AIR QUALITY IMPACT ASSESSMENT

TECHNICAL PAPER 4

AIR QUALITY IMPACT ASSESSMENT: PROPOSED OPEN CYCLE GAS TURBINE PLANT AT MUNMORAH POWER STATION

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1. INTRODUCTION

This report has been prepared by Holmes Air Sciences on behalf of Parsons Brinckerhoff. Delta Electricity have proposed the construction and operation of an open cycle gas turbine (OCGT) plant on the grounds of the existing Munmorah Power Station in NSW. Parsons Brinckerhoff are preparing an Environmental Impact Statement (EIS) on behalf of Delta Electricity for the project. The purpose of this report is to assess the potential air quality impacts of the project.

The assessment is based on the use of a computer-based dispersion model to predict ground-level pollutant concentrations due to emissions from the proposed plant. The existing air quality environment has been quantified by analysis of air quality monitoring data for the area. To assess the effect that the pollutant emissions would have on existing air quality, the dispersion model predictions have been compared to relevant air quality goals.

The assessment is based on a conventional approach following the procedures outlined in the NSW Department of Environment and Conservation's (NSW DEC, formerly EPA) document titled "Approved Methods and Guidance for the Modelling and Assessment of Air Pollutants in NSW" (**NSW DEC, 2005**).

In summary, the report provides information on the following:

- Description of the project
- The air quality standards and goals relevant for this project
- Review of climatic and meteorological conditions in the area
- Review of existing air quality in the area
- The methods used for determining pollutant emissions and impacts
- Interpretation and analysis of predicted air quality impacts

2. LOCAL SETTING AND PROJECT DESCRIPTION

The Munmorah Power Station is located on the Central Coast of NSW and approximately 10 kilometres northeast of Wyong. **Figure 1** shows the study area, as well as the Munmorah, Eraring and Vales Point power stations. The terrain is diverse in the study area (see **Figure 2**) with the Pacific Ocean in the east and a number of lakes. Terrain rises to up to about 500 m above sea-level in the west of the study area.

The Munmorah Power Station site occupies approximately 940 hectares. Surrounding land is largely undeveloped however beyond the buffer lands of the site are the residential areas of Budgewoi, Doyalson and Lake Munmorah.

Delta Electricity have proposed the construction and operation of an OCGT peaking plant in the grounds of the Munmorah Power Station. The plant would only be operated as a peak-load plant and would supply electricity during periods of peak power demand. **Figure 3** shows the proposed plant layout in relation to the existing Munmorah Power Station.

The plant would comprise four turbines with a combined total net power output of approximately 600 MW. The turbines in the plant would generally run on natural gas however distillate could be used as a back-up fuel. The current concept design of the plant has been based on 500 operating hours per year. There would be up to 75 hours per year where the plant operates using distillate fuel.

The operation the proposed plant is summarised by **Table 1**.

Table 1 : Summary of OCGT plant operation

Operating hours (natural gas and distillate)	500 hours per gas turbine per year
Operating hours on distillate fuel	Up to 75 hours per gas turbine per year (cumulative total)
Gas firing duration	Up to 5 hours per day
Number of starts	166 starts per gas turbine per year

The potential air quality impacts of the project will be mainly short-term since the operation of the plant would be of a sporadic nature.

3. AIR QUALITY GOALS

In assessing any project with significant air emissions, it is necessary to compare the impacts of the project with relevant air quality goals. Air quality standards or goals are used to assess the potential for ambient air quality to give rise to adverse health or nuisance effects.

Table 2 lists the air quality goals for criteria pollutants noted by the DEC and National Environment Protection Measures (NEPM) that are relevant to this study. The primary air quality objective for most projects is to ensure that the air quality goals listed in **Table 2** are not exceeded at any location where there is a possibility of human exposure.

It is important to note that the standards established as part of the NEPM are designed to be measured to give an 'average' representation of general air quality. That is, the NEPM monitoring protocol was not designed to apply to monitoring peak concentrations from major emission sources (**NEPC, 1998**).

Table 2 : Air quality goals referred to by DEC

POLLUTANT	GOAL	AVERAGING PERIOD	SOURCE
Carbon monoxide (CO)	25 ppm or 30 mg/m^3	1-hour maximum	NSW DEC
	9 ppm or 10 mg/m^3	8-hour maximum	NSW DEC
Nitrogen dioxide (NO_2)	0.12 ppm or 246 μg/m^3	1-hour maximum[1]	NSW DEC, NEPM
	0.03 ppm or 62 μg/m^3	Annual mean	NSW DEC, NEPM
Particulate matter less than 10 μm (PM_{10})	50 μg/m^3	24-hour maximum	NSW DEC, NEPM[2]
	30 μg/m^3	Annual mean	NSW DEC long term reporting goal
Sulfur Dioxide (SO_2)	25 pphm or 712 μg/m^3	10-minute maximum	NSW DEC
	0.20 ppm or 570 μg/m^3	1-hour maximum	NSW DEC, NEPM[1]
	0.08 ppm or 228 μg/m^3	24-hour maximum	NSW DEC, NEPM[1]
	0.02 ppm or 60 μg/m^3	Annual average	NSW DEC, NEPM
Benzene	0.029 mg/m^3	1-hour maximum	NSW DEC
Formaldehyde	0.02 mg/m^3	1-hour maximum	NSW DEC
Toluene	0.36 mg/m^3	1-hour maximum	NSW DEC
Xylene	0.19 mg/m^3	1-hour maximum	NSW DEC
PAH (as benzo(a)pyrene)	0.0004 mg/m^3	1-hour maximum	NSW DEC

[1] *One day per year maximum allowable exceedances*
[2] *Five days per year maximum allowable exceedances*

Table 3 provides the ambient air quality NEPM's developed by NEPC (**NEPC, 2004**). At this stage values for $PM_{2.5}$ and air toxics are termed "investigation levels" rather than goals which are applied on a project basis. As indicated in the footnote of **Table 3**, the goals for $PM_{2.5}$, are referred to as Advisory Reporting Standards.

Table 3 : Air quality NEPM's for $PM_{2.5}$ and air toxics

POLLUTANT	GOAL	AVERAGING PERIOD	SOURCE
Particulate matter less than 2.5 µm ($PM_{2.5}$)*	25 µg/m^3 8 µg/m^3	24-hour maximum Annual average	NEPM NEPM
Benzene	0.003 ppm	Annual average	NEPM (Air Toxics)
Formaldehyde	0.04 ppm	24-hour maximum	NEPM (Air Toxics)
Toluene	1 ppm 0.1 ppm	24-hour maximum Annual average	NEPM (Air Toxics) NEPM (Air Toxics)
Xylene	0.25 ppm 0.2 ppm	24-hour maximum Annual average	NEPM (Air Toxics) NEPM (Air Toxics)
PAH	0.3 ng/m^3	Annual average	NEPM (Air Toxics)

* *The goals for $PM_{2.5}$, referred to as Advisory Reporting Standards, have been set for the purposes of gathering data to facilitate a review of these standards as part of the development of the $PM_{2.5}$ NEPM*

4. EXISTING ENVIRONMENT

This section describes the dispersion meteorology, general climate and existing air quality of the study area. As well as information on prevailing wind patterns, historical data on temperature, humidity and rainfall are presented to give a more complete picture of the local climate.

4.1 Dispersion Meteorology

The meteorology in the study area would be influenced by several factors including the local terrain and land-use. On a relatively small scale, winds would be largely affected by the local topography (see **Figure 2** for a representation of the local terrain). At larger scales, winds are affected by synoptic scale winds, which are modified by sea breezes near the coast in the daytime in summer (also to a certain extent in the winter) and also by a complex pattern of regional drainage flows that develop overnight.

Given the relatively diverse terrain and landuse in the study area, differences in wind patterns at different locations in the study area would be expected. These varying wind patterns would arise as a result of the interaction of the air flow with the surrounding topography and the differential heating of the land and water.

In the air quality assessment undertaken in this report it is not necessary to understand the complex mechanisms that affect air movements in the area, it is simply necessary to ensure that these air movements are incorporated into the dispersion modelling studies that are done. A limitation of common Gaussian plume dispersion models (such as AUSPLUME) is that they assume that the meteorological conditions are the same spatially over the entire modelling domain for any given hour. This may be adequate for sources in relatively uncomplicated terrain however when the terrain or landuse is more complex the meteorological conditions can be more accurately represented using wind field and puff models.

In the last decade there has been a significant improvement in the capability of dispersion models to handle dispersion in areas where complex wind flows occur. In this assessment we have made extensive use of the CALPUFF dispersion model. The CALPUFF model makes use of wind fields generated by the CALMET model. CALMET generates a three-dimensional wind field on an hourly basis by taking observations of winds at selected locations and interpolating these to produce information on wind speed and direction at a grid of regularly spaced points covering the area of interest. Modifications that are imposed on this interpolated wind field (by topography and differential heating and differential surface roughness) are then applied to the winds at each grid point to develop a final wind field.

The final wind field reflects the effect of local topography and the effects of different temperatures experienced by water bodies and land surfaces as well as different surface roughness that arise because of changes in vegetation or other variations in land use such as the presence of residential developments, etc.

A wind field has been generated by CALMET for each hour of the 2003 calendar year using meteorological data collected by Delta at Dora Creek, Marks Point and

Munmorah. **Figure 4** shows the location of the meteorological monitoring sites, as well as air quality monitoring sites. The CALMET model has essentially used the data from these sites to determine wind patterns over the entire modelling domain given information on the local landuse and terrain features. In addition, the wind data from the three sites have also been used as input to the CSIRO's prognostic model (The Air Pollution Model, TAPM) in order to generate upper air information on higher altitude winds and temperature profiles as required by the CALMET model. TAPM is a prognostic model which has the ability to generate meteorological data for any location in Australia (from 1997 onwards) based on synoptic information determined from the six hourly Limited Area Prediction System (LAPS) (**Puri *et al.,* 1997**). The model is discussed further in the accompanying user manual (see **Hurley, 2002**).

A summary of the data and parameters used as part of the meteorological component of this study are shown in **Table 4**.

Table 4 : Summary of meteorological parameters used for this study

TAPM (v 2.0)	
Number of grids (spacing)	4 (30 km, 10 km, 3 km, 1 km)
Number of grids point	25 x 25 x 25
Year of analysis	Jan 2003 to Dec 2003
Centre of analysis	33°9' S, 151°34.5' E
Data assimilation	3 sites: Dora Creek, Marks Point and Munmorah
CALMET (v 5.5)	
Meteorological grid domain	25 km x 25 km
Meteorological grid resolution	1.0 km
Number of grid cells	40 x 40 x 10
Surface meteorological station	3 sites: Dora Creek, Marks Point and Munmorah for wind velocity. Cloud cover from Sydney Airport (BoM). Ceiling height, pressure, temperature and relative humidity by TAPM for each site
Upper air meteorological station	Data extracted from TAPM simulation for Munmorah Power Station site
Simulation length	8760 hours (Jan 2003 to Dec 2003)
Mode	Diagnostic wind module

Meteorological data collected from Dora Creek, Marks Point and Munmorah included hourly records of wind speed, wind direction and sigma-theta (a measure of horizontal wind direction fluctuations). The Dora Creek and Marks Point are operated by Eraring Energy. Data available for the purposes of this study covered the period from June 2002 to May 2005 inclusive and 2003 has been selected for development of the meteorological wind field as this year had the most complete data recovery for all three sites. The number of hourly records for each year of data and for each site is shown in **Table 5**. Also shown in this table is the mean wind speed for each data period.

Table 5 : Wind speed statistics from available meteorological data

Period	Dora Creek		Marks Point		Munmorah	
	Mean wind speed (m/s)	No. of hourly records	Mean wind speed (m/s)	No. of hourly records	Mean wind speed (m/s)	No. of hourly records
2002	1.3	5101	3.0	4880	2.4	5068
2003	1.4	8759	3.1	8663	2.4	8675
2004	1.7	8767	2.9	8725	2.3	8086
2005	1.4	3623	2.1	3610	2.4	2856
All data	1.5	26250	2.9	25878	2.4	24685

Figure 5 shows a snapshot of winds simulated by the CALMET model for stable night-time conditions. The diagram shows the effect of the terrain on the flow of winds for a particular set of atmospheric conditions.

Annual and seasonal windrose diagrams have been constructed for each meteorological monitoring site for 2003. These windroses are presented in **Figures 6** to **8**.

Winds at Dora Creek were predominantly from the east in summer, as shown by **Figure 6**. These winds are likely to represent the direction of the sea-breeze. In winter the most common winds were from the northwest. There was a high frequency of calms (winds less than or equal to 0.5 m/s) measured at the Dora Creek site. Annually, calm periods were recorded for 23% of the time and in autumn the proportion of calm periods was even higher at 41%. The Dora Creek site had the lowest average wind speed of the three sites with 1.4 m/s (see **Table 5**).

Average wind speed at the Marks Point site were higher than at the Dora Creek site in 2003 (3.1 m/s compared with 1.4 m/s). Windroses created from the 2003 Marks Point data are presented in **Figure 7**. It can be seen from this figure that, annually, the most common winds were from the northwest, south-southwest and east-northeast.

Figure 8 shows the windroses from the Munmorah Climatic meteorological site for 2003. The most common winds at this site were from the west-southwest, southwest and south, with winds from the northeast also recorded. The seasonal windroses highlighted seasonal trends that are common for a coastal location with seas-breezes and southerly winds prevailing in summer and offshore winds prevailing in winter and the cooler months. The frequency of calm periods at this site for 2003 was around 5%.

There are some differences in the wind patterns measured from each site however all three sites had some common features. These features included the presence of a sea-breeze in the summer months and winds from the western sector in the winter months.

4.2 Atmospheric Stability

Dispersion models typically require information on atmospheric stability class[1] and mixing height[2]. Plume dispersion models usually assume that the atmospheric stability is uniform over the entire study domain and these estimates are commonly calculated from measurements of sigma-theta, cloud cover information or solar radiation and temperature. Hourly estimates of mixing height can be determined by a combination of empirical methods and/or soundings.

The CALPUFF dispersion model, however, obtains estimates of atmospheric stability and mixing height from the CALMET meteorological model. CALMET determines these parameters using the cloud cover data and temperature profiles it is provided in order to run. The output of the CALMET model can subsequently be processed to extract meteorological information for any site of interest in the modelling domain, including atmospheric stability. **Table 6** provides the frequency of occurrence of the six stability classes as determined by CALMET for the Munmorah Climatic meteorological monitoring site.

It can be seen from **Table 6** that the most common stability class was determined to be F-class. Dispersion of pollutants is slow under these circumstances as F-class stabilities are generally associated with night-time conditions when a temperature inversion is present.

Table 6 : Frequency of occurrence of atmospheric stability class

Pasquill-Gifford-Turner stability class	Munmorah Climatic, %
A	0.3
B	8.7
C	18.7
D	29.5
E	7.8
F	35.0
TOTAL	100

Joint wind speed, wind direction and stability class frequency tables generated for this site are presented in **Appendix A**. Tables of stability class by hour of day (provided in **Appendix A**) show that a large proportion of night-time hours were determined to be associated with F-class stability.

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[1] In dispersion modelling stability class is used to categorise the rate at which a plume will disperse. In the Pasquill-Gifford-Turner stability class assignment scheme 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 mixed-layer height refers 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.

4.3 Local Climatic Conditions

The Bureau of Meteorology collects climatic information from Norah Head Lighthouse, in the southeast of the study area. A range of meteorological data collected from this station are presented in **Table 7** (**Bureau of Meteorology, 2005**). 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 and median monthly rainfall and the average number of raindays per month.

The annual average maximum and minimum temperatures experienced at Norah Head are 21.7°C and 14.6°C respectively. On average February is the hottest month with an average maximum temperature of 25.2°C. July is the coldest month, with an average minimum temperature of 9.3°C.

The annual average humidity reading collected at 9 am from the Norah Head site is 77 percent, and at 3 pm the annual average is 71 percent. The month with the highest humidity on average is February with a 9 am average of 83 percent, and the lowest is August with a 3 pm average of 63 percent.

Rainfall data collected at Norah Head shows that February is the wettest month, with an average rainfall of 142 mm over 11.9 days. The average annual rainfall is 1,227 mm over an average of 136 raindays.

