.

Table 8 : Stack characteristics and emissions for modelling of stack sources

	Vent	Generator*, assuming operation 48 weeks per year
Assumed stack location (easting and northing in MGA)	295368, 6216979	295368, 6216979
Height (m)	9	3.3
Diameter (m)	0.25	0.12
Stack cross-section (m ²)	0.05	0.01
Flow rate (l/s)	400	-
Flow rate (Am ³ /s)	0.4	0.67
Temperature (deg C)	30	300
Exit velocity (m/s)	8.15	28
Emissions (l/s)		
CH ₄	347.423	-
CO	0.004	-
CO ₂	31.021	-
Pollutant emissions (g/s)		
PM ₁₀	-	0.0294
CO	0.005	0.0900
NO _x	-	0.4184
SO _x as (SO ₂)	-	0.0098
VOCs	-	0.0306
Acetaldehyde	-	0.000073
Benzene	-	0.000088
1,3-Butadiene	-	0.000004
Formaldehyde	-	0.000112
Total PAHs	-	0.000016
Toluene	-	0.000039
Xylene	-	0.000027
Odour emissions (OU.m³/s)		
Odour emission rate	4,600	-
OER (Stabilities A,B,C)	55,200	-
OER (Stabilities D,E,F)	115,000	-

Flow rate, exhaust temperature and exhaust velocity have been estimated from an equivalent size CAT diesel-powered generator: <http://www.cat.com/cda/components/fullArticle?m=39280&x=7&id=538612&languageId=7>

Dust will be generated during the construction stage of each site. Construction will involve the use of a 13 or 30 t excavator to level the site. A pad of 30 m by 40 m will be constructed and the excavator will also dig the drill cuttings sump. The same excavator will prepare any access road. Typical site and access road preparation time is less than 5 days and activities will be constrained to within 7 am and 5 pm.

The two major dust generating activities are identified as the stripping of topsoil and general construction work by excavators and wind erosion from exposed areas. An estimate of the dust emissions due to these activities has been made and the calculations are provided below in **Table 9**.

Table 9 : Estimated dust emissions during site construction

ACTIVITY	Intensity	Emission factor	TSP (kg/y)	TSP (kg/d)
Stripping topsoil and general construction work	8 h/d	14.0 kg/h	40,880	112
Wind erosion from exposed areas of site	0.3 ha	0.4 kg/ha/h	876	2.4
Total emissions (kg)	-	-	41,756	114

The dust emissions presented above are conservative estimates as they assume that an excavator will be working for 8 hours per day and emitting at a rate equivalent to bulldozers (14 kg/h). Therefore, it is estimated that up to 114 kg of dust would be generated per day due to construction activities

6. APPROACH TO ASSESSMENT

In August 2005, the DECC published guidelines for the assessment of air pollution sources using dispersion models (DEC, 2005). The guidelines specify how assessments based on the use of air dispersion models should be undertaken. They include guidelines for the preparation of meteorological data, emissions data and relevant air quality criteria. The approach taken in this assessment follows as closely as possible the approaches suggested by the guidelines.

This assessment focuses on odour, dust (PM₁₀) and NO_x concentrations arising from goaf well activities and concentrations of these pollutants have been predicted using AUSPLUME. AUSPLUME (Version 6.0) is an advanced Gaussian dispersion model developed on behalf of the Victorian EPA (VEPA, 1986) and is based on the United States Environmental Protection Agency's Industrial Source Complex (ISC) model. It is widely used throughout Australia and is regarded as a "state-of-the-art" model. AUSPLUME is the model required for use by the DECC unless project characteristics dictate otherwise (DEC, 2005).

Odour, PM₁₀ and NO_x levels have been predicted over an area of approximately 4 km by 4 km. The modelling has considered activities at one surface goaf well location only and the extent of the predicted impact zone has been taken to be representative of the impact zone around each of the other surface goaf well locations. Local terrain has been taken to be flat for the purposes of the modelling.

The modelling has been performed using the meteorological data discussed in Section 4.1 and the emission estimates from Section 5. Model predictions have been made at 80 discrete receptors around the emission source. Since activities would occur at each site for a period of approximately 8 weeks, the focus of the modelling was on the prediction of short-term pollutant levels.

6.1 Odour

The way in which the model has been used in the odour assessment has been to predict the maximum 1-hour average odour levels corrected to nose response times (expressed in odour units) at each receptor. The 1-hour averaging times have been used for consistency with the DECC odour criteria.

For the purposes of presenting the results, plots of maximum odour levels have been compiled. The DECC odour criteria relate to odour levels at the 99th percentile. Since the location of the surface goaf wells will change approximately every eight weeks the modelled odour levels at the 99th percentile cannot be produced.

6.2 Dust

This section is provided so that technical reviewers can appreciate how the modelling of different particle size categories was carried out.

The modelling has been based on the use of three particle-size categories (0 to 2.5 µm - referred to as PM_{2.5}, 2.5 to 10 µm - referred to as CM (coarse matter) and 10 to

30 µm - referred to as the Rest). Emission rates of TSP have been calculated using emission factors developed both within NSW and by the US EPA.

The distribution of particles has been derived from measurements published by the **SPCC (1986)**. The distribution of particles in each particle size range is as follows:

- PM_{2.5} (FP) is 4.7% of the TSP;
- PM_{2.5-10} (CM) is 34.4% of TSP; and
- PM₁₀₋₃₀ (Rest) is 60.9% of TSP.

Modelling was done using three AUSPLUME source groups with each group corresponding to a particle size category. Each source in the group was assumed to emit at the full TSP emission rate and to deposit from the plume in accordance with the deposition rate appropriate for particles with an aerodynamic diameter equal to the geometric mean of the limits of the particle size range, except for the PM_{2.5} group, which was assumed to have a particle size of 1 µm. The predicted concentration in the three output files for each group were then combined according to the weightings in the dot points above to determine the concentration of PM₁₀ and TSP.

The AUSPLUME model also has the capacity to take into account dust emissions that vary in time, or with meteorological conditions. This has proved particularly useful for simulating emissions at operations where wind speed is an important factor in determining the rate at which dust is generated.

For the current study, the construction activities for a particular site were represented by a volume source. Estimates of emissions were developed on an hourly time step taking into account the activities that would take place at that location. Due to the short-term nature of construction activities, the modelling focused on maximum 24-hour average PM₁₀ concentrations only.

Wind erosion was modelled for 24-hours per day, while other activities were modelled between 7 am and 5 pm. The dust modelling is considered to be worst-case since emissions were simulated for every day in the meteorological data file and the worst-case day for each receptor was extracted. The construction activities will occur for approximately 25 days per year only.

6.3 Oxides of Nitrogen

Maximum 1-hour average NO_x concentrations have been predicted due to emissions from the diesel-powered generator.

Generally, at the point of emission NO will comprise the greatest proportion of the emission with 95% by volume of the NO_x. The remaining 5% will be mostly NO₂. Ultimately, however, all nitric oxides emitted into the atmosphere are oxidised to NO₂ and then further to other higher oxides of nitrogen. Generally, for plumes impacting close to the source, the time interval for oxidation is not sufficient to have converted a large proportion of the plume to the more harmful NO₂.

For the purposes of this report it was assumed that 20% of the NO_x was NO₂ at the point of maximum ground-level concentration.

7. ASSESSMENT OF IMPACTS

7.1 Odour Impacts

Figure 6 shows the predicted maximum ground-level odour levels (corrected for nose response times), assuming one location for the surface goaf well. The contours will move around with the location of the surface goaf well. The pattern of dispersion will also be dependent on the meteorology at the time each well is operating.