Table 7 : Climate information for the study area

Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean daily maximum temperature - deg C	25	25.2	24.4	22.7	20.1	17.7	17.2	18.4	20.2	21.8	22.6	24.8	21.7
Mean no. of days where Max Temp >= 40.0 deg C	0.1	0	0	0	0	0	0	0	0	0	0	0.1	0.3
Mean no. of days where Max Temp >= 35.0 deg C	0.5	0.4	0.2	0	0	0	0	0	0	0.2	0.4	0.8	2.4
Mean no. of days where Max Temp >= 30.0 deg C	1.6	1.1	0.7	0.3	0	0	0	0	0.4	1.7	1.3	2.2	9.4
Highest daily Max Temp - deg C	42.3	39.9	41.9	35.6	28.5	25	26	30.1	34.8	38.2	41.8	42.4	42.4
Mean daily minimum temperature - deg C	19.3	19.6	18.4	15.7	12.9	10.2	9.3	9.9	11.9	14.2	16	18.2	14.6
Mean no. of days where Min Temp <= 2.0 deg C	0	0	0	0	0	0	0	0	0	0	0	0	0
Mean no. of days where Min Temp <= 0.0 deg C	0	0	0	0	0	0	0	0	0	0	0	0	0
Lowest daily Min Temp - deg C	13.3	11.6	11.1	8.5	6.1	3.6	3.4	4	5.5	6.6	9.5	8.3	3.4
Mean 9am air temp - deg C	22.1	22.1	21.3	19.3	16	13.2	12.3	13.8	16.4	18.5	19.4	21.4	18
Mean 9am wet bulb temp - deg C	19.9	20.2	19.1	17	14	11.3	10.4	11.3	13.3	15.5	16.8	18.8	15.6
Mean 9am relative humidity - %	82	83	81	79	79	78	77	72	70	72	76	78	77
Mean 9am wind speed - km/h	15.4	16	14.7	13.3	13.2	14	12.9	13.1	13.9	15.3	15.4	15	14.3
Mean 3pm air temp - deg C	23.7	23.9	23	21.2	18.8	16.6	16.1	17.1	18.4	19.6	20.9	23	20.2
Mean 3pm wet bulb temp - deg C	20.7	21.1	20	18.1	15.6	13.4	12.6	13.2	14.4	16.1	17.7	19.6	16.9
Mean 3pm relative humidity - %	76	77	75	73	71	69	66	63	65	70	73	73	71
Mean 3pm wind speed - km/h	23	22.5	21.1	19.8	17.4	17.8	16.7	19.3	22.4	22.8	23.2	23	20.8
Mean monthly rainfall – mm	106.4	142	129	118.1	132.2	126.5	80.4	69.4	73.7	72.7	96.5	80.6	1227.4
Median (5th decile) monthly rainfall - mm	86	107.9	114.3	89.1	115.6	102.7	68.6	43	54.6	56.9	103.4	66.2	1195.8
9th decile of monthly rainfall - mm	219	343.6	251.3	335.9	300.5	298.8	149.3	149.5	170.1	169.9	162.2	188.4	1636
Mean no. of raindays	12.2	11.9	13	11.2	12.9	11.3	9.9	9.1	9.8	11	12.7	10.7	135.6
Highest monthly rainfall – mm	439	605.8	339.4	416.6	445.2	424.1	370.3	334.1	289.8	202.8	231	236.8	
Lowest monthly rainfall – mm	7.2	6.7	13.2	6.4	4.8	1.8	0.3	2.8	0.4	1	11.6	8.2	
Highest recorded daily rainfall – mm	235.2	246	148.1	105	149.1	151	118.3	113	134	112	168	122.6	246
Mean no. of clear days	6.6	5.5	7.4	8.6	8	8.8	10.8	12.2	9.4	7.4	5.9	7.1	97.7
Mean no. of cloudy days	12.4	12.3	11.4	10.4	11.6	10.5	9.1	8	8.5	11.2	12.1	11.6	129.1

Climate averages for Station: 061273 NORAH HEAD LIGHTHOUSE. Commenced: 1969; Last record: 2004; Latitude (deg S): -33.2815; Longitude (deg E): 151.5759; State: NSW
Source: Bureau of Meteorology, 2005

4.4 Ambient Air Quality

One of the most difficult aspects in air quality assessments is accounting for the existing levels of pollutants from sources that are not included in the dispersion model. At any location within the airshed the concentration of the pollutant is determined by the contributions from all sources that have at some stage or another been upwind of the source. In the case of PM_{10} for example, the background concentration may contain emissions from the combustion of wood from domestic heating, from bushfires, from industry, other roads, wind blown dust from nearby and remote areas, fragments of pollens, moulds, sea-salts and so on.

In general, the further away a particular source is from the area of interest, the smaller will be its contribution to air pollution at the area of interest. However the larger the area considered, the greater would be the number of sources contributing to the background.

Ambient air quality data is available for two sites in the study area, referred to as the Munmorah and Wyee sites. The location of these sites is shown in **Figure 4**. Ten minute average records of SO_2 and NO_x are available for both sites over the period from June 2002 to May 2005. Hourly averages of these data are presented graphically in **Figures 9** and **10**.

The ambient air quality monitoring data available for this study are summarised below in **Table 8**. There was no known long-term monitoring of CO for the study area.

Table 8 : Summary of ambient air quality monitoring data

Measurement	Munmorah ($\mu g/m^3$)			Wyee ($\mu g/m^3$)			Relevant air quality goal
	2002	2003	2004	2002	2003	2004	
NO_x (maximum 1-hour average)	381	383	457	694	619	562	-
NO_x (annual average)	17	17	20	67	57	55	-
NO_2 (maximum 1-hour average)	85	103	90	94	78	197	246
NO_2 (annual average)	13	10	15	14	15	15	62
SO_2 (10-minute maximum)	194	263	378	400	297	375	712
SO_2 (maximum 1-hour average)	163	140	189	212	177	226	570
SO_2 (maximum 24-hour average)	49	22	43	46	32	29	228
SO_2 (annual average)	6	3	6	6	3	3	60
PM_{10} (maximum 24-hour average)	-	-	-	133	-	-	50
PM_{10} (annual average)	-	-	-	25	-	-	30

The highest hourly average NO_2 from the available monitoring data was measured at the Munmorah site at 103 $\mu g/m^3$ (approximately 5 pphm on 10-Nov-03 hour 13). This is below the DEC goal of 246 $\mu g/m^3$. For the 2002 to 2004 period, average NO_2 levels ranged from 10 to 15 $\mu g/m^3$ which is well below the annual average NO_2 goal of 62 $\mu g/m^3$.

There were no exceedances of the 10-minute average SO_2 air quality goal (712 $\mu g/m^3$) for the 2002 to 2004 period. The highest 10-minute average SO_2 concentration was 400 $\mu g/m^3$ at Wyee in 2002. The maximum hourly average SO_2 concentration (226 $\mu g/m^3$) was recorded at Wyee in 2004. This concentration is below the 570 $\mu g/m^3$ air quality goal. Similarly, maximum 24-hour average and annual average SO_2 concentrations (49 and 6 $\mu g/m^3$ respectively) were below their respective air quality goals.

Measurements of PM_{10} by Tapered Element Oscillating Microbalance (TEOM) were made at Wyee from December 2001 to December 2002 and are shown graphically by **Figure 11**. For this period, there was over twenty days when the measured PM_{10} concentration was above the 50 $\mu g/m^3$ goal. The majority of the exceedances were measured in the summer months, when bushfires are common, however there was one occasion when the PM_{10} concentration was above 50 $\mu g/m^3$ in the cooler months (22-Jul-2002). The measured highest 24-hour average PM_{10} concentration was 133 $\mu g/m^3$ and the annual average was 25 $\mu g/m^3$. The annual average PM_{10} concentration is below the 30 $\mu g/m^3$ goal.

Figure 12 shows the correlation between pollutant concentrations and wind direction (pollution roses). This figure has been constructed to assess whether pollutant concentrations could be attributed to a particular power station source. These graphs can be reviewed by considering the location of the air quality monitors in relation to potential pollutant sources in the area (refer **Figure 4**). A "signal" from direction of power stations is most likely to be detected from SO_2 measurements as this pollutant would be considered to contain the least contribution from non-power station sources.

At the Lake Munmorah School monitoring site there is not a clear correlation between elevated NO_x or SO_2 concentrations and winds from power station sources. This monitor is located to the northeast of Munmorah Power Station and to the southeast of the Eraring and Vales Point power stations. It is recognised that there would be many sources of NO_x in the area, including motor vehicles.

The Wyee air quality monitor is located to the northwest of Munmorah Power Station, to the west of Vales Point Power Station and to the southwest of Eraring Power Station. There is not a clear pattern of elevated NO_x concentrations from the direction of these power station sources. The F3 freeway, to the west of the monitoring site, would be considered a significant source of NO_x in the area. For SO_2, however, the pollution rose has two "arms" in the general direction of the Eraring (to the northeast) and Vales Point (to the east) power stations. The measured SO_2 concentrations are below air quality goals.

Some analysis of the percentage of NO_x which has been converted to NO_2 is particularly useful for this project as estimates of NO_2 concentrations are commonly derived from NO_x predictions.

Nitrogen oxides are produced in most combustion processes and are formed during the oxidation of nitrogen in the fuel and nitrogen in the air. During high-temperature processes a variety of nitrogen oxides are formed including nitric oxide (NO) and NO_2. 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 NO_2[3]. The effects of NO on human health are such that it is not regarded as an air pollutant at the concentrations at which it is normally found in the environment. The presence of NO_x emissions can be of concern in urban environments where the control of photochemical smog is important.

Ultimately, however, all nitric oxides emitted into the atmosphere are oxidised to NO_2 and then further to other higher oxides of nitrogen. The rate at which this oxidisation takes place depends on prevailing atmospheric conditions including temperature, humidity and the presence of other substances in the atmosphere such as ozone. It can vary from a few minutes to many hours. The rate of conversion is quite important because from the point of emission to the point of maximum ground-level concentration there will be an interval of time during which some oxidation will take place. If the dispersion is sufficient to have diluted the plume to the point where the concentration is very low it is unimportant that the oxidation has taken place. However, if the oxidation is rapid and the dispersion slow then high concentrations of NO_2 can occur.

Analysis of the oxides of nitrogen monitoring data reveals that the percentage of NO_2 in the air is inversely proportional to the total NO_x concentration. **Figure 13** shows this relationship for the two monitoring sites.

It can be seen from **Figure 13** that lower fractions of NO_2 in the NO_x are observed when the NO_x concentration is high. Conversely, when the NO_x concentration is low, high fractions of NO_2 in the NO_x can occur. It can be seen from **Figure 13** that, at the Lake Munmorah site, the fraction of NO_2 in the NO_x is below about 20% when the NO_x concentrations are high. At Wyee the NO_2 fraction appears to be even lower when the NO_x concentration is high – of the order of 20% or lower. For dispersion model predictions of maximum hourly average NO_x concentrations it would therefore be reasonable that the NO_x predictions would comprise around 20% NO_2.

The fraction of NO_2 in the maximum hourly NO_x concentration would be expected to be less than 20% close to NO_x sources. 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 NO_2. The ratio of NO_2 to NO_x will increase from about 5%, at the point of emission, to about 20% by the time that the plume has reached the point where the maximum hourly average ground-level concentrations are predicted.

---

[3] For start-up conditions of the open cycle gas turbine plant there is likely to be a high proportion of NO_2 in the NO_x.

5. ESTIMATED AIR EMISSIONS

The CALPUFF 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 emissions rates can be provided to the model as hourly records for an entire year (variable emissions) or as constant emissions.

Emission estimates for the proposed OCGT were provided by Parsons Brinckerhoff. **Table 9** provides the emissions information used as input into CALPUFF. There are four emission scenarios for the OCGT depending on whether the plant is natural gas or distillate fired and under normal or start-up conditions.

Table 9 : Emission characteristics for the dispersion modelling

Proposed OCGT	Natural gas fired		Distillate fired	
	Normal	Start-up	Normal	Start-up
Stack easting (m)	364129	364129	364129	364129
Stack northing (m)	6324355	6324355	6324355	6324355
Stack base elevation (m)	15	15	15	15
Height (m)	35	35	35	35
Stack tip diameter (m)	6	6	6	6
Temperature (K)	797	671	791	674
Velocity (m/s)	43	27	44	27
Emissions (g/s)				
CO	4.44	895.56	35.56	1711.11
NO_x (as NO_2)	81.11	117.78	112.22	162.22
SO_2	4.92	2.23	6.11	13.06
PM_{10}	4.44	4.44	9.44	9.44

Table 10 provides information on the in-stack concentrations for the OCGT. These data can be compared with the amendments to the Protection of the Environment Operations (Clean Air) Regulation (POEO) (**DEC, 2004**). The OCGT pollutant concentrations were calculated from the mass emission rates and flow characteristics in **Table 9**.

Table 10 : In-stack concentrations for the OCGT

Pollutant	OCGT Normal operations (mg/Nm^3)		POEO limit (mg/Nm^3)	
	Natural gas fired	Distillate fired	Gas	Other
CO	3	21	-	-
NO_x (as NO_2)	49	65	70	90
SO_2	3	4	-	-
PM_{10}	3	5	50	50

6. APPROACH TO MODELLING

This section provides a brief description of the method used to model stack emissions from the proposed OCGT plant. This information is required as input to the dispersion model and is used to predict ground-level concentrations of the various pollutants.

The model used was the most recent release of the CALPUFF modelling system (Version 5.7) using the meteorological information described in **Section 4.1**. The modelling took account of stack dimensions, characteristics and emissions to predict ground-level concentrations of pollutants emitted from the stacks. Local terrain and landuse in the study area has been incorporated into the modelling. Dispersion modelling was undertaken for a 40 km by 40 km grid domain defined by the limits of the area shown in **Figure 1**. Predictions were made at a set of gridded receptors with 1 km spacing. A finer spaced (200 m spacing) set of receptors was included for an area 2 km around the proposed OCGT plant. Discrete receptors were also placed at the location of each air quality monitor.

In order to employ the PDF (Probability Density Function) algorithm in CALPUFF, the dispersion coefficients were determined using turbulence computed from micrometeorology. The PDF algorithm is considered suitable for modelling emissions from tall stacks. Building wake effects were included in the modelling. The CALMET and CALPUFF model input files can be provided on request.

Four dispersion modelling scenarios have been developed for this study:

1. Natural gas fired OCGT plant for normal operations
2. Natural gas fired OCGT plant for start-up conditions
3. Distillate fired OCGT plant for normal operations
4. Distillate fired OCGT plant for start-up conditions

A conservative approach has been adopted for the purposes of this study. Firstly, the existing air quality environment has been quantified in terms of the maximum background pollutant levels that have been measured in the study area. Dispersion modelling has been used to predict the contribution of the OCGT emissions to the existing air quality. The maximum measured background concentrations were then added to the maximum dispersion model predictions to determine the cumulative effect of the project. The resultant cumulative concentrations were then compared with the relevant air quality criteria. This is a conservative approach.

Since dispersion models generally only predict on time scales of 1-hour or more, the predicted maximum 10-minute SO_2 concentrations were determined from the 1-hour predictions using an empirical relationship. The empirical relationship has the form as follows:

Equation 1 (from **VEPA, 1986):**

$$C_t = C_{60}\left[\frac{60}{t}\right]^{0.2}$$

where:
C_t = Concentration for time, t
C_{60} = Concentration for averaging time, 60 minutes
t = time, in minutes

The ratio of 10-minute maximum to 60-minute average SO_2 concentrations has also been examined from the air quality monitoring data available from Lake Munmorah and Wyee. **Figure 14** shows the relationship between the ratio of 10-minute to 60-minute average SO_2 concentrations and hourly average concentrations. The monitoring data shows that higher hourly average SO_2 concentrations are generally associated with lower ratios. For hourly average SO_2 concentrations above about 5 pphm, the ratio falls below 2. It will be discussed later (**Section 7.2**) that the selection of a higher or lower peak-to-mean factor than the one derived from **Equation 2** (i.e. 1.43) will not affect the conclusions of the study.

7. ASSESSMENT OF IMPACTS

7.1 Preamble

The dispersion modelling has been undertaken using the emissions data from **Section 5** and the meteorological information described in **Section 4.1**. Model results have been presented in tabular form and as contour plots. The contour plots present the dispersion patterns in the study area for CO, NO_x, SO_2 and PM_{10}.

7.2 Dispersion Model Results

Table 11 shows the dispersion model results for the OCGT for various operating scenarios. Predictions which are over the relevant air quality goals are shown in bold red font. It should be noted that adding maximum predicted to maximum measured is a conservative approach. The probability of maximum levels from the OCGT stack coinciding with maximum background levels is very low. This study has taken a tiered approach with a conservative impact presented in the first instance. If the impact of the conservative impact is above the relevant air quality goal then a more refined assessment has been undertaken. The predicted impacts are discussed below.

Contour plots (see **Figures 15** to **20**) have been constructed to show the pattern of dispersion due to emissions from the OCGT. Plots showing maximum 1-hour, 8-hour and 24-hour average ground-level concentrations do not present the pattern of pollutant concentrations at any one time, but show the maximum concentrations that could be reached at each location under the modelled conditions. The figures are helpful in determining where the maximum modelled concentrations shown in **Table 11** are predicted to occur.

Table 11 : Results from the dispersion modelling

Pollutant	Averaging period	Predictions maximum GLC in the study area due to OCGT (μg/m³)*	Background	Total cumulative impact (increment + background)	Relevant air quality goal (μg/m³)
Natural gas fired OCGT for normal operations					
CO	1-hour maximum	2.81		2.8	30,000
	8-hour maximum	0.63		0.6	10,000
NO_x	1-hour maximum	51.35	197	**248.3**	246
	Annual average	0.20	15	15.2	62
SO_2	10-minute maximum	4.46	400	404.5	712
	1-hour maximum	3.12	226	229.1	570
	24-hour maximum	0.24	49	49.2	228
	Annual average	0.01	6	6.0	60
PM_{10}	24-hour maximum	0.22	133	**133.2**	50
	Annual average	0.01	25	25.0	30
Natural gas fired OCGT for start-up operations					
CO	1-hour maximum	1063.12	-	1063.1	30,000
	8-hour maximum	236.67	-	236.7	10,000
NO_x	1-hour maximum	140.05	197	**337.0**	246

Pollutant	Averaging period	Predictions maximum GLC in the study area due to OCGT ($\mu g/m^3$)*	Background	Total cumulative impact (increment + background)	Relevant air quality goal ($\mu g/m^3$)
	Annual average	0.42	15	15.4	62
SO_2	10-minute maximum	3.79	400	403.8	712
	1-hour maximum	2.65	226	228.6	570
	24-hour maximum	0.20	49	49.2	228
	Annual average	0.01	6	6.0	60
PM_{10}	24-hour maximum	0.40	133	**133.4**	50
	Annual average	0.02	25	25.0	30
Distillate fired OCGT for normal operations					
CO	1-hour maximum	22.29	-	22.3	30,000
	8-hour maximum	5.00	-	5.0	10,000
NO_x	1-hour maximum	70.39	197	**267.4**	246
	Annual average	0.27	15	15.3	62
SO_2	10-minute maximum	5.48	400	405.5	712
	1-hour maximum	3.83	226	229.8	570
	24-hour maximum	0.30	49	49.3	228
	Annual average	0.01	6	6.0	60
PM_{10}	24-hour maximum	0.46	133	**133.5**	50
	Annual average	0.02	25	25.0	30
Distillate fired OCGT for start-up operations					
CO	1-hour maximum	2026.61	-	2026.6	30,000
	8-hour maximum	453.22	-	453.2	10,000
NO_x	1-hour maximum	192.35	197	**389.4**	246
	Annual average	0.58	15	15.6	62
SO_2	10-minute maximum	22.14	400	422.1	712
	1-hour maximum	15.47	226	241.5	570
	24-hour maximum	1.18	49	50.2	228
	Annual average	0.05	6	6.0	60
PM_{10}	24-hour maximum	0.85	133	**133.9**	50
	Annual average	0.03	25	25.0	30

** GLC = Ground-level concentration predicted outside the boundary of the Munmorah Power Station land.*

It can be seen from **Table 11** that, for emissions due to the OCGT, maximum air quality impacts would generally be observed during start-up conditions and when the plant is distillate fuelled.