For a single rural residence (that is, with population of 2 or less) the relevant odour criterion is 7 odour units at the 99th percentile (**DEC, 2006**). The model results therefore suggest that odour could be detectable on occasions at the nearest residences however the occurrence of odour events should be short-term, given that the location of the surface wells will move approximately every 8 weeks. For this reason the 99th percentile contours, which are based on annual exposure, cannot accurately be produced to compare with the DECC criteria.

Further, the analysis of wind patterns in the area (refer **Section 4.1**) showed that the most common winds are from the south-southeast. Examination of **Figure 6** shows that there are only 5 or 6 proposed surface goaf well locations that would be “upwind” of residences. Thus, the frequency of observed odour impacts should be low.

It is important to recognise also the uncertainty associated with the odour emissions data used in the modelling. The assumptions used for this assessment could be confirmed with odour emission measurements from the gas vent stacks, although given the short-term nature of the activities at each site, impacts are expected to be low.

7.2 Dust Impacts

Figure 7 shows the predicted maximum 24-hour average PM₁₀ concentrations due to construction activities. The DECC criterion is 50 µg/m³, which represents the contribution from all sources of dust, not just the contribution from the modelled sources. Background PM₁₀ concentration should be considered when examining the results in **Figure 7**.

It can be seen from **Figure 7** that the 50 µg/m³ contour is predicted to extend out approximately 300 m from the centre of activities. The 20 µg/m³ contour extends approximately 500 m from the centre of activities.

As discussed in **Section 4.3**, average PM₁₀ concentrations are estimated to be of the order of 15 µg/m³. The PM₁₀ concentrations will vary from day to day however for the purposes of this assessment it has been assumed that the background level is 15 µg/m³ for the days of maximum 24-hour average PM₁₀ predictions. This means that the allowable contribution from site activity emissions would be 35 µg/m³ before the 50 µg/m³ criterion is reached. The 35 µg/m³ contour extends approximately 400 m from

the location of the surface goaf well. There are approximately 10 out of the 17 surface goaf wells which are within 400 m of the nearest residences.

Given the conservative nature of the dust emission estimates, adverse PM₁₀ concentrations are unlikely to be observed and the activities would not be a significant dust source. However, the following measures will ensure that dust emissions are subject to a high level of control:

- Watering of exposed areas to prevent dust emissions;
- Re-vegetating or stabilising disturbed areas as soon as practicable to prevent or minimise wind-blown dust; and
- If necessary, stop or modify dust-generating activities during periods of high wind.

Dust emissions during the surface goaf well operation will be substantially lower than during the construction stage, since there will be little to no earthworks taking place. Compliance with ambient air quality criteria would be anticipated.

7.3 Oxides of Nitrogen

Maximum 1-hour average NO₂ concentrations due to the diesel-powered generator are shown in **Figure 8**. This assumes that 20% of the NO_x is NO₂, at the point of maximum ground-level impact.

It can be seen from **Figure 8** that the maximum 1-hour average NO₂ concentrations are of the order of 40 µg/m³. Background concentrations have been measured up to 90 µg/m³ (**Section 4.3**) which, when added to 40 µg/m³, gives 130 µg/m³. The modelling therefore demonstrates compliance with the 246 µg/m³ criterion noted by the DECC.

8. CONCLUSIONS

This report has assessed the air quality impacts of the West Cliff Mine Surface Gas Drainage Project. Dispersion modelling has been used to predict odour, PM₁₀ and NO_x levels due to activities taking place at proposed surface goaf wells. Due to the short period of activity at each goaf well location, the dispersion modelling focussed on short-term air quality impacts.

The conclusions of the assessment are as follows:

- Odour could be detectable on occasions at the nearest residences, however the shifting nature of the odour sources should ensure that the frequency of odour events is kept to a minimum.
- Compliance with dust concentration criteria would be anticipated during the construction stage and mitigation measures will ensure that dust emissions are subject to a high level of control.
- Dust emissions due the gas extraction stage will be lower than those during the construction stage.
- Off-site NO₂ concentrations will be below the DECC ambient air quality criteria. This pollutant was considered to be the most significant emission from the diesel-powered generator.

9. REFERENCES

- Bureau of Meteorology (2007)
Climatic Averages Australia, Bureau of Meteorology website,
www.bom.gov.au
- DEC (2005)
"Approved Methods and Guidance for the Modelling and Assessment of Air Pollutants in NSW", August 2005.
- DEC (2006)
"Technical framework: Assessment and management of odour from stationary sources in NSW". November 2006. Available for download from
www.epa.nsw.gov.au .
- EPA (1997)
Quarterly air quality monitoring reports for 1997.
- Holmes Air Sciences (2005)
"Air quality assessment: Dendrobium Underground Mine, NSW South Coast".
June 2005.
- Katestone Scientific (1995)
"Evaluation of Peak-to-Mean Ratios for Odour Assessments" Katestone Scientific Pty Ltd.
- Katestone Scientific (1998)
"Report from Katestone Scientific to Environment Protection Authority of NSW, Peak-to-Mean Ratios for Odour Assessments".
- NPI (2003)
"Emissions estimation technique manual for combustion engines version 2.3".
National Pollutant Inventory.
- NPI (2005)
"Emissions estimation technique manual for oil and gas exploration and production version 1.1". National Pollutant Inventory, 1 June 2005.
- Powell D C (1976)
"A Formulation of Time-varying Depths of Daytime Mixed Layer and Night-time Stable Layer for use in Air Pollution Assessment Models", Annual Report for 1976 Part 3, Battelle PNL Atmospheric Sciences, 185-189.
- SPCC (1986)
"Particle size distributions in dust from open cut coal mines in the Hunter Valley", Report Number 10636-002-71, Prepared for the State Pollution Control Commission of NSW (now DECC) by Dames & Moore, 41 McLaren Street, North Sydney, NSW 2060.

US EPA (1986)

"Guideline on air quality models (revised)", Prepared by the United States Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711, EPA-450/2-78-027R.

VEPA (1986)

"The Ausplume Gaussian Plume Dispersion Model", Environment Protection Authority, Olderfleet Buildings, 477 Collins Street, Melbourne Victoria 3000, Publication Number 264.

Venkatram (1980)

"Estimating the Monin-Obukhov Length in the Stable Boundary Layer for Dispersion Calculations", Boundary-Layer Meteorology, Volume 19, 481-485.

**APPENDIX A
PEAK-TO-MEAN TABLE**

Table A1 : Recommended factors for estimating peak concentrations for different source types, distances and stabilities

Source type	Stability	Near field				Far field			p
		i_{max}	x_{max}	P/M 60	P/M 3	i	P/M 60	P/M 3	
Area	Neutral, Convective	0.5	500 – 1000	2.5	1.9	0.4	2.3	1.7	0.15
	Stable	0.5	300 – 800	2.3	1.7	0.3	1.9	1.4	0.10
Line	Neutral, Convective	1.0	350	6	2.8	0.75	6	2.8	0.25
	Stable	1.0	250	6	2.8	0.65	6	2.8	0.25
Surface point	Neutral	2.5	200	25	10	1.2	5 - 7	3	0.2
	Stable	2.5	200	25	10	1.2	5 - 7	3	0.2
	Convective	2	1000	12	7	0.6	3 - 4	2.5	0.15
Tall point	Neutral, Stable	4.5	5 h	35	8	1.0	6	1.3	0.5
	Convective	2.3	2.5 h	17	4	0.5	3	1.1	0.5
Wake affected point	Neutral, Convective	0.4	-	2.3	1.4	-	2.3	1.4	0.1
Volume	Neutral, Convective	0.4	-	2.3	1.4	-	2.3	1.4	0.1

i_{max} is maximum centreline intensity of concentration

x_{max} is the approximation location of i_{max} in metres

P/M 60 is the peak-to-mean ratio for long averaging times (typically 1 hour), at a probability of 10^{-3}

P/M 3 is the best estimates of the peak-to-mean ratio for 3 minute averages, at probability 10^{-3}

p is the averaging time power law exponent

h is stack height

Source: **Katestone Scientific (1998)**

APPENDIX B
JOINT WIND SPEED, WIND DIRECTION AND STABILITY CLASS FREQUENCY
TABLES

STATISTICS FOR FILE: C:\Jobs\WestCliff\metdata\appin_1995.aus
 MONTHS: All
 HOURS: All
 OPTION: Frequency

PASQUILL STABILITY CLASS 'A'

		Wind Speed Class (m/s)								
WIND	0.50	1.50	3.00	4.50	6.00	7.50	9.00	GREATER		
SECTOR	TO	TO	TO	TO	TO	TO	TO	THAN		TOTAL
	1.50	3.00	4.50	6.00	7.50	9.00	10.50	10.50		
NNE	0.001233	0.001603	0.000370	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.003205
NE	0.001109	0.001356	0.000616	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.003205
ENE	0.001849	0.000740	0.000493	0.000247	0.000000	0.000000	0.000000	0.000000	0.000000	0.003328
E	0.000740	0.000740	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001479
ESE	0.000493	0.001233	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001849
SE	0.001972	0.000986	0.000247	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.003205
SSE	0.004191	0.001603	0.000370	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.006164
S	0.006040	0.001726	0.000247	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.008013
SSW	0.002465	0.000740	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.003205
SW	0.001972	0.000986	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.002959
WSW	0.002835	0.000616	0.000000	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.003575
W	0.004438	0.000863	0.000370	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.005671
WNW	0.003205	0.003698	0.000616	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.007520
NW	0.005794	0.003205	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.009122
NNW	0.003575	0.005547	0.000247	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.009369
N	0.003945	0.006780	0.000370	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.011095
CALM										0.011218
TOTAL	0.045858	0.032421	0.004191	0.000493	0.000000	0.000000	0.000000	0.000000	0.000000	0.094181

MEAN WIND SPEED (m/s) = 1.49
 NUMBER OF OBSERVATIONS = 764

PASQUILL STABILITY CLASS 'B'

		Wind Speed Class (m/s)								
WIND	0.50	1.50	3.00	4.50	6.00	7.50	9.00	GREATER		
SECTOR	TO	TO	TO	TO	TO	TO	TO	THAN		TOTAL
	1.50	3.00	4.50	6.00	7.50	9.00	10.50	10.50		
NNE	0.000370	0.001849	0.000863	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.003205
NE	0.000493	0.000616	0.000863	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.002096
ENE	0.000123	0.000740	0.000616	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.001603
E	0.000123	0.000616	0.000616	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001356
ESE	0.000000	0.000863	0.000247	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001109
SE	0.000863	0.000740	0.000370	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001972
SSE	0.001109	0.001233	0.000616	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.003082
S	0.002096	0.001109	0.000740	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.004068
SSW	0.001233	0.001109	0.000616	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.003082
SW	0.001109	0.001972	0.000863	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.004068
WSW	0.000616	0.000986	0.000986	0.000247	0.000000	0.000000	0.000000	0.000000	0.000000	0.002835
W	0.001233	0.001603	0.002219	0.000247	0.000000	0.000000	0.000000	0.000000	0.000000	0.005301
WNW	0.001479	0.001233	0.000370	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.003205
NW	0.000863	0.001233	0.000370	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.002589
NNW	0.001479	0.003698	0.001109	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.006287
N	0.000740	0.004561	0.003205	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.008506
CALM										0.000863
TOTAL	0.013930	0.024162	0.014670	0.001603	0.000000	0.000000	0.000000	0.000000	0.000000	0.055227

MEAN WIND SPEED (m/s) = 2.41
 NUMBER OF OBSERVATIONS = 448

PASQUILL STABILITY CLASS 'C'

Wind Speed Class (m/s)

WIND SECTOR	0.50	1.50	3.00	4.50	6.00	7.50	9.00	GREATER	TOTAL
	TO 1.50	TO 3.00	TO 4.50	TO 6.00	TO 7.50	TO 9.00	TO 10.50	THAN 10.50	
NNE	0.000616	0.001726	0.003821	0.000247	0.000000	0.000000	0.000000	0.000000	0.006410
NE	0.000370	0.000616	0.001479	0.000616	0.000000	0.000000	0.000000	0.000000	0.003082
ENE	0.000370	0.000740	0.001233	0.001109	0.000000	0.000000	0.000000	0.000000	0.003452
E	0.000247	0.000986	0.001849	0.002465	0.000000	0.000000	0.000000	0.000000	0.005547
ESE	0.000493	0.000740	0.001233	0.002342	0.000000	0.000000	0.000000	0.000000	0.004808
SE	0.000616	0.000740	0.002835	0.001479	0.000000	0.000000	0.000000	0.000000	0.005671
SSE	0.001233	0.002096	0.001109	0.000247	0.000000	0.000000	0.000000	0.000000	0.004684
S	0.001109	0.002712	0.001972	0.001726	0.000000	0.000000	0.000000	0.000000	0.007520
SSW	0.000740	0.002219	0.003452	0.000986	0.000000	0.000000	0.000000	0.000000	0.007396
SW	0.000616	0.003452	0.002465	0.000370	0.000000	0.000000	0.000000	0.000000	0.006903
WSW	0.000740	0.001972	0.002959	0.002219	0.000000	0.000000	0.000000	0.000000	0.007890
W	0.001972	0.001479	0.001972	0.005794	0.000000	0.000000	0.000000	0.000000	0.011218
WNW	0.001479	0.001356	0.001972	0.003082	0.000000	0.000000	0.000000	0.000000	0.007890
NW	0.000616	0.001109	0.000986	0.000616	0.000000	0.000000	0.000000	0.000000	0.003328
NNW	0.000247	0.006657	0.003945	0.000740	0.000000	0.000000	0.000000	0.000000	0.011588
N	0.000000	0.003698	0.010478	0.001726	0.000000	0.000000	0.000000	0.000000	0.015902
CALM									0.000370
TOTAL	0.011464	0.032298	0.043762	0.025764	0.000000	0.000000	0.000000	0.000000	0.113659

MEAN WIND SPEED (m/s) = 3.43
NUMBER OF OBSERVATIONS = 922

PASQUILL STABILITY CLASS 'D'

Wind Speed Class (m/s)

WIND SECTOR	0.50	1.50	3.00	4.50	6.00	7.50	9.00	GREATER	TOTAL
	TO 1.50	TO 3.00	TO 4.50	TO 6.00	TO 7.50	TO 9.00	TO 10.50	THAN 10.50	
NNE	0.000863	0.006657	0.006534	0.000863	0.000000	0.000000	0.000000	0.000000	0.014916
NE	0.001726	0.003328	0.004191	0.003575	0.000616	0.000000	0.000000	0.000000	0.013437
ENE	0.001233	0.004808	0.008259	0.004438	0.000863	0.000123	0.000000	0.000000	0.019724
E	0.001726	0.006534	0.008383	0.001726	0.000247	0.000000	0.000000	0.000000	0.018614
ESE	0.002835	0.005671	0.008136	0.005054	0.001479	0.000000	0.000123	0.000000	0.023299
SE	0.004931	0.009615	0.010602	0.015656	0.010725	0.004068	0.001479	0.000247	0.057322
SSE	0.011834	0.029832	0.012081	0.017382	0.010848	0.005178	0.002589	0.000616	0.090360
S	0.004315	0.019847	0.006657	0.005917	0.004315	0.000863	0.000000	0.000000	0.041913
SSW	0.001233	0.012574	0.005424	0.001972	0.000740	0.000000	0.000000	0.000000	0.021943
SW	0.000616	0.013314	0.008136	0.000123	0.000000	0.000000	0.000000	0.000000	0.022189
WSW	0.000247	0.008752	0.007396	0.003328	0.002342	0.000986	0.000247	0.000000	0.023299
W	0.000370	0.002342	0.006903	0.007396	0.010232	0.004191	0.001109	0.000000	0.032544
WNW	0.000247	0.002959	0.004068	0.004315	0.005671	0.002712	0.001603	0.000123	0.021696
NW	0.000370	0.003082	0.003452	0.002219	0.000616	0.000740	0.000123	0.000000	0.010602
NNW	0.000616	0.005547	0.004931	0.001726	0.000247	0.000123	0.000000	0.000000	0.013190
N	0.001233	0.006780	0.008013	0.001603	0.001479	0.000000	0.000000	0.000000	0.019107
CALM									0.000370
TOTAL	0.034393	0.141642	0.113166	0.077293	0.050419	0.018984	0.007273	0.000986	0.444527