The potentially highest CO impacts are predicted for the OCGT fuelled by distillate and during start-up conditions. The predicted maximum 1-hour average ground-level CO concentration due to the plant emissions is 2 mg/m^3 which is well below the 30 mg/m^3 goal. Compliance with the 1-hour CO goal would be anticipated. Similarly, for 8-hour averages, the predicted maximum concentration is 0.4 mg/m^3 which is well below the 10 mg/m^3 goal.

Predicted NO_x concentrations are up to 192 $\mu g/m^3$ due to a distillate fired plant during start-up conditions. Assuming that 100% of the NO_x is NO_2 and adding this to a maximum measured NO_2 concentration of 197 $\mu g/m^3$ results in a total cumulative impact above the 246 µg/m^3 goal however it should be noted that the plant will only take approximately 30-minutes to reach normal operating conditions.

Taking the conservative approach of assuming that 100% of the predicted NO_x concentration is NO_2 and then adding this prediction to maximum measured background NO_2 concentrations results in predictions which are above the 246 µg/m^3 goal. A more refined assessment of NO_2 impacts has therefore been done using the Ozone Limiting Method (OLM). This is discussed in **Section 7.3**.

Predictions of annual average NO_x concentrations due to the plant are very low – less than 1 µg/m^3 for all operating scenarios. The total cumulative impacts are below the 62 µg/m^3 goal even on the assumption that 100% of the NO_x is NO_2.

The predicted highest 10-minute, 1-hour, 24-hour and annual average off-site ground-level SO_2 concentration due to OCGT emissions are below their respective air quality goals. As discussed in **Section 6**, the 10-minute average SO_2 concentrations were derived from the 1-hour average predictions. It is recognised that the exponent in the empirical relationship between 1-hour averages and shorter time averages may have some variation. The model predictions, however, are sufficiently low to allow some variation to the exponent in the equation without causing predictions to be above the 712 µg/m^3 goal. Even if the ratio of the 10-minute peak to 60-minute average were the maximum theoretically possible value of six, the predicted concentrations would be below the goal.

Predicted maximum 24-hour average ground-level PM_{10} concentrations due to emissions from the proposed OCGT are very low. The highest prediction is 0.9 µg/m^3 and is for a distillate fuelled plant during start-up operations. This is well below the 50 µg/m^3 goal noted by the DEC. Measured 24-hour average PM_{10} concentrations have been up to 133 µg/m^3 which is above 50 µg/m^3 however it is highly unlikely that the emissions from the proposed OCGT would be the cause of any additional exceedances of the PM_{10} goal. Compliance with the NEPM $PM_{2.5}$ investigation level (25 µg/m^3) would also be anticipated even if it is conservatively assumed that all of the PM_{10} is $PM_{2.5}$.

7.3 NO_2 by OLM

There are various methods for estimating NO_2 concentrations from model predictions of NO_x. Air quality monitoring data can be used to assess the fraction of NO_2 in the NO_x when the NO_x concentration is high and since dispersion models are generally configured to predict maximum NO_x concentrations the fraction of NO_2 in the NO_x for high NO_x concentrations may provide a reasonable estimate of the NO_2 concentration.

Alternatively, the oxidation of NO to NO_2 can be estimated using the Ozone Limiting Method or OLM. This method uses the predicted NO_x concentration with background ozone and NO_2 data to estimate the NO_2 concentration. The OLM has the form of an equation as shown below.

Equation 2 (from **NSW DEC, 2005):**

$$[NO_2]_{total} = \{0.1 \times [NO_x]_{pred}\} + MIN\left\{(0.9) \times [NO_x]_{pred}\, or \left(\frac{46}{48}\right) \times [O_3]_{bkgd}\right\} + [NO_2]_{bkgd}$$

The DEC provide two levels of assessment using OLM – level 1 or level 2. A level 1 assessment is based on the use of maximum predicted and maximum background concentrations. A level 2 assessment requires contemporaneous hourly NO_2 and O_3 data for the area of interest. The DEC collect NO_2 and O_3 data at various locations in Sydney and the Lower Hunter however there are no DEC monitoring sites in the study area. Therefore, a level 1 OLM assessment is feasible.

CSIRO have carried out a photochemical pollution assessment for the proposed OCGT (**CSIRO, 2005**). This report highlighted large spatial variations of both NO_2 and O_3 from Sydney to Newcastle and the Central Coast with O_3 levels near Munmorah much lower than in the more populated regions.

Hourly NO_x and O_3 data for Lindfield and three Lower Hunter sites have been obtained for 2003 from the DEC and these data, together with the CSIRO report and monitoring data for Wyee and Lake Munmorah have been used to determine the following NO_2 and O_3 concentrations for the OLM assessment:

- Maximum measured 1-hour average NO_2 concentration for modelled year (2003) = 103 µg/m^3
- Maximum measured 1-hour O_3 concentration for modelled year (2003) = 8.1 pphm or 173 µg/m^3

These concentrations have been used to estimate NO_2 concentrations by OLM. The results are shown below in **Table 12**.

Normal operations using distillate have been assessed by the OLM method as this represents the worst-case. Under start-up conditions, it has been assumed that all the emitted NO_x is NO_2 and the OLM method provides no further information. Although the predicted concentrations are higher for start-up conditions, the conditions persist for only 30-minutes or so. The predictions are therefore an overestimate of a 1-hour average by a factor of two. The maximum predicted 1-hour NO_2 concentration would therefore be 96 µg/m^3 (192/2) which with a background of 103 µg/m^3 makes a total of 199 µg/m^3 which is below the DEC goal of. 246 µg/m^3.

Table 12 : Prediction of NO_2 by the ozone limiting method

Scenario	OCGT using distillate, normal operations
Predicted maximum 1-hour average NO_x (µg/m^3)	70
Maximum measured 1-hour average NO_2 (µg/m^3)	103
Maximum measured 1-hour average O_3 (µg/m^3)	173
Estimated maximum 1-hour average NO_2 by OLM (µg/m^3)	173

The level 1 assessment using OLM is a conservative approach. Results indicate that the maximum 1-hour average ground-level NO_2 concentrations due to emissions from the proposed OCGT are below the DEC 246 μg/m³ goal.

7.4 Air Toxics

In general, emissions of air toxics are relatively low for gas turbines compared to other combustion sources, due to the relatively high temperatures reached during normal operations and also, in the case of natural gas, the composition of the input fuel. Information on air toxic emission has been drawn from the **US EPA (1995)** AP-42 publication which provides emission rates for criteria pollutants and air toxics for turbines fuelled with natural gas and diesel distillate. Both controlled and uncontrolled emission rates are provided for NO_x and CO.

The approach adopted in this report has been to normalise the air toxics emission rate to the NO_x emission rate for controlled natural gas-fired turbines. AP-42 reports a NO_x emission rate of 0.13 lb/MMBtu (pounds per million British Thermal Units of fuel input). This is equivalent to 0.056 kg/GJ [0.13/(2.2(lb to kg) x 1.054(MMBtu to GJ)] which is similar to the NO_x emission rate of 0.039 kg/GJ estimated under normal operating conditions for the proposed turbines fuelled with natural gas. **Table 13** provides emission estimates of selected air toxics from the proposed turbines.

Table 13 : Emission estimates and model predictions for selected air toxics

OCGT fuel (normal operation)	Natural gas	Distillate
Emissions (kg/h)		
NO_x	292	404
Benzene	2.70E-02	1.24E-01
Formaldehyde	1.59E+00	6.29E-01
Toluene	2.92E-01	n/a
Xylene	1.44E-01	n/a
PAH	2.02E-03	1.12E-02
Predicted maximum 1-hour average ground-level concentrations (by pro-rata of NO_x emissions and results)		
Benzene (mg/m³, Goal = 0.029 mg/m³)	4.73E-06	2.16E-05
Formaldehyde (mg/m³, Goal = 0.36 mg/m³)	2.80E-04	1.10E-04
Toluene (mg/m³, Goal = 0.02 mg/m³)	5.13E-05	-
Xylene (mg/m³, Goal = 0.19 mg/m³)	2.52E-05	-
PAH (mg/m³, Goal = 0.0004 mg/m³)	3.55E-07	1.95E-06

The model predictions can be seen to be below the DEC air quality goals for each of the selected air toxics.

8. CONCLUSIONS

This report has assessed the air quality impacts of a proposed open cycle gas turbine plant on the grounds of the existing Munmorah Power Station. Dispersion modelling has been used to predict ground-level pollutant concentrations due to emissions from the plant. The conclusions of the assessment are summarised as follows:

- Air quality monitoring data suggests that existing NO_2 and SO_2 concentrations are below their respective air quality goals.
- Sources such as bushfires may continue to result in elevated particulate matter concentrations in the study area.
- Compliance with air quality goals is predicted when the modelled impact of the OCGT is added to measured background pollutant concentrations.
- In-stack pollutant concentrations for the OCGT have been calculated to comply emission limits published in the amendments to the Protection of the Environment Operations (Clean Air) Regulation.

The plant would operate only during periods of peak power demands and as such, the frequency of high air quality impacts would be expected to be low.

It is concluded that air emissions due to the operation of the plant would result in an acceptable air quality impact within the study area.

9. REFERENCES

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APPENDIX A
JOINT WIND SPEED AND WIND DIRECTION FREQUENCY TABLES

```
STATISTICS FOR FILE:  C:\Jobs\MunmorPS\calmet\prtmet\muncal.aus
MONTHS: All
HOURS : All
OPTION: Frequency

                     PASQUILL STABILITY CLASS 'A'

                        Wind Speed Class (m/s)

             0.50     1.50     3.00     4.50     6.00     7.50     9.00  GREATER
 WIND         TO       TO       TO       TO       TO       TO       TO     THAN
SECTOR       1.50     3.00     4.50     6.00     7.50     9.00    10.50    10.50    TOTAL
-----------------------------------------------------------------------------------------

   NNE   0.000000 0.000114 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000114
    NE   0.000000 0.000457 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000457
   ENE   0.000000 0.000228 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000228
     E   0.000000 0.000343 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000343
   ESE   0.000000 0.000571 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000571
    SE   0.000000 0.000114 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000114
   SSE   0.000114 0.000228 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000343
     S   0.000114 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000114
   SSW   0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
    SW   0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
   WSW   0.000114 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000114
     W   0.000000 0.000228 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000228
   WNW   0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
    NW   0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
   NNW   0.000000 0.000114 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000114
     N   0.000000 0.000228 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000228

  CALM                                                                          0.000000
-----------------------------------------------------------------------------------------
  TOTAL  0.000343 0.002627 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.002970

   MEAN WIND SPEED (m/s) = 2.22
  NUMBER OF OBSERVATIONS = 26




                     PASQUILL STABILITY CLASS 'B'

                        Wind Speed Class (m/s)

             0.50     1.50     3.00     4.50     6.00     7.50     9.00  GREATER
 WIND         TO       TO       TO       TO       TO       TO       TO     THAN
SECTOR       1.50     3.00     4.50     6.00     7.50     9.00    10.50    10.50    TOTAL
-----------------------------------------------------------------------------------------

   NNE   0.001142 0.004798 0.001142 0.000114 0.000000 0.000000 0.000000 0.000000 0.007197
    NE   0.001257 0.002399 0.002285 0.000228 0.000000 0.000000 0.000000 0.000000 0.006169
   ENE   0.000457 0.001371 0.006740 0.001028 0.000000 0.000000 0.000000 0.000000 0.009596
     E   0.000114 0.003084 0.006283 0.000343 0.000000 0.000000 0.000000 0.000000 0.009824
   ESE   0.000228 0.003655 0.004684 0.000000 0.000000 0.000000 0.000000 0.000000 0.008568
    SE   0.000685 0.001371 0.005141 0.000571 0.000000 0.000000 0.000000 0.000000 0.007768
   SSE   0.000228 0.001142 0.001142 0.000000 0.000000 0.000000 0.000000 0.000000 0.002513
     S   0.001028 0.002056 0.001485 0.000114 0.000000 0.000000 0.000000 0.000000 0.004684
   SSW   0.001714 0.002627 0.001485 0.000000 0.000000 0.000000 0.000000 0.000000 0.005826
    SW   0.000914 0.001485 0.000343 0.000000 0.000000 0.000000 0.000000 0.000000 0.002742
   WSW   0.001599 0.001371 0.000571 0.000000 0.000000 0.000000 0.000000 0.000000 0.003541
     W   0.000800 0.001371 0.001485 0.000000 0.000000 0.000000 0.000000 0.000000 0.003655
   WNW   0.000457 0.001257 0.001599 0.000000 0.000000 0.000000 0.000000 0.000000 0.003313
    NW   0.000685 0.000685 0.001028 0.000000 0.000000 0.000000 0.000000 0.000000 0.002399
   NNW   0.002170 0.000914 0.000800 0.000000 0.000000 0.000000 0.000000 0.000000 0.003884
     N   0.002285 0.001599 0.000914 0.000000 0.000000 0.000000 0.000000 0.000000 0.004798

  CALM                                                                          0.000914
-----------------------------------------------------------------------------------------
  TOTAL  0.015764 0.031186 0.037126 0.002399 0.000000 0.000000 0.000000 0.000000 0.087389

   MEAN WIND SPEED (m/s) = 2.72
  NUMBER OF OBSERVATIONS = 765
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                     PASQUILL STABILITY CLASS 'C'

                        Wind Speed Class (m/s)

             0.50     1.50     3.00     4.50     6.00     7.50     9.00  GREATER
 WIND         TO       TO       TO       TO       TO       TO       TO     THAN
SECTOR       1.50     3.00     4.50     6.00     7.50     9.00    10.50    10.50    TOTAL
-----------------------------------------------------------------------------------------

   NNE   0.004341 0.004341 0.001485 0.000000 0.000000 0.000000 0.000000 0.000000 0.010167
    NE   0.003427 0.004455 0.004341 0.001257 0.000000 0.000000 0.000000 0.000000 0.013480
   ENE   0.002513 0.004569 0.006626 0.002742 0.000000 0.000000 0.000000 0.000000 0.016450
     E   0.000685 0.003313 0.005483 0.002285 0.000000 0.000000 0.000000 0.000000 0.011766
   ESE   0.000800 0.003770 0.001942 0.000114 0.000000 0.000000 0.000000 0.000000 0.006626
    SE   0.001371 0.002627 0.005940 0.000800 0.000000 0.000000 0.000000 0.000000 0.010738
   SSE   0.000914 0.001028 0.003770 0.001942 0.000571 0.000000 0.000000 0.000000 0.008225
     S   0.001371 0.001942 0.004112 0.005026 0.000914 0.000457 0.000114 0.000000 0.013936
   SSW   0.001942 0.002513 0.004798 0.001828 0.000000 0.000000 0.000000 0.000000 0.011081
    SW   0.005026 0.005597 0.003655 0.000457 0.000000 0.000000 0.000000 0.000000 0.014736
   WSW   0.005141 0.004912 0.001942 0.000343 0.000000 0.000000 0.000000 0.000000 0.012337
     W   0.001485 0.002627 0.002970 0.001142 0.000000 0.000000 0.000000 0.000000 0.008225
   WNW   0.001257 0.002970 0.005940 0.002627 0.000000 0.000000 0.000000 0.000000 0.012794
    NW   0.002970 0.002056 0.003427 0.000571 0.000000 0.000000 0.000000 0.000000 0.009024
   NNW   0.005940 0.004112 0.001142 0.000457 0.000000 0.000000 0.000000 0.000000 0.011652
     N   0.004912 0.004569 0.001028 0.000228 0.000000 0.000000 0.000000 0.000000 0.010738

  CALM                                                                           0.005255
-----------------------------------------------------------------------------------------
  TOTAL  0.044094 0.055403 0.058602 0.021819 0.001485 0.000457 0.000114 0.000000 0.187229

   MEAN WIND SPEED (m/s) = 2.80
  NUMBER OF OBSERVATIONS = 1639



                     PASQUILL STABILITY CLASS 'D'

                        Wind Speed Class (m/s)

             0.50     1.50     3.00     4.50     6.00     7.50     9.00  GREATER
 WIND         TO       TO       TO       TO       TO       TO       TO     THAN
SECTOR       1.50     3.00     4.50     6.00     7.50     9.00    10.50    10.50    TOTAL
-----------------------------------------------------------------------------------------

   NNE   0.003199 0.008225 0.003199 0.000000 0.000000 0.000000 0.000000 0.000000 0.014622
    NE   0.002742 0.011880 0.004684 0.000457 0.000000 0.000000 0.000000 0.000000 0.019762
   ENE   0.001028 0.008682 0.004684 0.000343 0.000343 0.000000 0.000000 0.000000 0.015079
     E   0.000571 0.006511 0.005026 0.001142 0.000000 0.000000 0.000000 0.000000 0.013251
   ESE   0.000343 0.005369 0.002513 0.000114 0.000000 0.000000 0.000000 0.000000 0.008339
    SE   0.000228 0.005141 0.007882 0.001485 0.000228 0.000000 0.000000 0.000000 0.014965
   SSE   0.000571 0.004912 0.013480 0.011652 0.001942 0.000000 0.000000 0.000000 0.032557
     S   0.000914 0.006054 0.019762 0.017935 0.010281 0.001828 0.000000 0.000000 0.056774
   SSW   0.001142 0.008568 0.013594 0.009139 0.003313 0.000228 0.000228 0.000228 0.036440
    SW   0.001257 0.016450 0.006968 0.000800 0.000000 0.000000 0.000000 0.000000 0.025474
   WSW   0.001485 0.009596 0.001599 0.000228 0.000457 0.000000 0.000000 0.000000 0.013365
     W   0.000457 0.004227 0.001142 0.000685 0.000228 0.000000 0.000000 0.000000 0.006740
   WNW   0.001142 0.003998 0.003084 0.001371 0.000228 0.000000 0.000000 0.000000 0.009824
    NW   0.001485 0.003884 0.001257 0.000228 0.000800 0.000457 0.000000 0.000000 0.008111
   NNW   0.002056 0.003313 0.001599 0.001142 0.000000 0.000000 0.000000 0.000000 0.008111
     N   0.002513 0.004569 0.001828 0.000000 0.000000 0.000000 0.000000 0.000000 0.008910

  CALM                                                                           0.002285
-----------------------------------------------------------------------------------------
  TOTAL  0.021133 0.111378 0.092301 0.046721 0.017820 0.002513 0.000228 0.000228 0.294608

   MEAN WIND SPEED (m/s) = 3.46
  NUMBER OF OBSERVATIONS = 2579
```

```
                     PASQUILL STABILITY CLASS 'E'

                        Wind Speed Class (m/s)

             0.50     1.50     3.00     4.50     6.00     7.50     9.00  GREATER
 WIND         TO       TO       TO       TO       TO       TO       TO      THAN
SECTOR       1.50     3.00     4.50     6.00     7.50     9.00    10.50    10.50    TOTAL
-----------------------------------------------------------------------------------------

   NNE   0.000000 0.003084 0.000914 0.000228 0.000000 0.000000 0.000000 0.000000 0.004227
    NE   0.000000 0.003998 0.000800 0.000000 0.000000 0.000000 0.000000 0.000000 0.004798
   ENE   0.000000 0.003199 0.000114 0.000000 0.000000 0.000000 0.000000 0.000000 0.003313
     E   0.000000 0.001714 0.000114 0.000000 0.000000 0.000000 0.000000 0.000000 0.001828
   ESE   0.000000 0.000343 0.000114 0.000000 0.000000 0.000000 0.000000 0.000000 0.000457
    SE   0.000000 0.001257 0.000914 0.000000 0.000000 0.000000 0.000000 0.000000 0.002170
   SSE   0.000000 0.002513 0.001599 0.000571 0.000000 0.000000 0.000000 0.000000 0.004684
     S   0.000000 0.004798 0.004341 0.000914 0.000000 0.000000 0.000000 0.000000 0.010053
   SSW   0.000000 0.002856 0.002056 0.000000 0.000000 0.000000 0.000000 0.000000 0.004912
    SW   0.000000 0.016107 0.002056 0.000114 0.000000 0.000000 0.000000 0.000000 0.018277
   WSW   0.000000 0.011195 0.000343 0.000114 0.000000 0.000000 0.000000 0.000000 0.011652
     W   0.000000 0.001142 0.000343 0.000000 0.000000 0.000000 0.000000 0.000000 0.001485
   WNW   0.000000 0.002056 0.001142 0.000000 0.000000 0.000000 0.000000 0.000000 0.003199
    NW   0.000000 0.000685 0.000685 0.000114 0.000000 0.000000 0.000000 0.000000 0.001485
   NNW   0.000000 0.001828 0.000571 0.000114 0.000000 0.000000 0.000000 0.000000 0.002513
     N   0.000000 0.002170 0.000343 0.000000 0.000000 0.000000 0.000000 0.000000 0.002513

  CALM                                                                           0.000000
-----------------------------------------------------------------------------------------
  TOTAL  0.000000 0.058944 0.016450 0.002170 0.000000 0.000000 0.000000 0.000000 0.077565

   MEAN WIND SPEED (m/s) = 2.65
  NUMBER OF OBSERVATIONS = 679



                     PASQUILL STABILITY CLASS 'F'

                        Wind Speed Class (m/s)

             0.50     1.50     3.00     4.50     6.00     7.50     9.00  GREATER
 WIND         TO       TO       TO       TO       TO       TO       TO      THAN
SECTOR       1.50     3.00     4.50     6.00     7.50     9.00    10.50    10.50    TOTAL
-----------------------------------------------------------------------------------------

   NNE   0.013708 0.005712 0.000343 0.000000 0.000000 0.000000 0.000000 0.000000 0.019762
    NE   0.016450 0.008111 0.000571 0.000000 0.000000 0.000000 0.000000 0.000000 0.025131
   ENE   0.006054 0.003084 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.009139
     E   0.001371 0.000800 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.002170
   ESE   0.000685 0.001142 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.001828
    SE   0.001485 0.001371 0.000114 0.000000 0.000000 0.000000 0.000000 0.000000 0.002970
   SSE   0.001485 0.002513 0.000228 0.000000 0.000000 0.000000 0.000000 0.000000 0.004227
     S   0.004227 0.003655 0.001028 0.000000 0.000000 0.000000 0.000000 0.000000 0.008910
   SSW   0.006054 0.003199 0.000114 0.000000 0.000000 0.000000 0.000000 0.000000 0.009367
    SW   0.021933 0.017021 0.000228 0.000000 0.000000 0.000000 0.000000 0.000000 0.039182
   WSW   0.035869 0.029244 0.000228 0.000000 0.000000 0.000000 0.000000 0.000000 0.065342
     W   0.012223 0.010966 0.000457 0.000000 0.000000 0.000000 0.000000 0.000000 0.023646
   WNW   0.009596 0.008796 0.001028 0.000000 0.000000 0.000000 0.000000 0.000000 0.019420
    NW   0.016221 0.010624 0.000343 0.000000 0.000000 0.000000 0.000000 0.000000 0.027188
   NNW   0.025131 0.003427 0.000114 0.000000 0.000000 0.000000 0.000000 0.000000 0.028673
     N   0.018049 0.006511 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.024560

  CALM                                                                           0.038725
-----------------------------------------------------------------------------------------
  TOTAL  0.190541 0.116175 0.004798 0.000000 0.000000 0.000000 0.000000 0.000000 0.350240

   MEAN WIND SPEED (m/s) = 1.31
  NUMBER OF OBSERVATIONS = 3066
```