MEAN WIND SPEED (m/s) = 4.00
NUMBER OF OBSERVATIONS = 3606

PASQUILL STABILITY CLASS 'E'

Wind Speed Class (m/s)

WIND SECTOR	0.50	1.50	3.00	4.50	6.00	7.50	9.00	GREATER	TOTAL
	TO 1.50	TO 3.00	TO 4.50	TO 6.00	TO 7.50	TO 9.00	TO 10.50	THAN 10.50	
NNE	0.000863	0.002096	0.000247	0.000123	0.000000	0.000000	0.000000	0.000000	0.003328
NE	0.000863	0.002835	0.000616	0.000000	0.000000	0.000000	0.000000	0.000000	0.004315
ENE	0.001356	0.001603	0.000247	0.000000	0.000000	0.000000	0.000000	0.000000	0.003205
E	0.001972	0.001603	0.000740	0.000000	0.000000	0.000000	0.000000	0.000000	0.004315
ESE	0.002589	0.004561	0.000740	0.000000	0.000000	0.000000	0.000000	0.000000	0.007890
SE	0.004068	0.005794	0.003945	0.000740	0.000000	0.000000	0.000000	0.000000	0.014546
SSE	0.008876	0.043393	0.005671	0.000986	0.000000	0.000000	0.000000	0.000000	0.058925
S	0.004931	0.015409	0.001849	0.000370	0.000000	0.000000	0.000000	0.000000	0.022559
SSW	0.002342	0.005178	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.007520
SW	0.002959	0.005424	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.008383
WSW	0.000986	0.002219	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.003205
W	0.000616	0.001726	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.002342
WNW	0.000247	0.001233	0.000370	0.000000	0.000000	0.000000	0.000000	0.000000	0.001849
NW	0.000370	0.000986	0.001356	0.000123	0.000000	0.000000	0.000000	0.000000	0.002835
NNW	0.000370	0.000740	0.000740	0.000123	0.000000	0.000000	0.000000	0.000000	0.001972
N	0.001479	0.001603	0.000247	0.000000	0.000000	0.000000	0.000000	0.000000	0.003328
CALM									0.000740
TOTAL	0.034887	0.096400	0.016765	0.002465	0.000000	0.000000	0.000000	0.000000	0.151257

MEAN WIND SPEED (m/s) = 2.13
NUMBER OF OBSERVATIONS = 1227

PASQUILL STABILITY CLASS 'F'

Wind Speed Class (m/s)

WIND SECTOR	0.50	1.50	3.00	4.50	6.00	7.50	9.00	GREATER	TOTAL
	TO 1.50	TO 3.00	TO 4.50	TO 6.00	TO 7.50	TO 9.00	TO 10.50	THAN 10.50	
NNE	0.002835	0.000616	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.003452
NE	0.002712	0.000616	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.003328
ENE	0.004191	0.000370	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.004561
E	0.003945	0.000986	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.004931
ESE	0.003698	0.000123	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.003821
SE	0.008999	0.000863	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.009862
SSE	0.010848	0.024038	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.034887
S	0.013560	0.006534	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.020094
SSW	0.007520	0.002835	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.010355
SW	0.006657	0.000986	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.007643
WSW	0.003945	0.001479	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.005424
W	0.002219	0.001356	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.003575
WNW	0.001603	0.000740	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.002342
NW	0.001479	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.001479
NNW	0.001849	0.001233	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.003082
N	0.001603	0.000740	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.002342
CALM									0.019970
TOTAL	0.077663	0.043516	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.141149

MEAN WIND SPEED (m/s) = 1.28
NUMBER OF OBSERVATIONS = 1145

ALL PASQUILL STABILITY CLASSES

WIND SECTOR	Wind Speed Class (m/s)								TOTAL
	0.50 TO 1.50	1.50 TO 3.00	3.00 TO 4.50	4.50 TO 6.00	6.00 TO 7.50	7.50 TO 9.00	9.00 TO 10.50	GREATER THAN 10.50	
NNE	0.006780	0.014546	0.011834	0.001356	0.000000	0.000000	0.000000	0.000000	0.034517
NE	0.007273	0.009369	0.007766	0.004438	0.000616	0.000000	0.000000	0.000000	0.029463
ENE	0.009122	0.008999	0.010848	0.005917	0.000863	0.000123	0.000000	0.000000	0.035873
E	0.008752	0.011464	0.011588	0.004191	0.000247	0.000000	0.000000	0.000000	0.036243
ESE	0.010108	0.013190	0.010478	0.007396	0.001479	0.000000	0.000123	0.000000	0.042776
SE	0.021450	0.018738	0.017998	0.017875	0.010725	0.004068	0.001479	0.000247	0.092579
SSE	0.038092	0.102194	0.019847	0.018738	0.010848	0.005178	0.002589	0.000616	0.198102
S	0.032051	0.047337	0.011464	0.008136	0.004315	0.000863	0.000000	0.000000	0.104167
SSW	0.015533	0.024655	0.009492	0.003082	0.000740	0.000000	0.000000	0.000000	0.053501
SW	0.013930	0.026134	0.011464	0.000616	0.000000	0.000000	0.000000	0.000000	0.052145
WSW	0.009369	0.016026	0.011341	0.005917	0.002342	0.000986	0.000247	0.000000	0.046228
W	0.010848	0.009369	0.011464	0.013437	0.010232	0.004191	0.001109	0.000000	0.060651
WNW	0.008259	0.011218	0.007396	0.007520	0.005671	0.002712	0.001603	0.000123	0.044502
NW	0.009492	0.009615	0.006287	0.003082	0.000616	0.000740	0.000123	0.000000	0.029956
NNW	0.008136	0.023422	0.010971	0.002589	0.000247	0.000123	0.000000	0.000000	0.045488
N	0.008999	0.024162	0.022313	0.003328	0.001479	0.000000	0.000000	0.000000	0.060281
CALM									0.033531
TOTAL	0.218195	0.370439	0.192554	0.107618	0.050419	0.018984	0.007273	0.000986	1.000000

MEAN WIND SPEED (m/s) = 2.94
NUMBER OF OBSERVATIONS = 8112

FREQUENCY OF OCCURENCE OF STABILITY CLASSES

A : 9.4%
B : 5.5%
C : 11.4%
D : 44.5%
E : 15.1%
F : 14.1%

STABILITY CLASS BY HOUR OF DAY

Hour	A	B	C	D	E	F
01	0000	0000	0000	0138	0099	0101
02	0000	0000	0000	0134	0101	0103
03	0000	0000	0000	0129	0110	0099
04	0000	0000	0000	0120	0100	0118
05	0000	0000	0000	0125	0105	0108
06	0008	0006	0010	0137	0090	0087
07	0040	0016	0029	0150	0047	0056
08	0079	0032	0044	0160	0010	0013
09	0094	0051	0079	0114	0000	0000
10	0096	0048	0105	0089	0000	0000
11	0092	0046	0113	0087	0000	0000
12	0088	0056	0098	0096	0000	0000
13	0078	0046	0110	0104	0000	0000
14	0080	0049	0096	0113	0000	0000
15	0064	0047	0092	0135	0000	0000
16	0038	0035	0089	0160	0005	0011
17	0005	0012	0047	0238	0019	0017
18	0002	0004	0010	0275	0035	0012
19	0000	0000	0000	0271	0049	0018
20	0000	0000	0000	0222	0076	0040
21	0000	0000	0000	0172	0083	0083
22	0000	0000	0000	0151	0101	0086
23	0000	0000	0000	0149	0099	0090
24	0000	0000	0000	0137	0098	0103

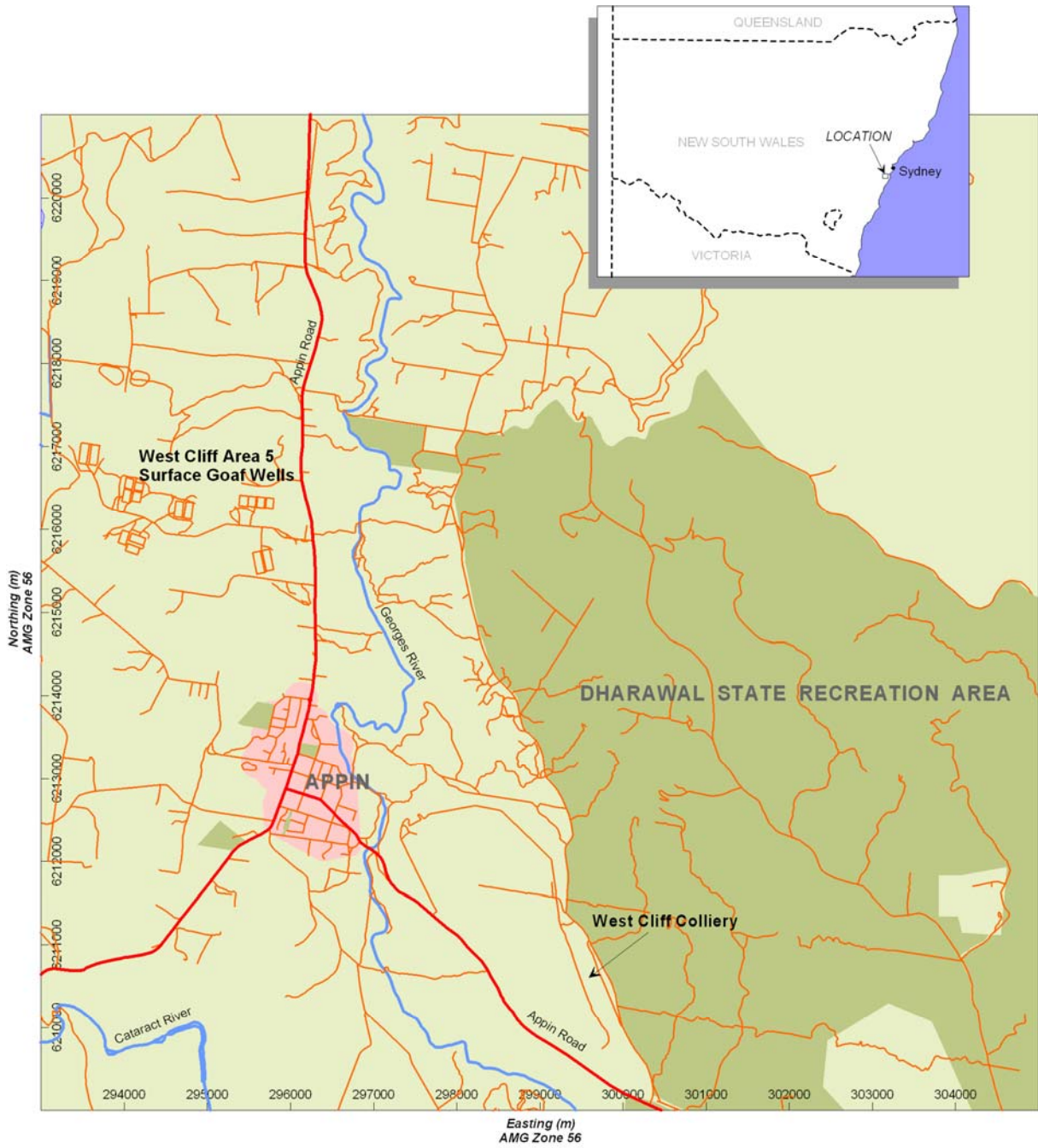
 STABILITY CLASS BY MIXING HEIGHT

Mixing height	A	B	C	D	E	F
<=500 m	0128	0063	0121	0614	1206	1120
<=1000 m	0348	0185	0369	1220	0008	0015
<=1500 m	0288	0200	0432	1360	0013	0010
<=2000 m	0000	0000	0000	0262	0000	0000
<=3000 m	0000	0000	0000	0139	0000	0000
>3000 m	0000	0000	0000	0011	0000	0000