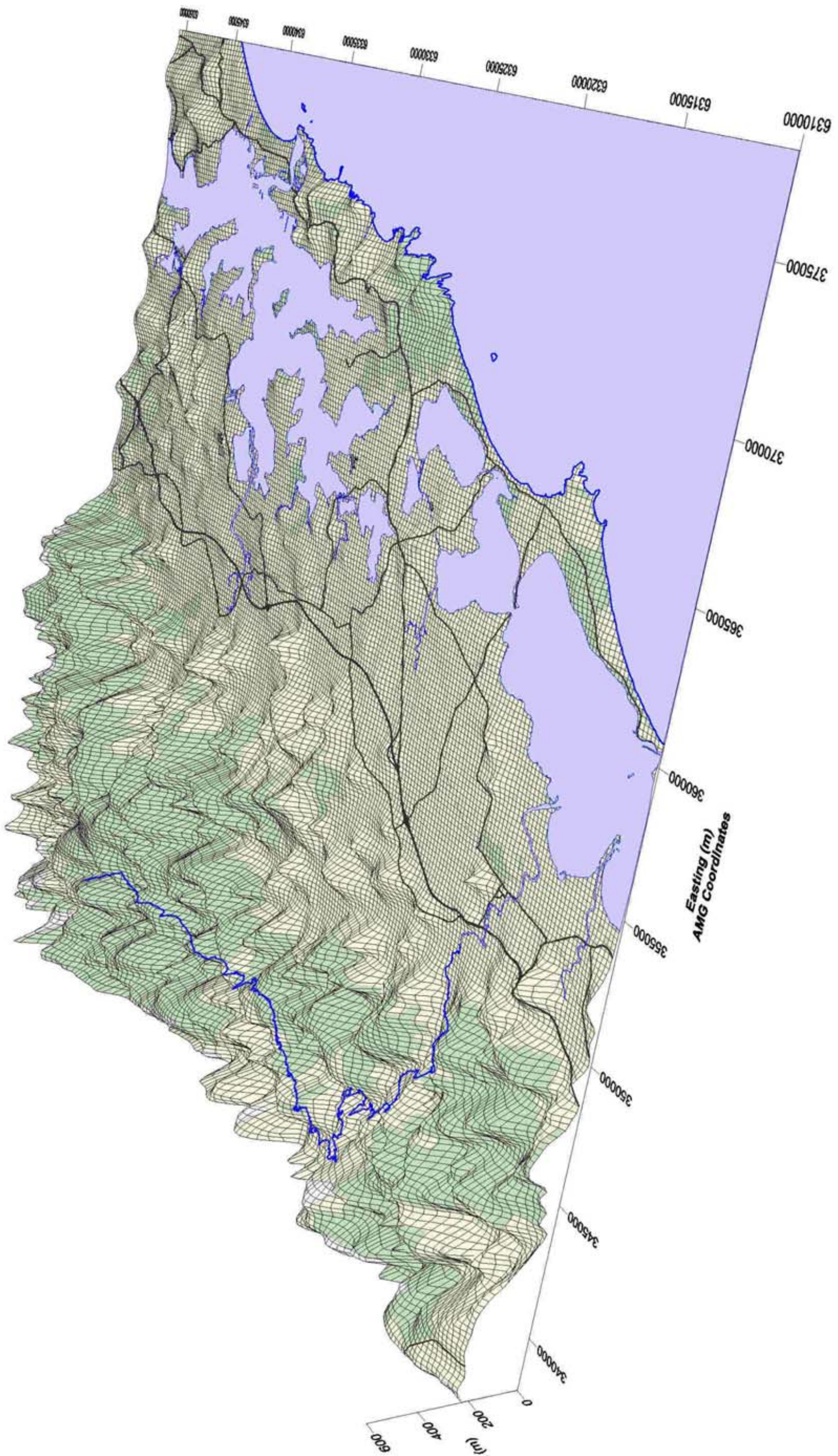
```
                   ALL PASQUILL STABILITY CLASSES

                        Wind Speed Class (m/s)

             0.50     1.50     3.00     4.50     6.00     7.50     9.00  GREATER
 WIND        TO       TO       TO       TO       TO       TO        TO     THAN
SECTOR       1.50     3.00     4.50     6.00     7.50     9.00    10.50    10.50    TOTAL
-----------------------------------------------------------------------------------------

   NNE   0.022390 0.026274 0.007082 0.000343 0.000000 0.000000 0.000000 0.000000 0.056089
    NE   0.023875 0.031300 0.012680 0.001942 0.000000 0.000000 0.000000 0.000000 0.069797
   ENE   0.010053 0.021133 0.018163 0.004112 0.000343 0.000000 0.000000 0.000000 0.053804
     E   0.002742 0.015764 0.016907 0.003770 0.000000 0.000000 0.000000 0.000000 0.039182
   ESE   0.002056 0.014850 0.009253 0.000228 0.000000 0.000000 0.000000 0.000000 0.026388
    SE   0.003770 0.011880 0.019991 0.002856 0.000228 0.000000 0.000000 0.000000 0.038725
   SSE   0.003313 0.012337 0.020219 0.014165 0.002513 0.000000 0.000000 0.000000 0.052547
     S   0.007654 0.018506 0.030729 0.023989 0.011195 0.002285 0.000114 0.000000 0.094471
   SSW   0.010852 0.019762 0.022047 0.010966 0.003313 0.000228 0.000228 0.000228 0.067626
    SW   0.029130 0.056660 0.013251 0.001371 0.000000 0.000000 0.000000 0.000000 0.100411
   WSW   0.044208 0.056317 0.004684 0.000685 0.000457 0.000000 0.000000 0.000000 0.106351
     W   0.014965 0.020562 0.006397 0.001828 0.000228 0.000000 0.000000 0.000000 0.043980
   WNW   0.012451 0.019077 0.012794 0.003998 0.000228 0.000000 0.000000 0.000000 0.048549
    NW   0.021362 0.017935 0.006740 0.000914 0.000800 0.000457 0.000000 0.000000 0.048207
   NNW   0.035298 0.013708 0.004227 0.001714 0.000000 0.000000 0.000000 0.000000 0.054946
     N   0.027759 0.019648 0.004112 0.000228 0.000000 0.000000 0.000000 0.000000 0.051748

  CALM                                                                           0.047178
-----------------------------------------------------------------------------------------
  TOTAL  0.271876 0.375714 0.209276 0.073109 0.019305 0.002970 0.000343 0.000228 1.000000

   MEAN WIND SPEED (m/s) = 2.45
  NUMBER OF OBSERVATIONS = 8754




  -------------------------------------------
  FREQUENCY OF OCCURENCE OF STABILITY CLASSES
  -------------------------------------------
    A : 0.3%
    B : 8.7%
    C : 18.7%
    D : 29.5%
    E : 7.8%
    F : 35.0%
```

```
------------------------------
STABILITY CLASS BY HOUR OF DAY
------------------------------
Hour   A    B    C    D    E    F
  01 0000 0000 0000 0055 0052 0257
  02 0000 0000 0000 0055 0056 0253
  03 0000 0000 0000 0054 0055 0255
  04 0000 0000 0000 0052 0060 0252
  05 0000 0000 0000 0055 0052 0258
  06 0000 0000 0065 0094 0036 0170
  07 0000 0024 0110 0128 0019 0084
  08 0000 0036 0160 0169 0000 0000
  09 0001 0091 0117 0156 0000 0000
  10 0001 0099 0094 0171 0000 0000
  11 0010 0111 0118 0126 0000 0000
  12 0007 0112 0123 0123 0000 0000
  13 0005 0109 0128 0123 0000 0000
  14 0002 0092 0138 0133 0000 0000
  15 0000 0055 0153 0157 0000 0000
  16 0000 0034 0170 0161 0000 0000
  17 0000 0001 0167 0197 0000 0000
  18 0000 0001 0081 0165 0018 0100
  19 0000 0000 0015 0125 0049 0176
  20 0000 0000 0000 0059 0069 0237
  21 0000 0000 0000 0061 0052 0252
  22 0000 0000 0000 0050 0058 0257
  23 0000 0000 0000 0057 0048 0259
  24 0000 0000 0000 0053 0055 0256

--------------------------------
STABILITY CLASS BY MIXING HEIGHT
--------------------------------
Mixing height    A    B    C    D    E    F
    <=500 m    0000 0104 0411 1125 0679 3066
   <=1000 m    0012 0361 0656 1051 0000 0000
   <=1500 m    0007 0212 0342 0276 0000 0000
   <=2000 m    0002 0059 0153 0066 0000 0000
   <=3000 m    0005 0029 0077 0061 0000 0000
    >3000 m    0000 0000 0000 0000 0000 0000

----------------------------
MIXING HEIGHT BY HOUR OF DAY
----------------------------
       0000  0100  0200  0400  0800  1600  Greater
        to    to    to    to    to    to   than
Hour   0100  0200  0400  0800  1600  3200  3200
  01   0311  0028  0020  0005  0000  0000  0000
  02   0311  0031  0016  0005  0001  0000  0000
  03   0311  0029  0019  0005  0000  0000  0000
  04   0317  0024  0019  0004  0000  0000  0000
  05   0312  0031  0018  0004  0000  0000  0000
  06   0278  0036  0037  0014  0000  0000  0000
  07   0162  0052  0051  0095  0005  0000  0000
  08   0064  0033  0072  0169  0027  0000  0000
  09   0000  0011  0059  0215  0080  0000  0000
  10   0000  0003  0024  0174  0160  0004  0000
  11   0000  0000  0007  0139  0204  0015  0000
  12   0000  0000  0002  0112  0212  0039  0000
  13   0000  0000  0000  0093  0217  0055  0000
  14   0000  0000  0000  0089  0210  0066  0000
  15   0000  0000  0000  0102  0195  0068  0000
  16   0000  0000  0000  0122  0178  0065  0000
  17   0000  0018  0051  0143  0110  0043  0000
  18   0118  0027  0047  0104  0053  0016  0000
  19   0219  0051  0054  0033  0005  0003  0000
  20   0287  0056  0017  0004  0001  0000  0000
  21   0295  0043  0024  0003  0000  0000  0000
  22   0304  0037  0021  0003  0000  0000  0000
  23   0308  0033  0020  0003  0000  0000  0000
  24   0306  0039  0017  0002  0000  0000  0000
```