 MIXING HEIGHT BY HOUR OF DAY

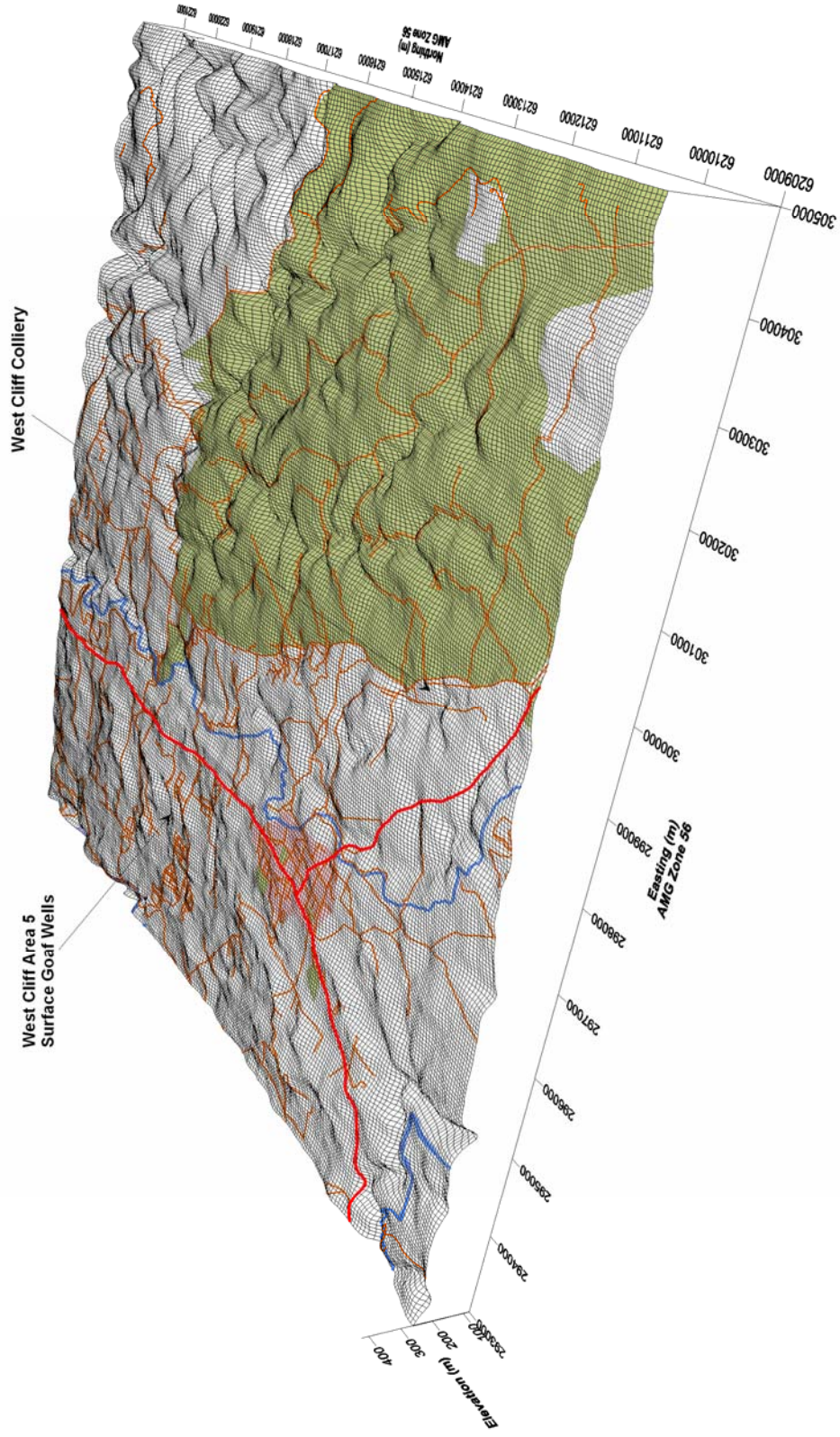
Hour	0000 to 0100	0100 to 0200	0200 to 0400	0400 to 0800	0800 to 1600	1600 to Greater than 3200	3200
01	0081	0107	0024	0048	0066	0012	0000
02	0082	0113	0018	0042	0066	0017	0000
03	0082	0113	0024	0044	0056	0018	0001
04	0100	0104	0018	0047	0053	0015	0001
05	0129	0100	0015	0039	0044	0011	0000
06	0093	0118	0071	0029	0019	0008	0000
07	0090	0059	0102	0077	0007	0003	0000
08	0000	0074	0103	0161	0000	0000	0000
09	0000	0000	0099	0165	0074	0000	0000
10	0000	0000	0000	0216	0122	0000	0000
11	0000	0000	0000	0133	0205	0000	0000
12	0000	0000	0000	0085	0253	0000	0000
13	0000	0000	0000	0020	0318	0000	0000
14	0000	0000	0000	0000	0338	0000	0000
15	0000	0000	0000	0000	0338	0000	0000
16	0000	0000	0000	0000	0338	0000	0000
17	0004	0008	0005	0005	0294	0022	0000
18	0011	0015	0014	0015	0244	0039	0000
19	0016	0031	0020	0024	0187	0060	0000
20	0036	0053	0028	0034	0136	0051	0000
21	0066	0077	0024	0049	0092	0029	0001
22	0077	0096	0019	0050	0074	0022	0000
23	0072	0103	0018	0054	0070	0021	0000
24	0079	0108	0019	0045	0062	0025	0000

FIGURES



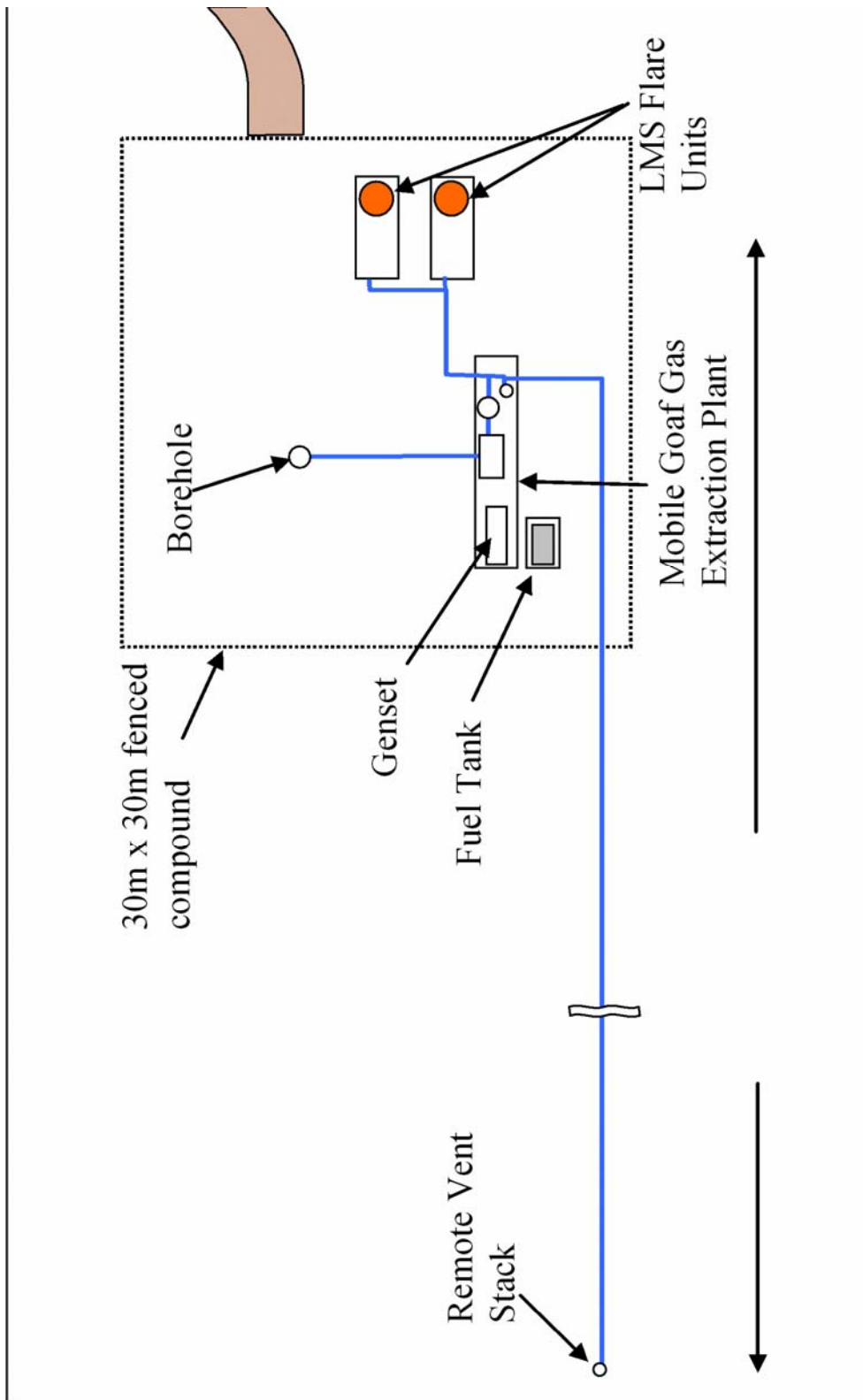
Location of study area

FIGURE 1



Pseudo three-dimensional representation of terrain in the study area

FIGURE 2



Schematic of surface goaf well layout

FIGURE 4

Annual and seasonal windroses for Appin (1995)

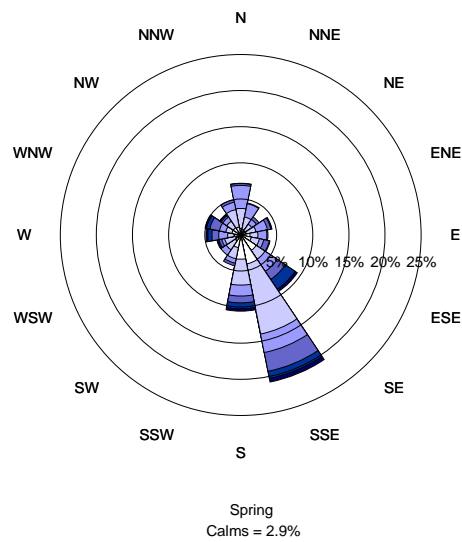
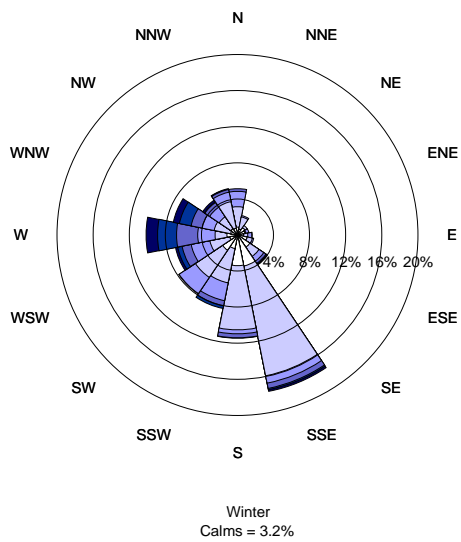
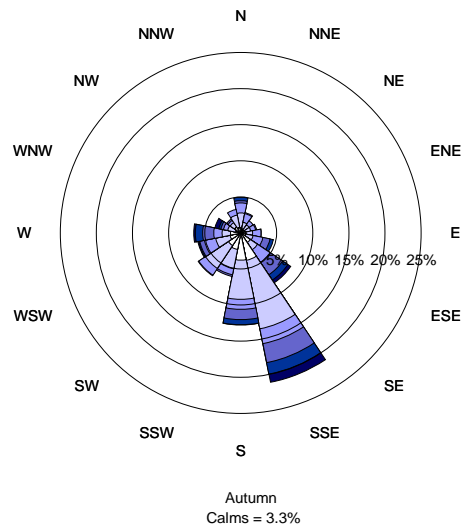
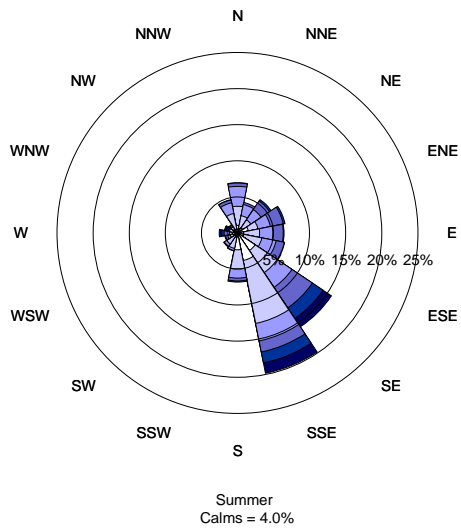
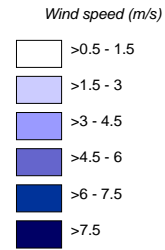
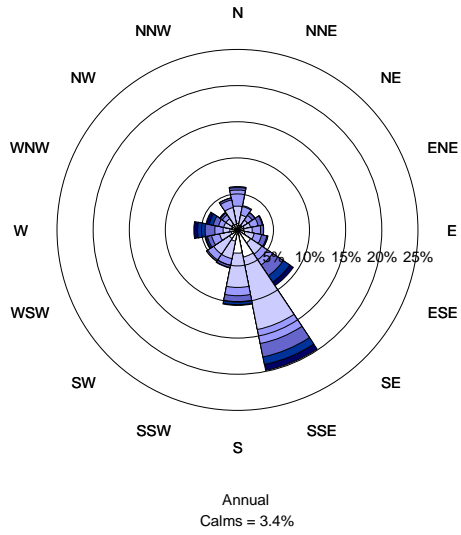
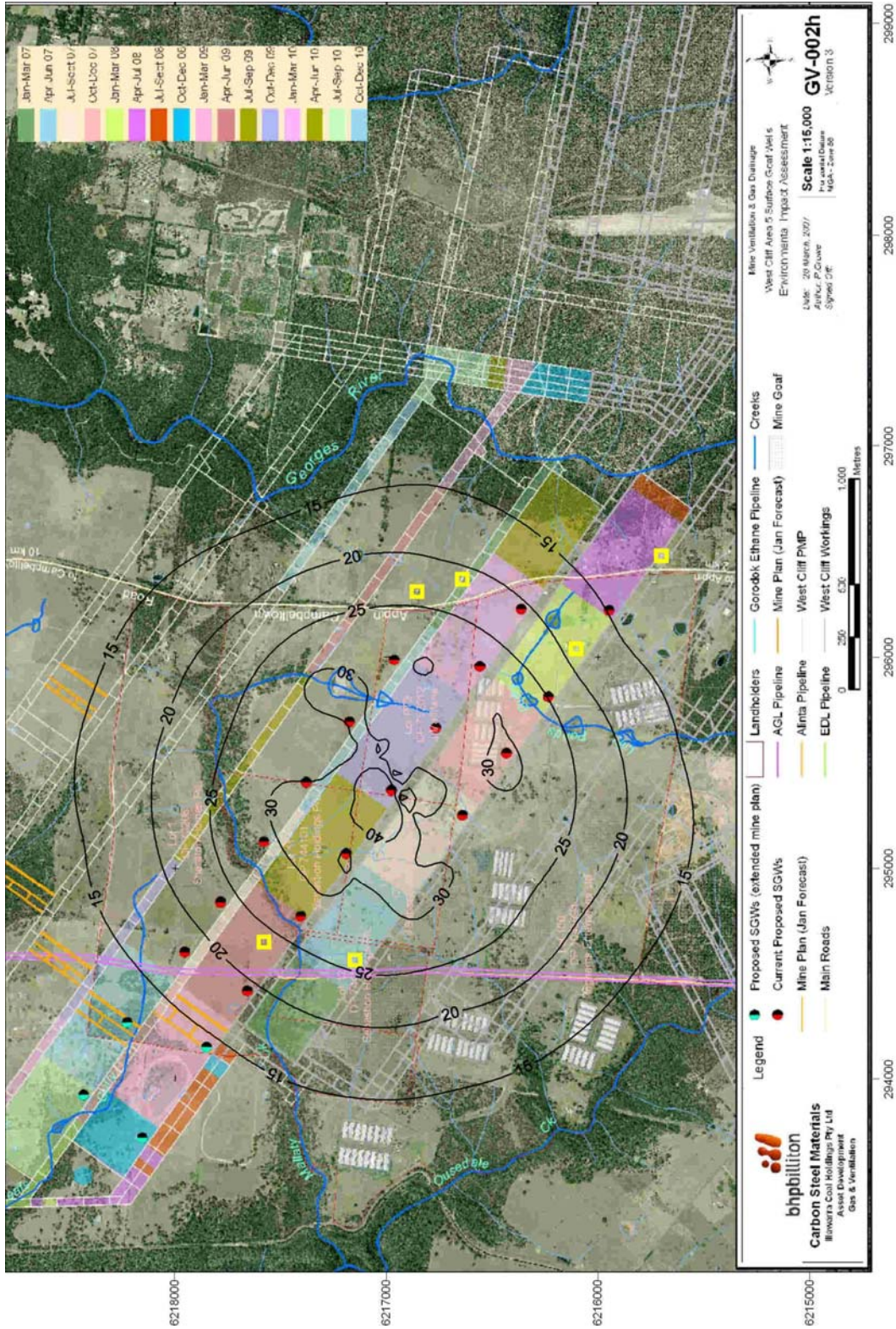
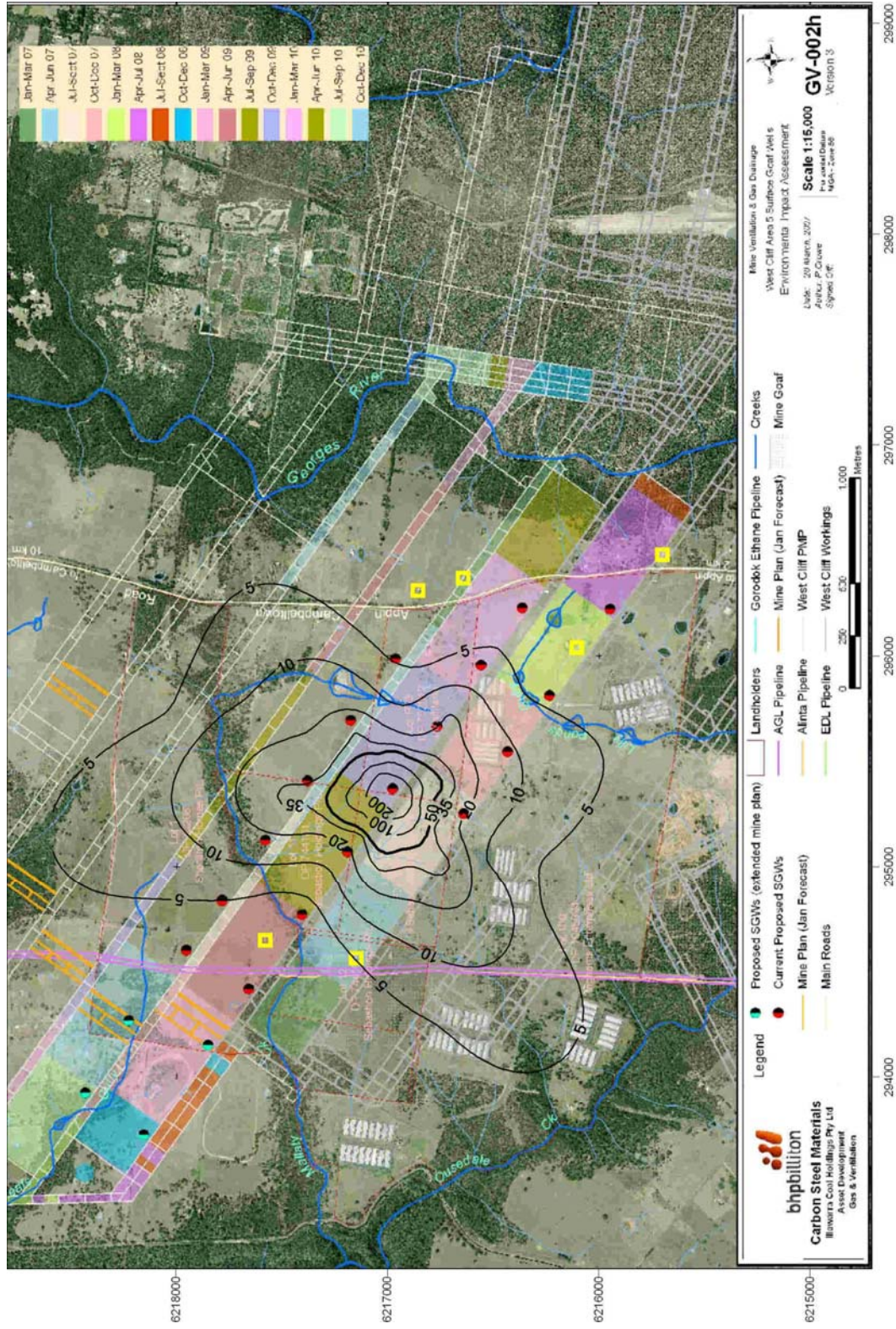