FIGURES

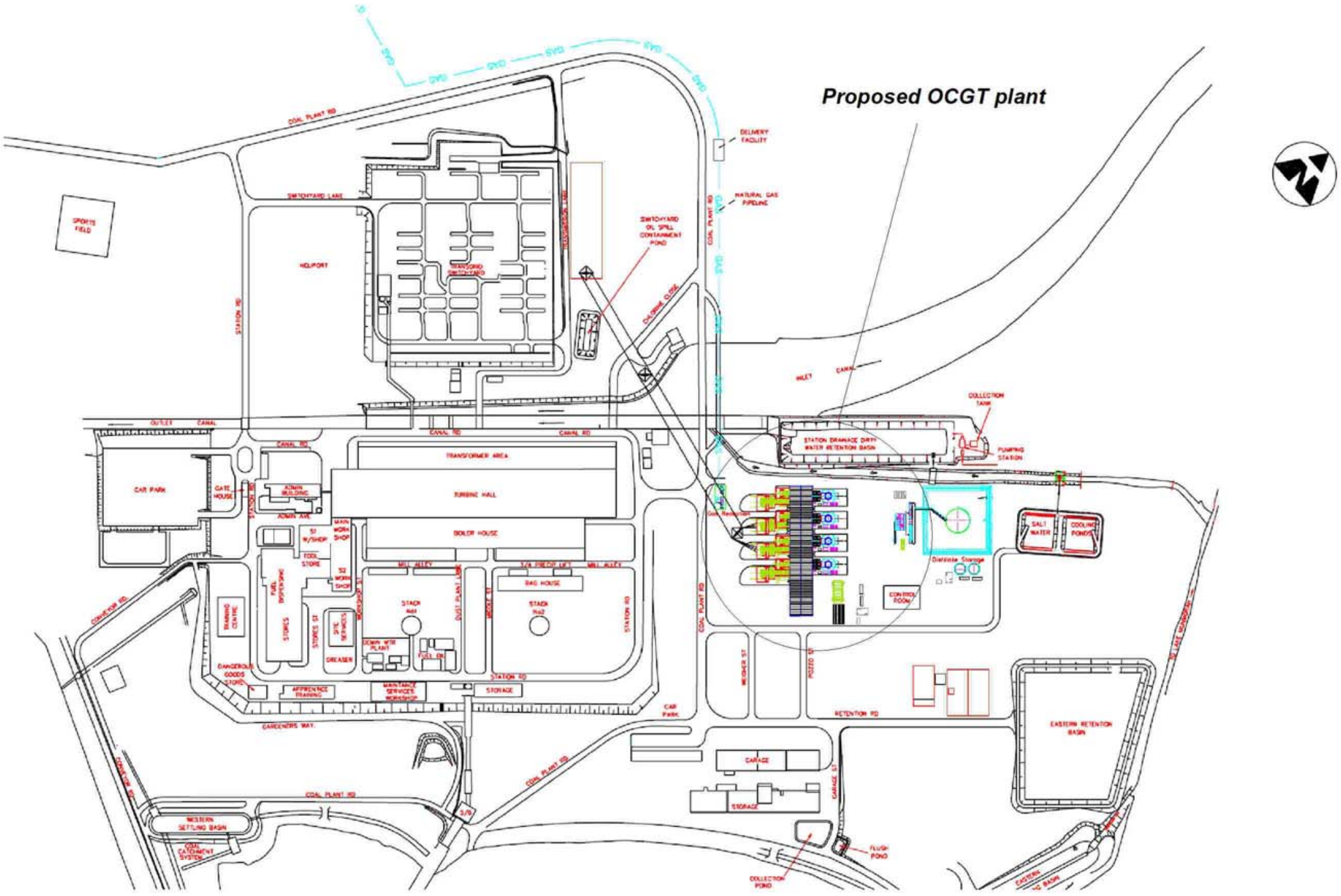
Location of study area

FIGURE 1



Pseudo three-dimensional representation of the study area

FIGURE 2

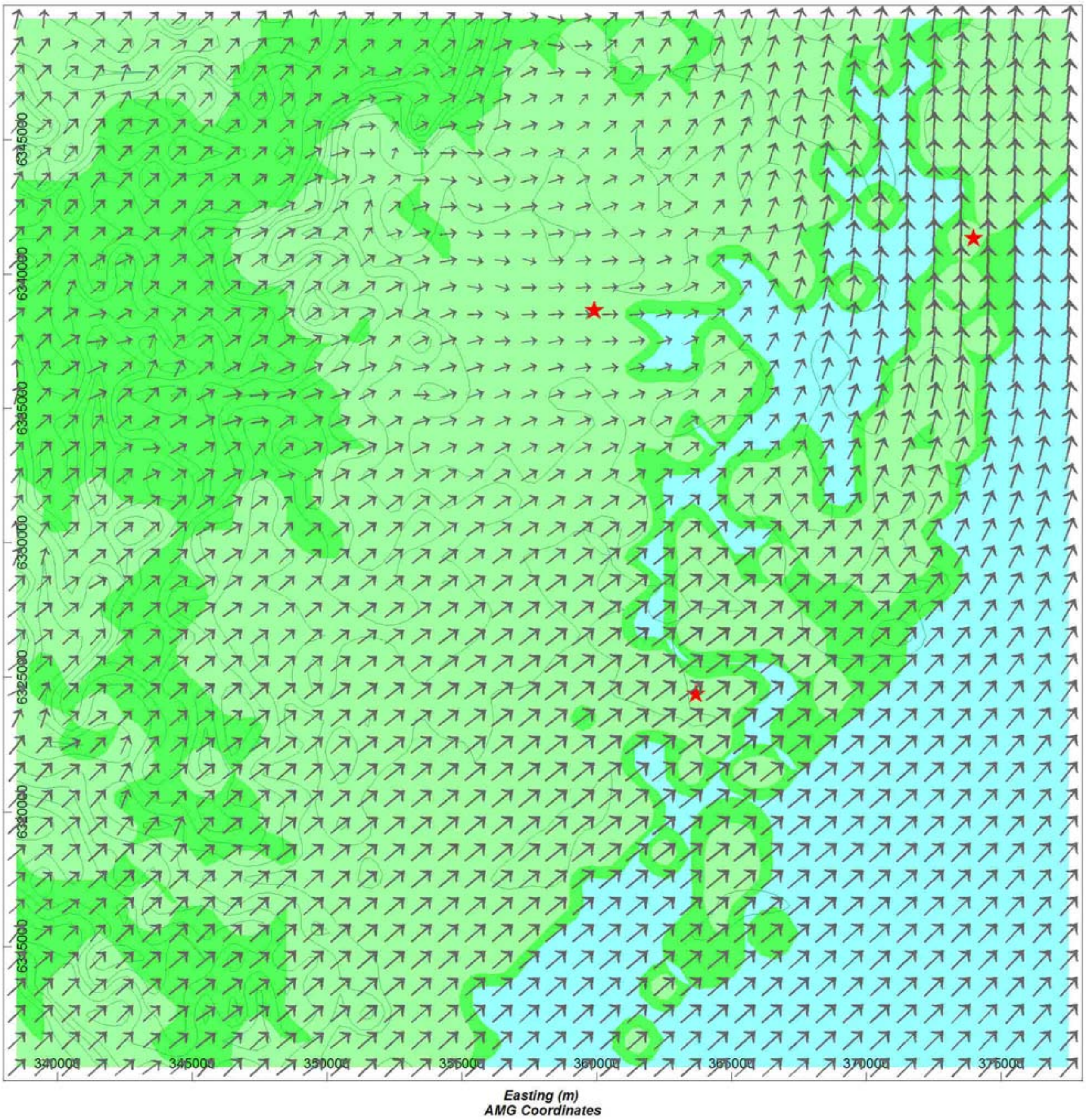


Proposed layout of OCGT plant

FIGURE 3

Meteorological and air quality monitoring in the study area

FIGURE 4



Ground-level wind patterns in the study area as simulated by CALMET (2 July 2003 Hour 1)

FIGURE 5

Annual and seasonal windroses for Dora Creek (2003)

Wind speed (m/s)

□ >0.5 - 1.5

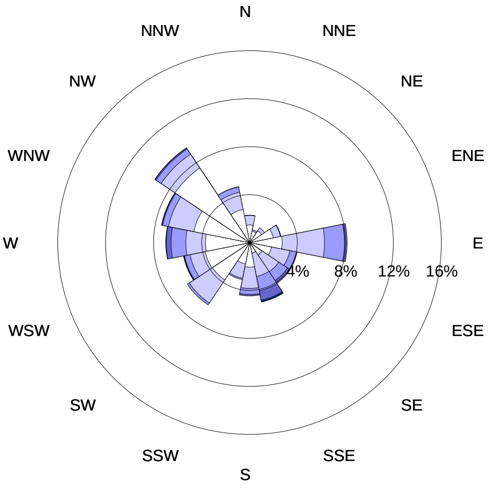
▨ >1.5 - 3

▨ >3 - 4.5

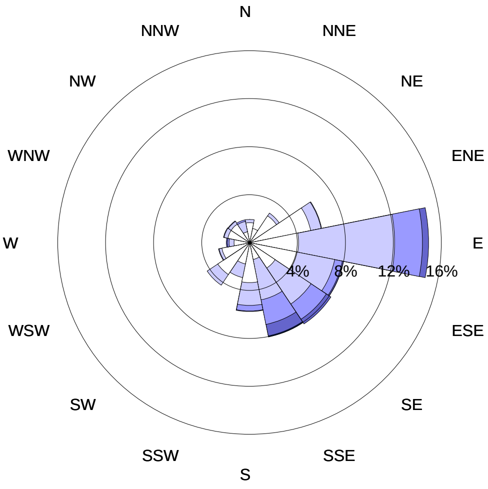
▨ >4.5 - 6

■ >6 - 7.5

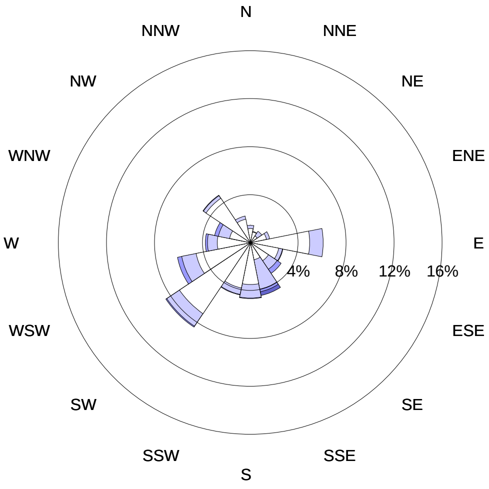
■ >7.5



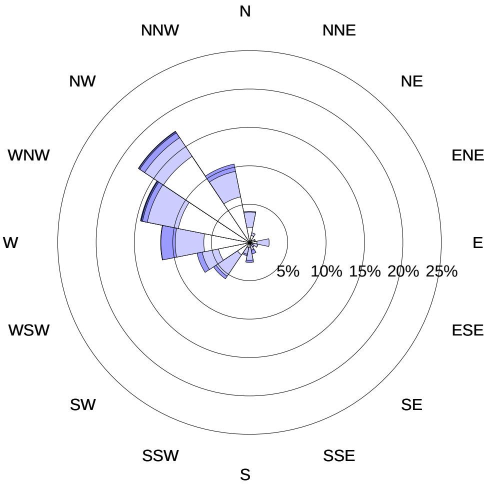
Annual
Calms = 23.0%



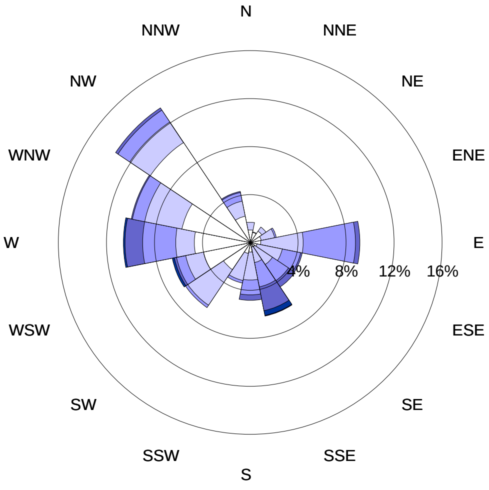
Summer
Calms = 24.9%



Autumn
Calms = 40.9%



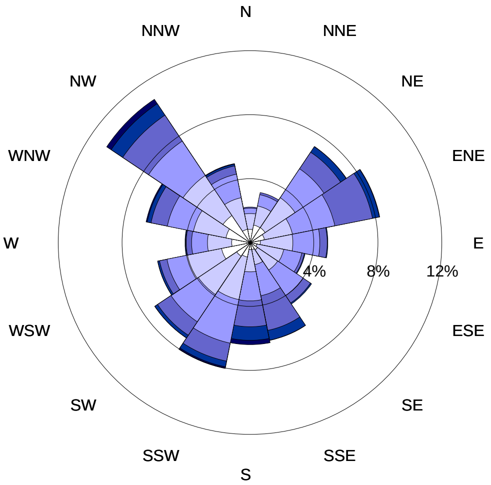
Winter
Calms = 16.8%



Spring
Calms = 9.5%

FIGURE 6

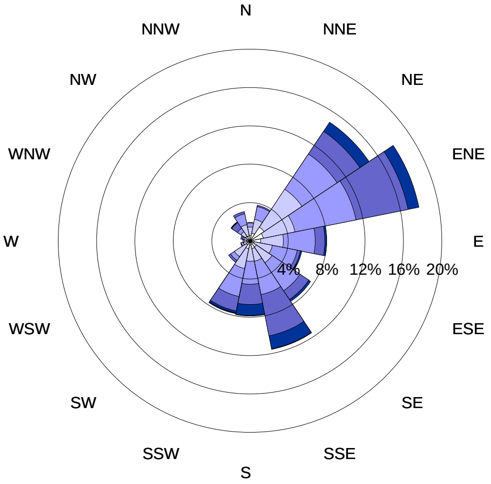
Annual and seasonal windroses for Marks Point (2003)



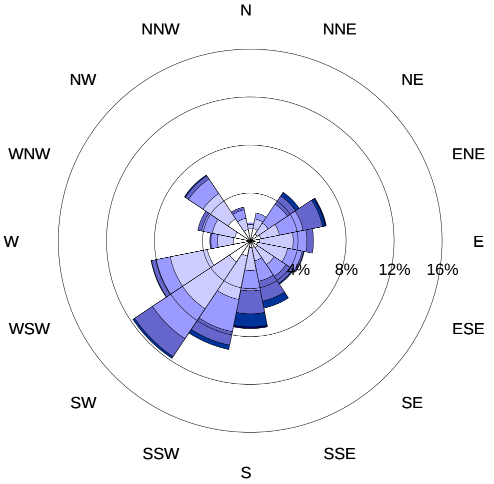
Annual
Calms = 5.9%

Wind speed (m/s)

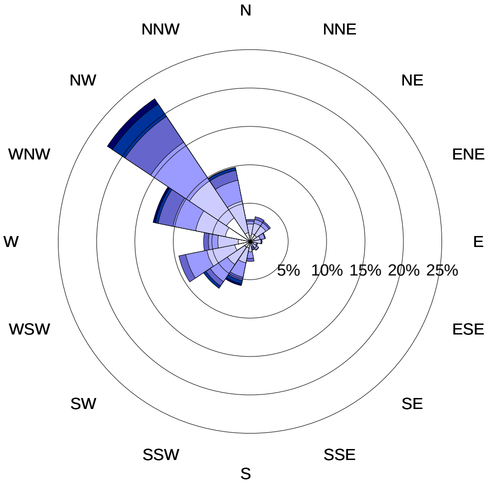
- ▢ >0.5 - 1.5
- ▢ >1.5 - 3
- ▢ >3 - 4.5
- ■ >4.5 - 6
- ■ >6 - 7.5
- ■ >7.5



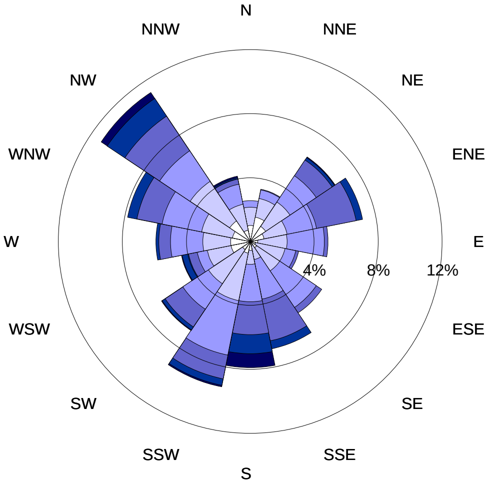
Summer
Calms = 2.4%



Autumn
Calms = 10.8%



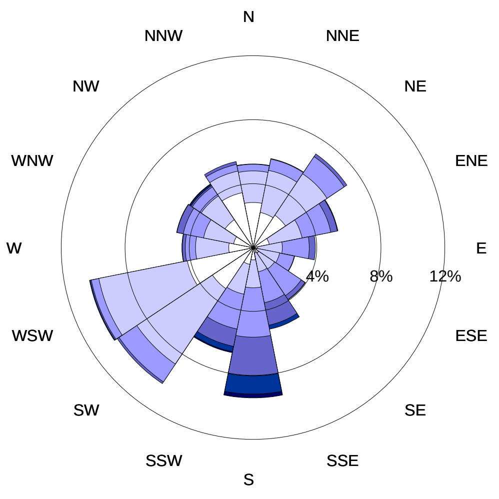
Winter
Calms = 7.2%



Spring
Calms = 3.2%

FIGURE 7

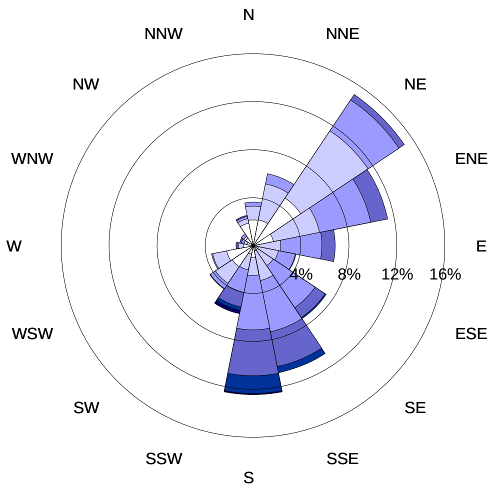
Annual and seasonal windroses for Munmorah Climatic (2003)