FIGURE 5



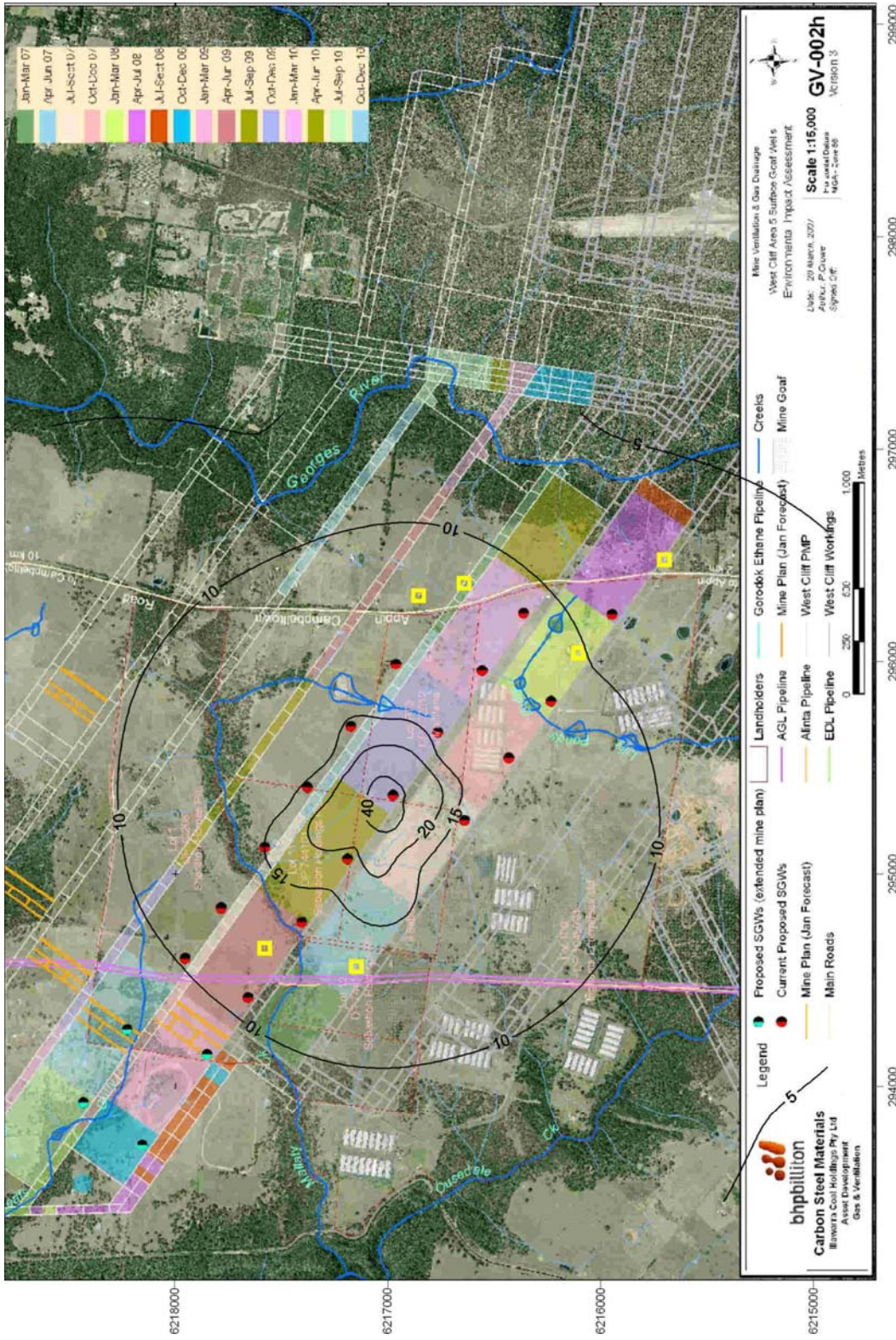
Predicted maximum ground-level odour levels due to gas venting (odour units)

FIGURE 6



Predicted maximum 24-hour average PM_{10} concentrations during goaf well construction ($\mu g/m^3$)

FIGURE 7



Predicted maximum 1-hour average ground-level NO₂ concentrations from diesel generator (µg/m³)