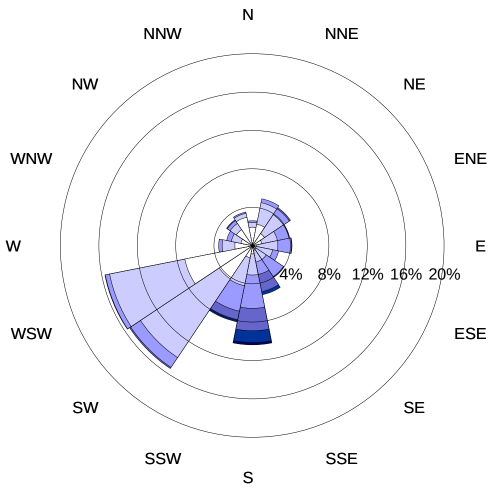
Annual
Calms = 4.7%

Wind speed (m/s)

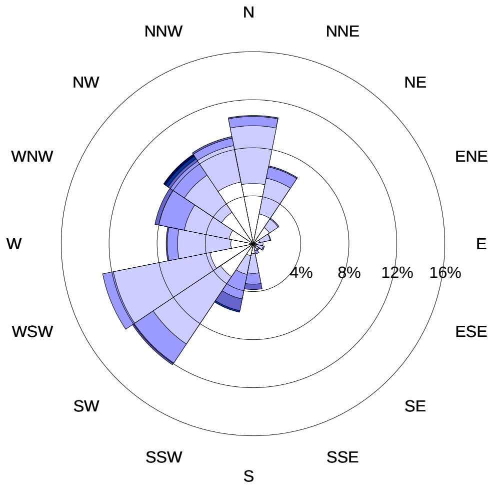
□ >0.5 - 1.5
■ >1.5 - 3
■ >3 - 4.5
■ >4.5 - 6
■ >6 - 7.5
■ >7.5



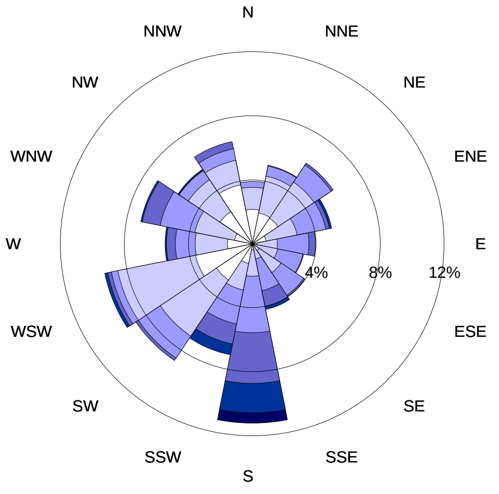
Summer
Calms = 2.7%



Autumn
Calms = 5.1%



Winter
Calms = 7.2%



Spring
Calms = 3.6%

FIGURE 8

Air quality monitoring data for Lake Munmorah School

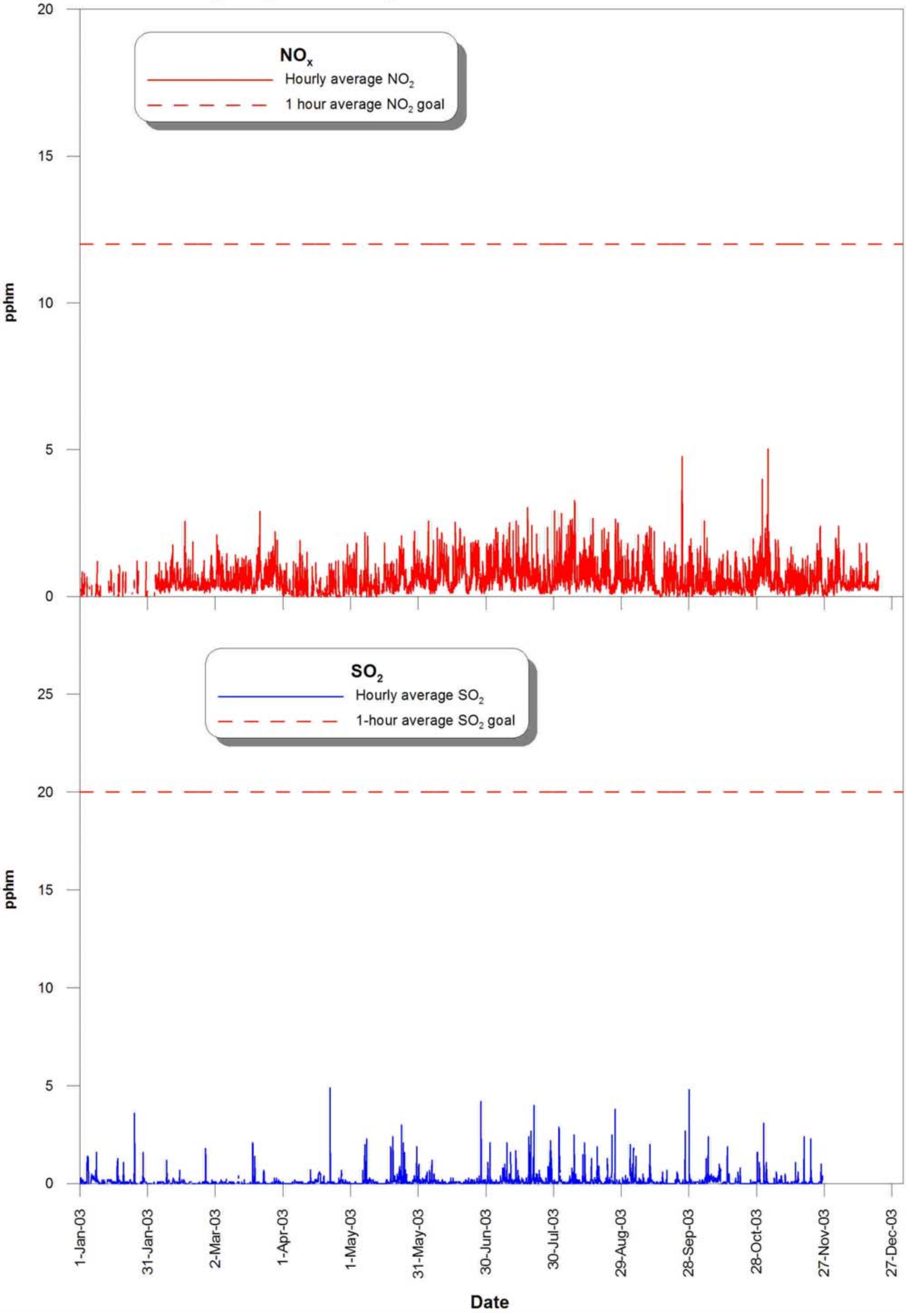


FIGURE 9

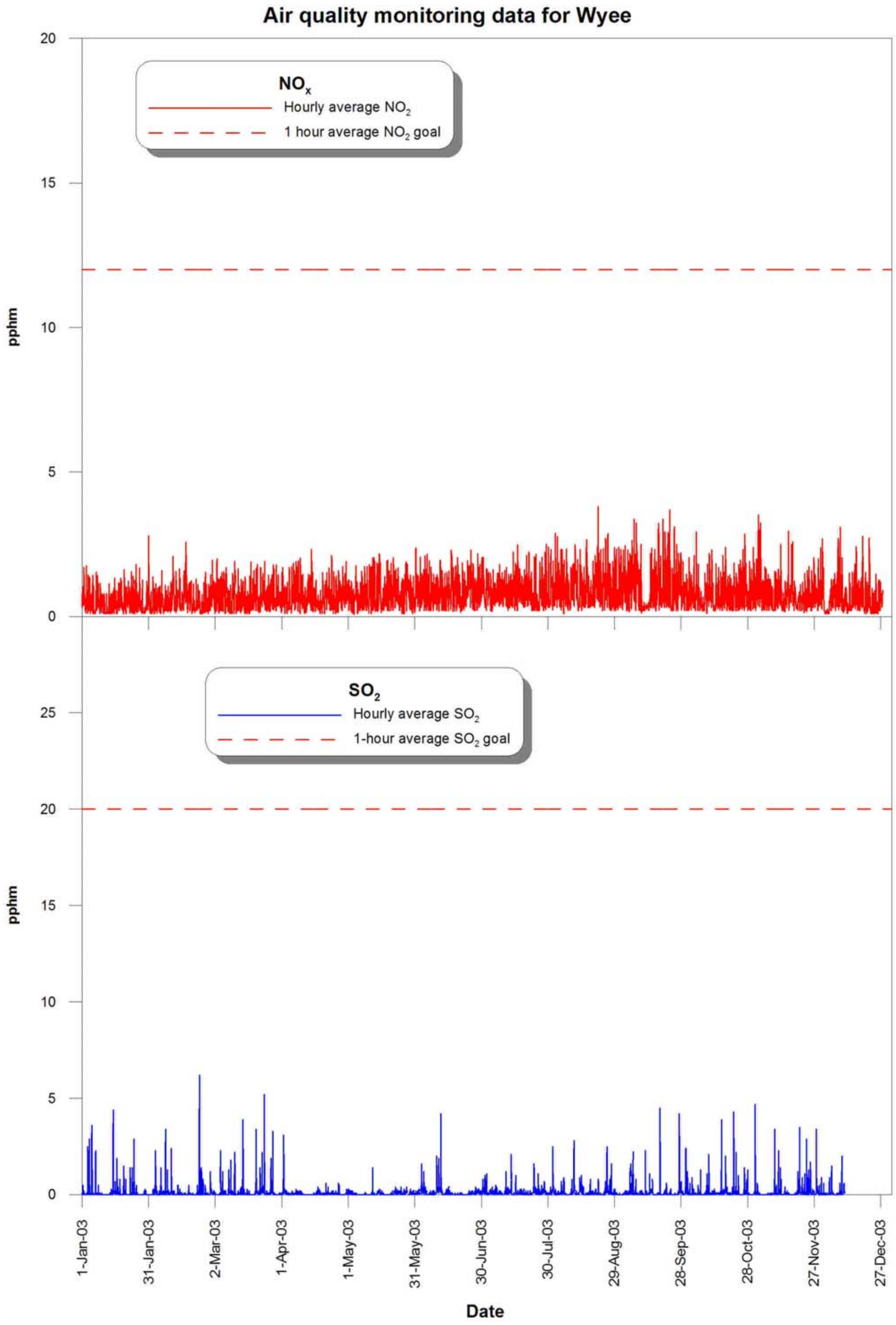

Air quality monitoring data for Wyee
NO$_x$
Hourly average NO$_2$
1 hour average NO$_2$ goal
SO$_2$
Hourly average SO$_2$
1-hour average SO$_2$ goal
pphm
pphm
20
15
10
5
0
25
20
15
10
5
0
1-Jan-03
31-Jan-03
2-Mar-03
1-Apr-03
1-May-03
31-May-03
30-Jun-03
30-Jul-03
29-Aug-03
28-Sep-03
28-Oct-03
27-Nov-03
27-Dec-03
Date

FIGURE 10

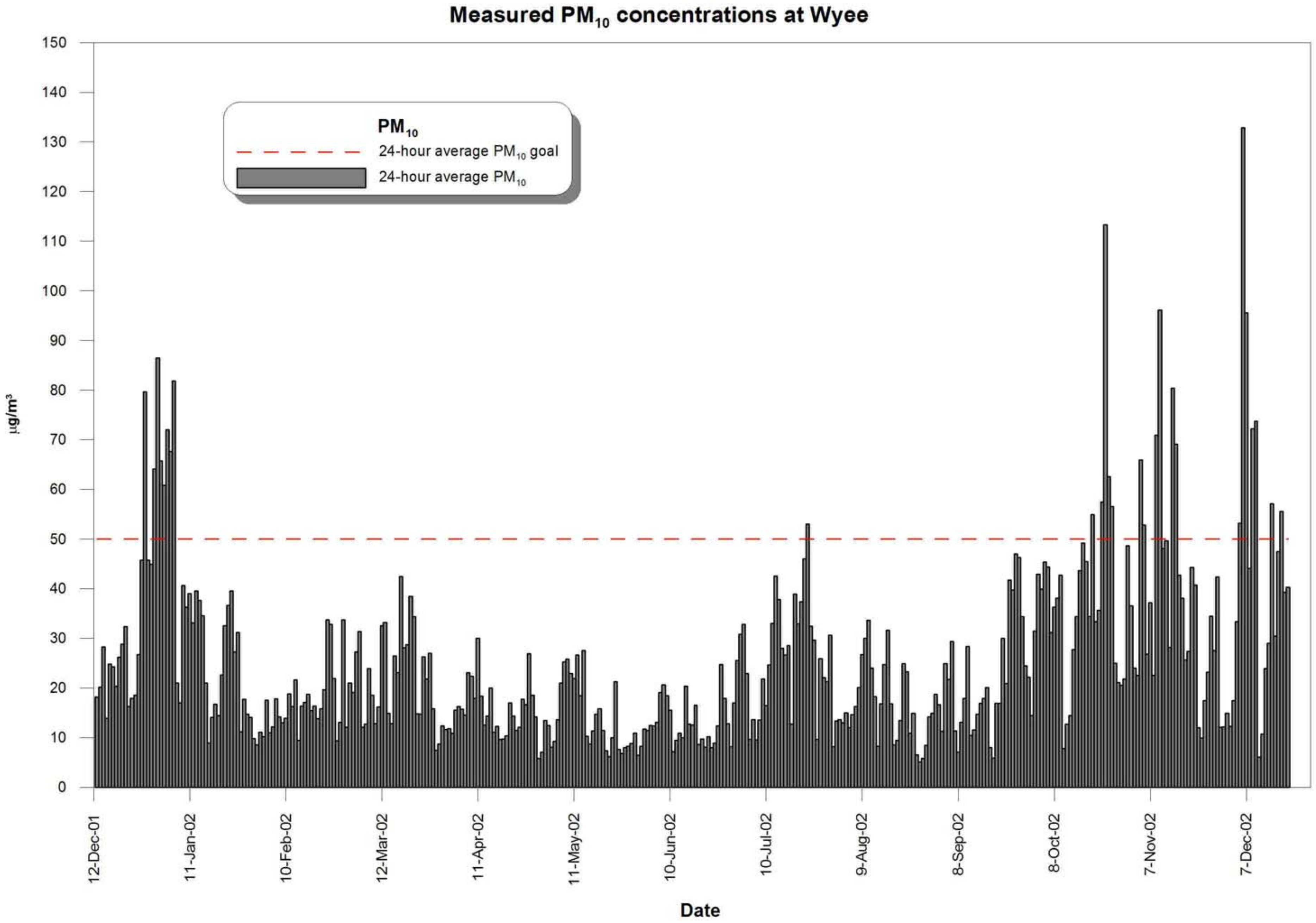
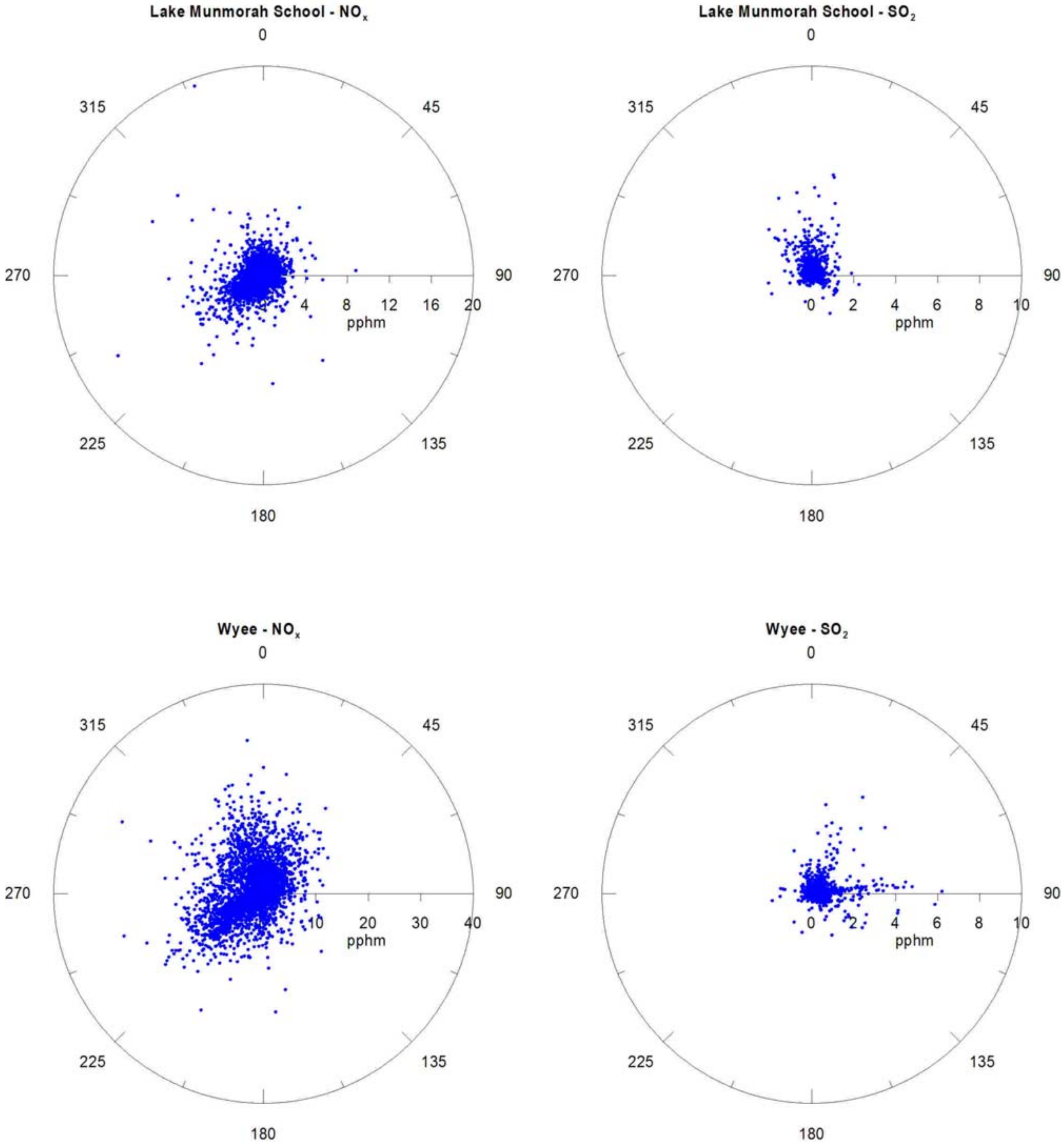

Measured PM_{10} concentrations at Wyee
PM_{10}
24-hour average PM_{10} goal
24-hour average PM_{10}
µg/m³
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
12-Dec-01
11-Jan-02
10-Feb-02
12-Mar-02
11-Apr-02
11-May-02
10-Jun-02
10-Jul-02
9-Aug-02
8-Sep-02
8-Oct-02
7-Nov-02
7-Dec-02
Date

FIGURE 11



Correlation between pollutant concentrations and wind direction

FIGURE 12

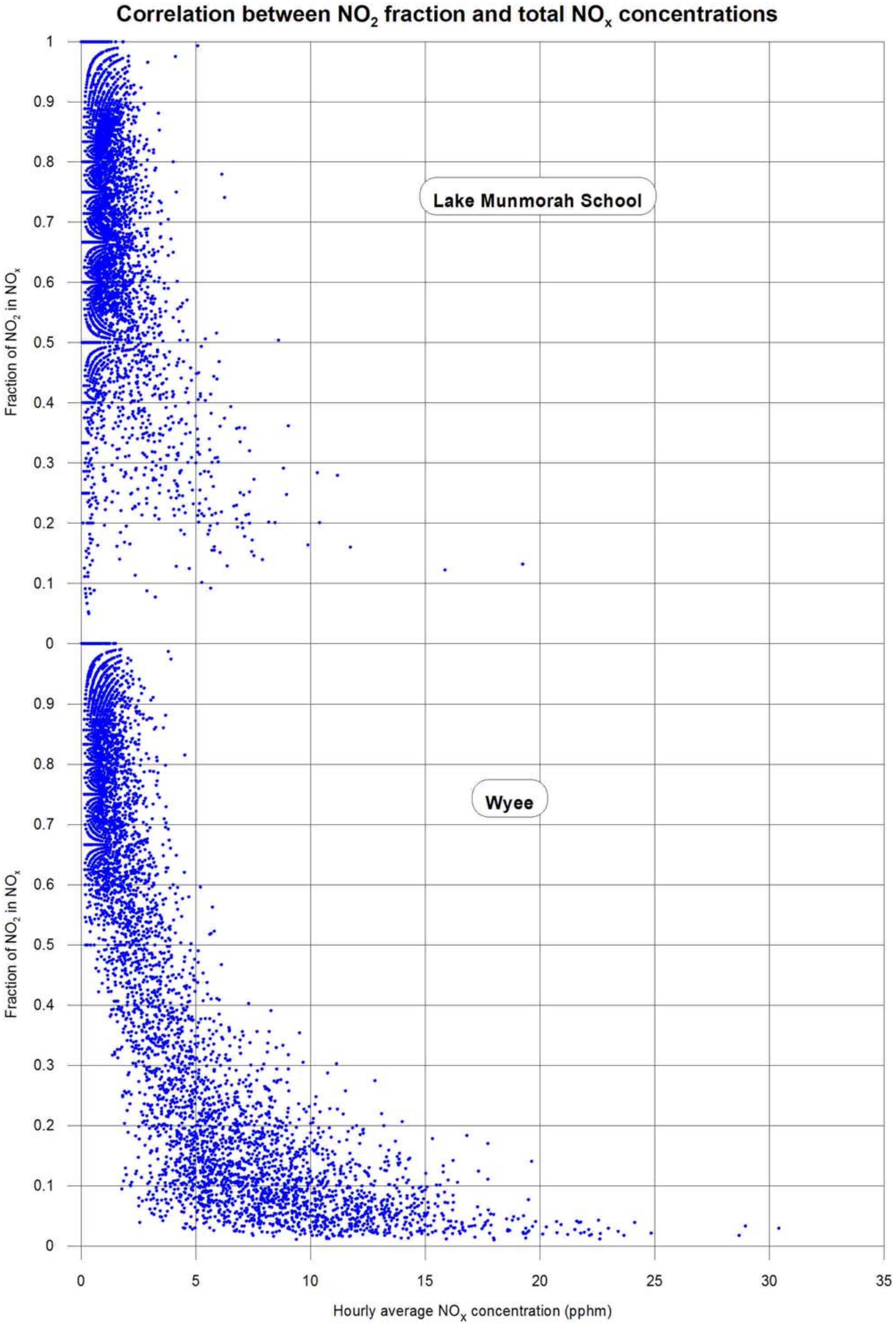
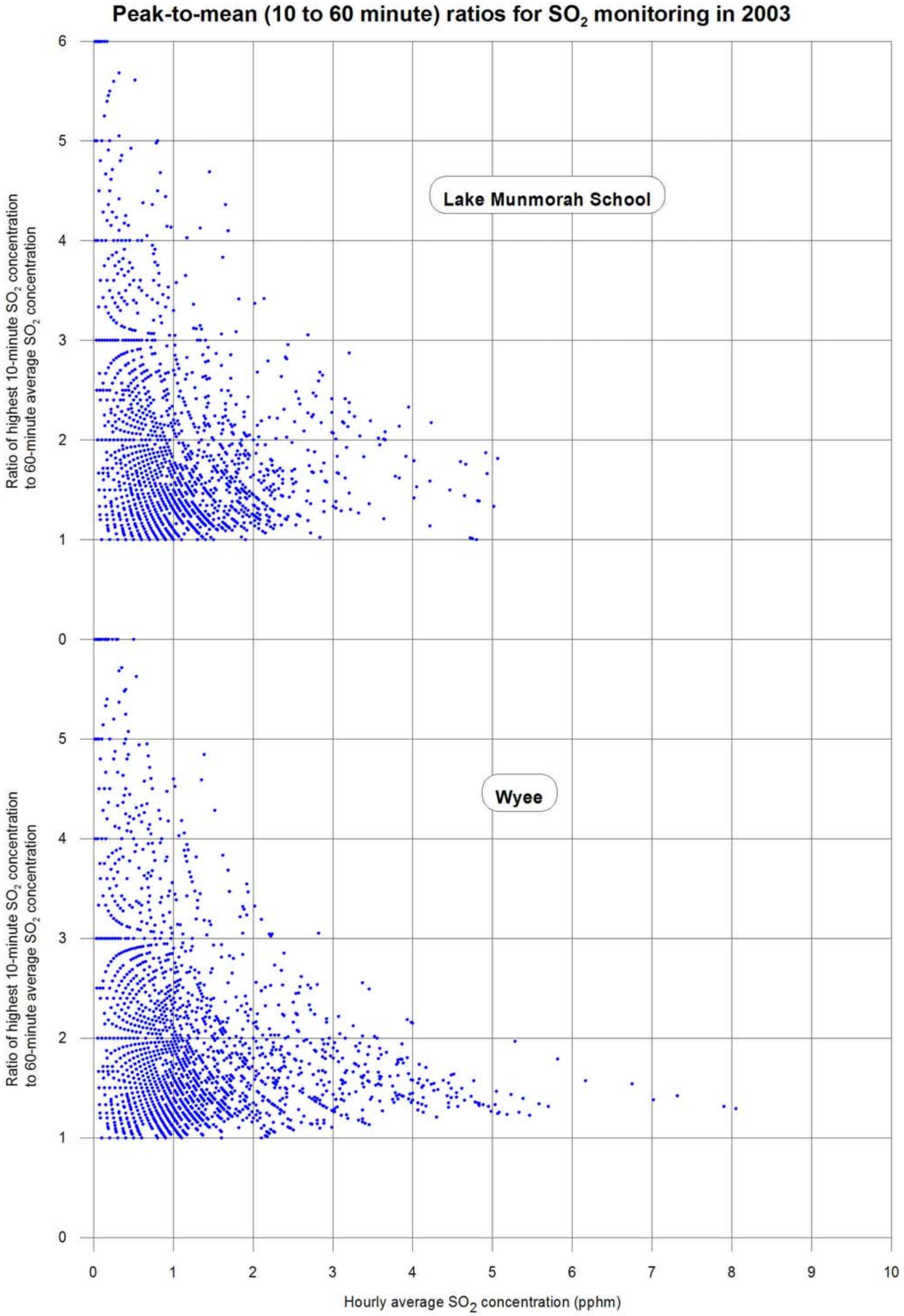
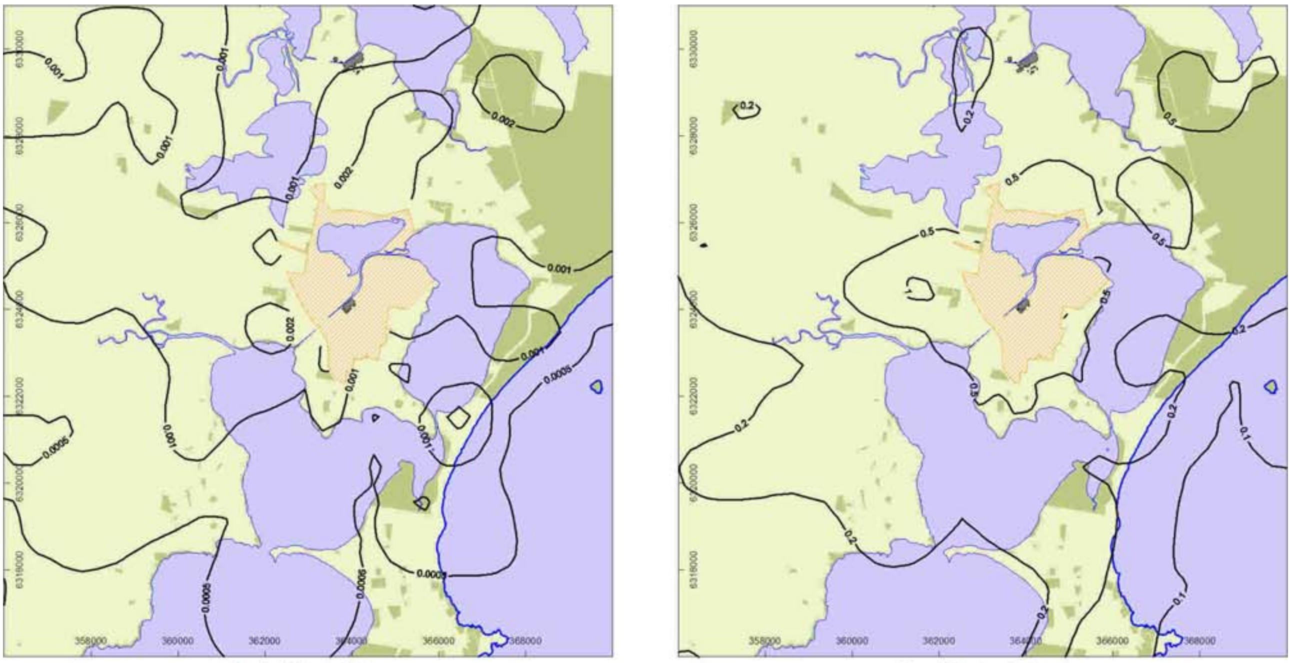

Correlation between NO_2 fraction and total NO_x concentrations
Lake Munmorah School
Wyee
Fraction of NO_2 in NO_x
Fraction of NO_2 in NO_x
Hourly average NO_x concentration (pphm)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
5
10
15
20
25
30
35

FIGURE 13



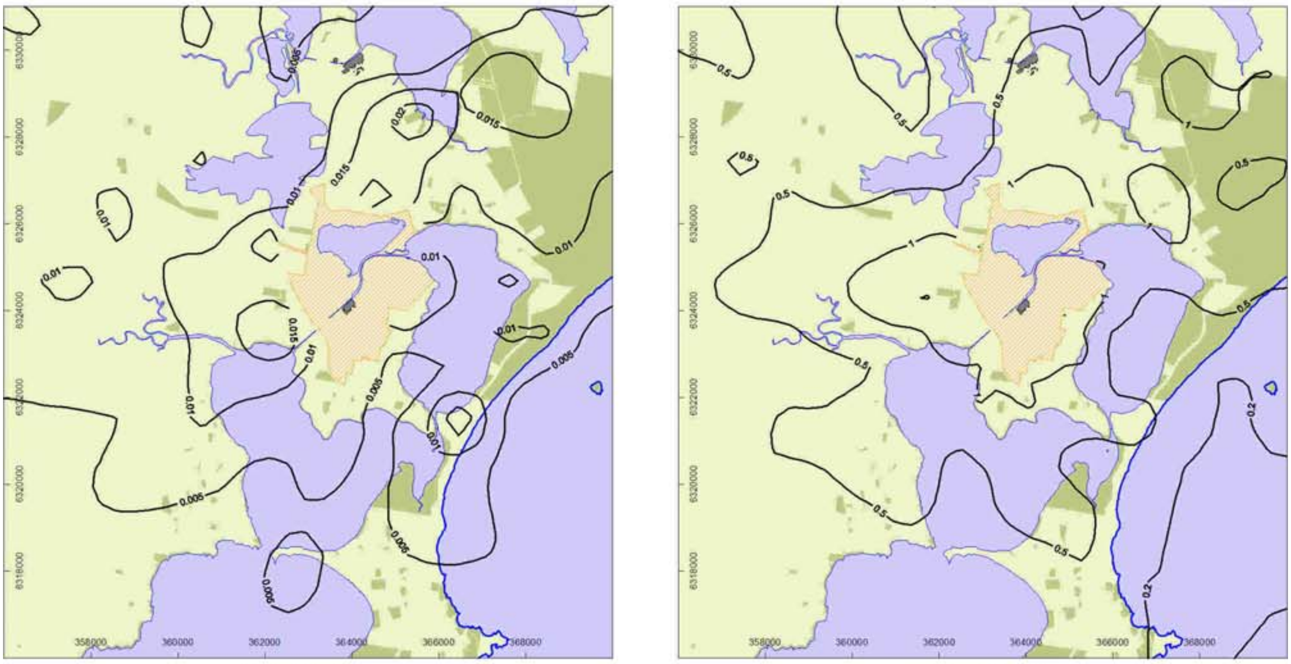
Peak-to-mean (10 to 60 minute) ratios for SO_2 monitoring in 2003
Lake Munmorah School
Wyee
Ratio of highest 10-minute SO_2 concentration to 60-minute average SO_2 concentration
Ratio of highest 10-minute SO_2 concentration to 60-minute average SO_2 concentration
6
5
4
3
2
1
0
5
4
3
2
1
0
0
1
2
3
4
5
6
7
8
9
10
Hourly average SO_2 concentration (pphm)

FIGURE 14



Fuel: Natural Gas
Normal operation

Fuel: Natural Gas
Start-up, worst case

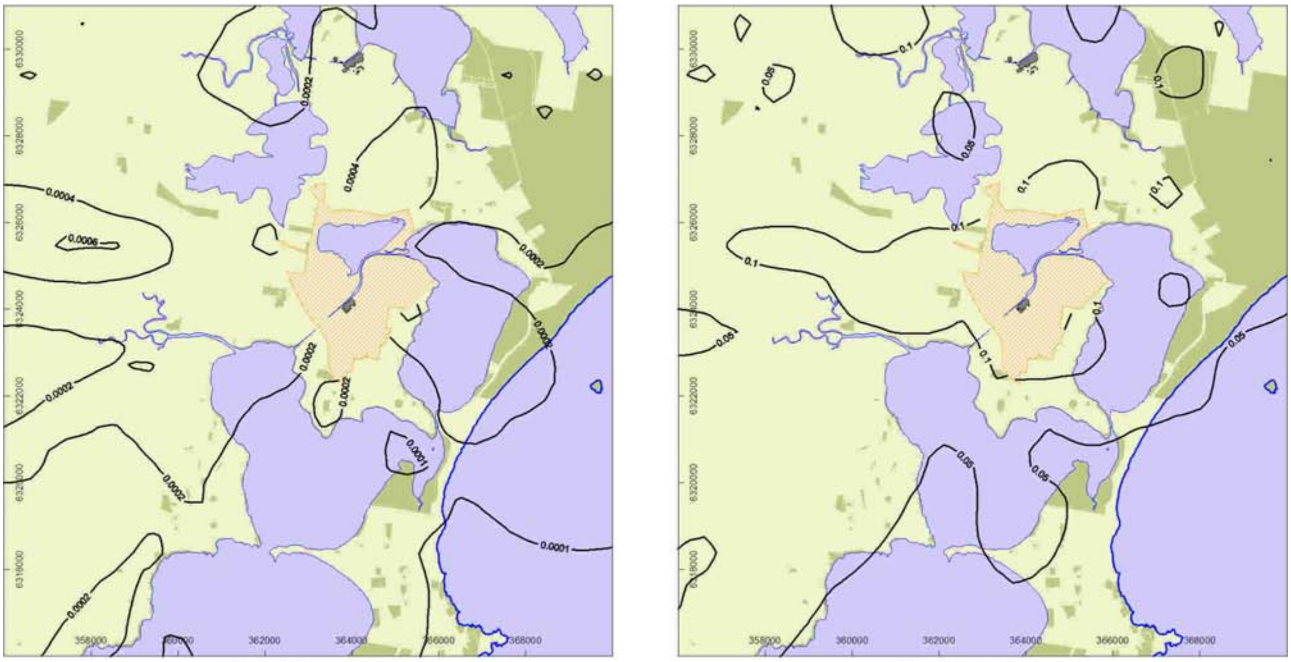


Fuel: Oil fired
Normal operation

Fuel: Oil fired
Start-up, worst case

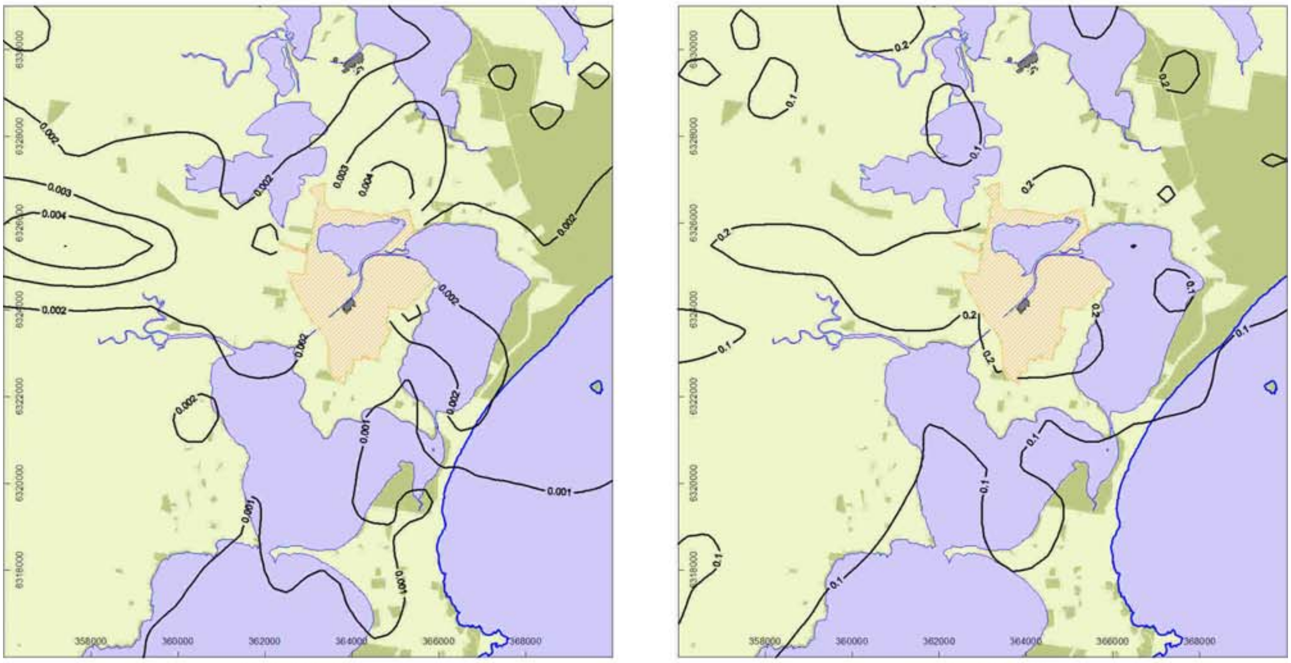
Predicted maximum 1-hour average CO concentrations at ground-level due to OCGT - mg/m^3

FIGURE 15



Fuel: Natural Gas
Normal operation

Fuel: Natural Gas
Start-up, worst case

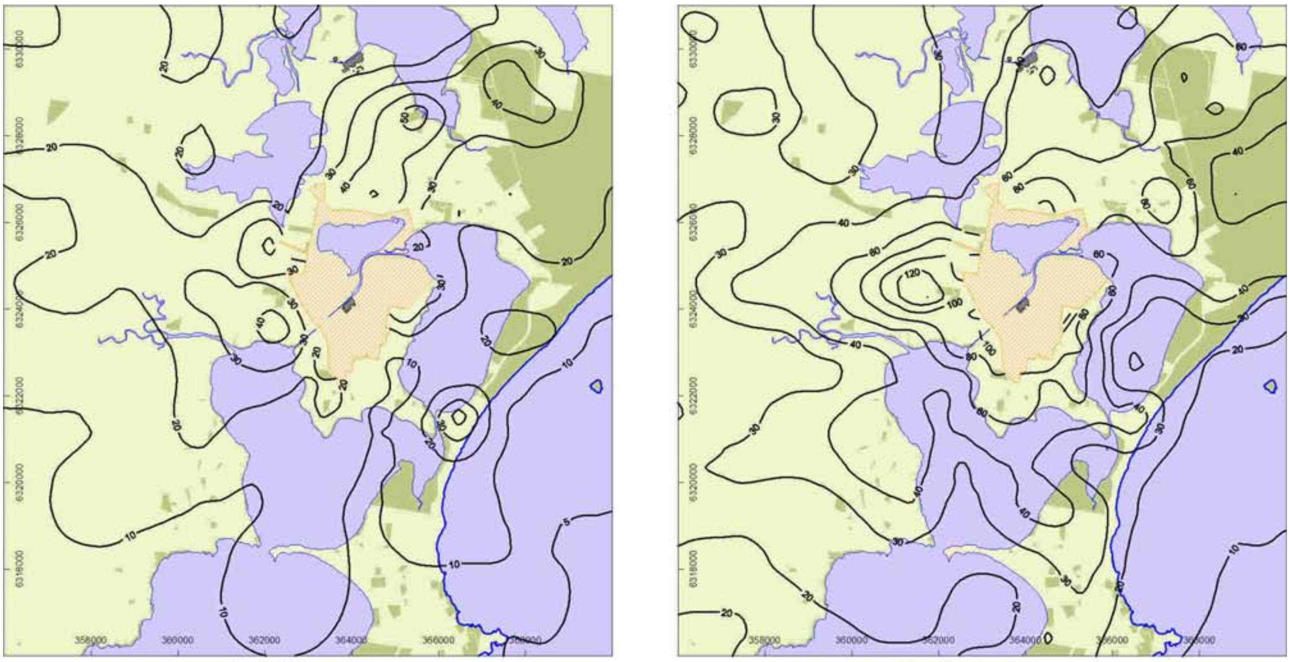


Fuel: Oil fired
Normal operation

Fuel: Oil fired
Start-up, worst case

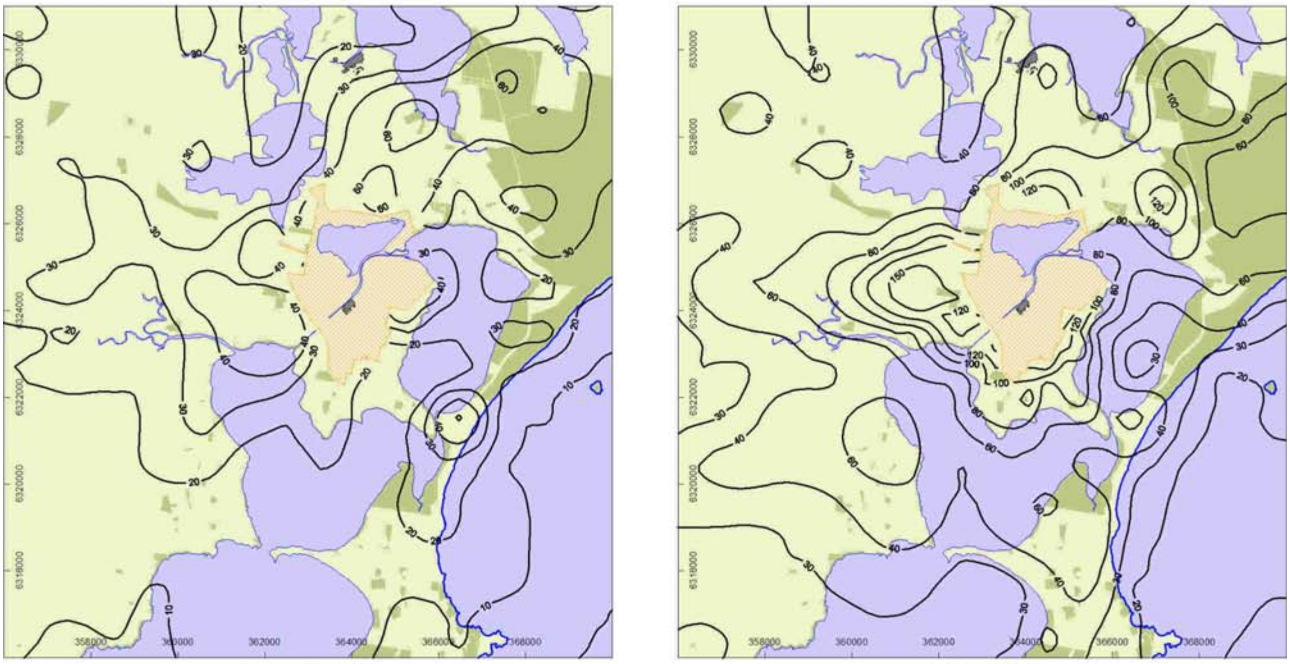
Predicted maximum 8-hour average CO concentrations at ground-level due to OCGT - mg/m^3

FIGURE 16



Fuel: Natural Gas
Normal operation

Fuel: Natural Gas
Start-up, worst case

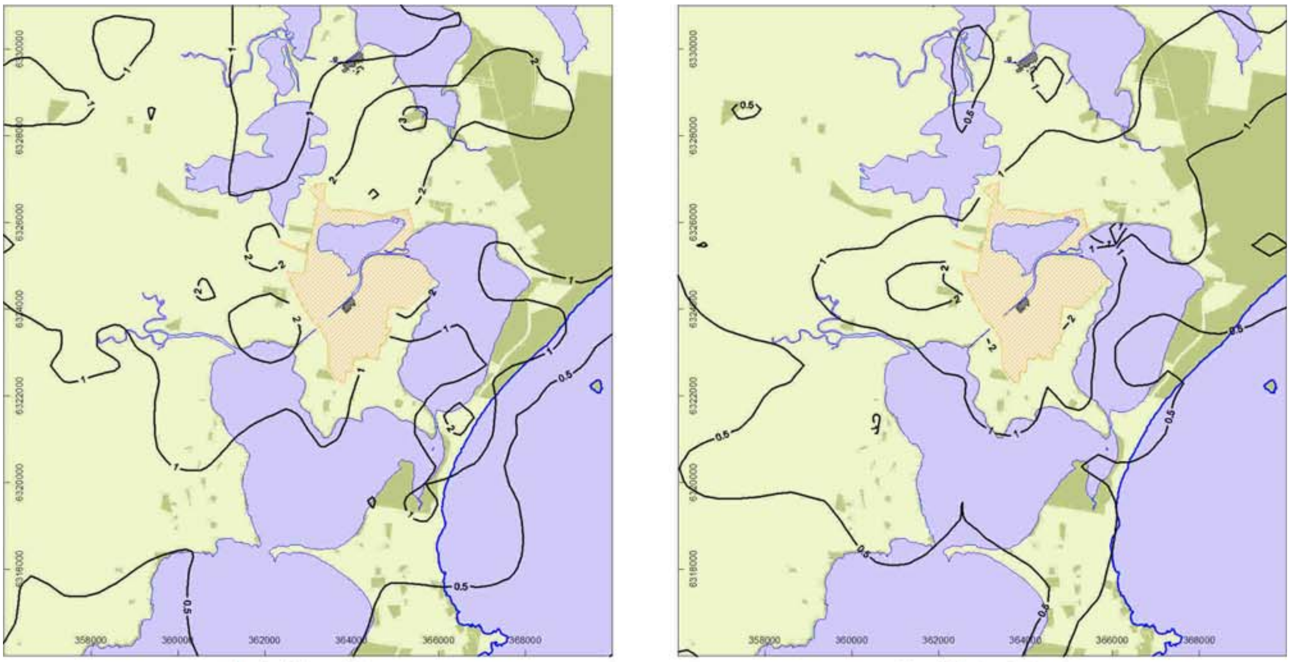


Fuel: Oil fired
Normal operation

Fuel: Oil fired
Start-up, worst case

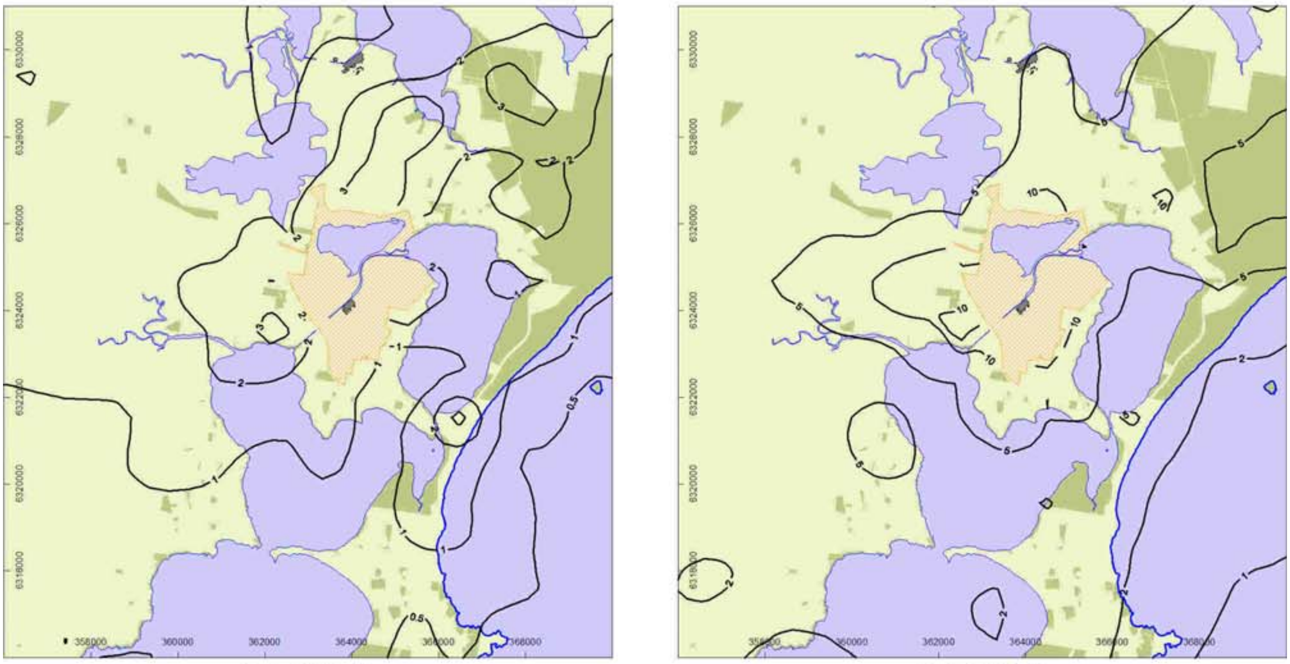
Predicted maximum 1-hour average NO_x concentrations at ground-level due to OCGT - µg/m^3

FIGURE 17



Fuel: Natural Gas
Normal operation

Fuel: Natural Gas
Start-up, worst case

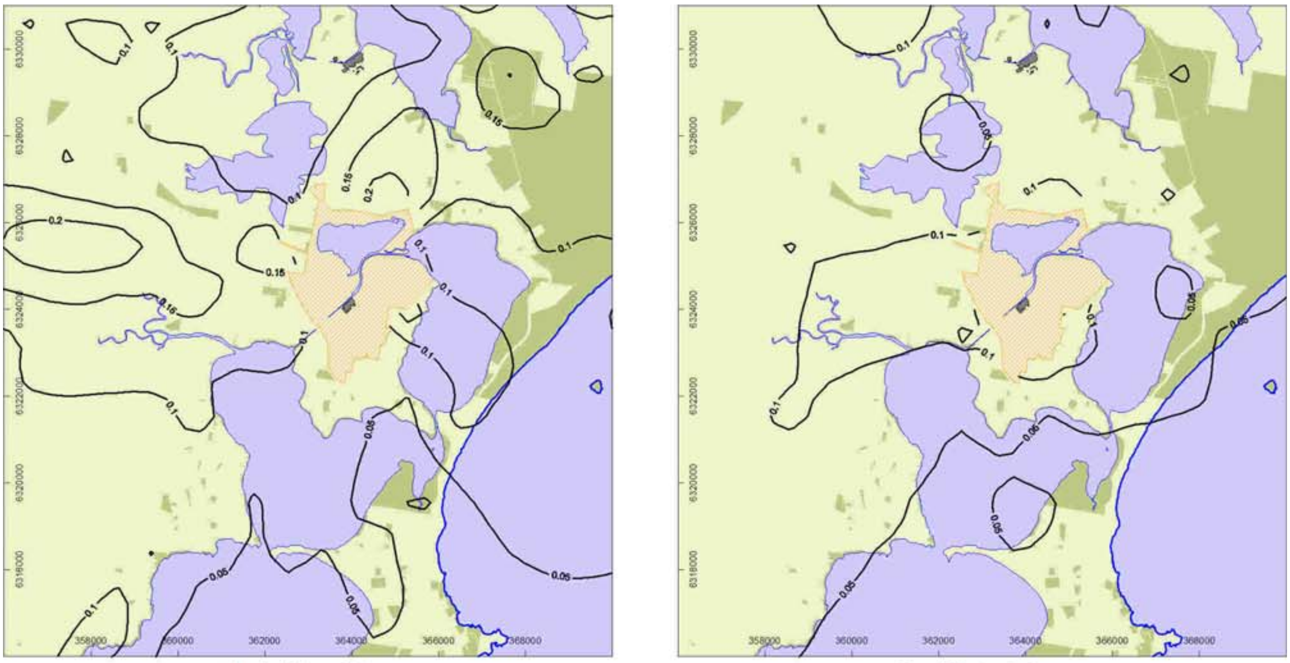


Fuel: Oil fired
Normal operation

Fuel: Oil fired
Start-up, worst case

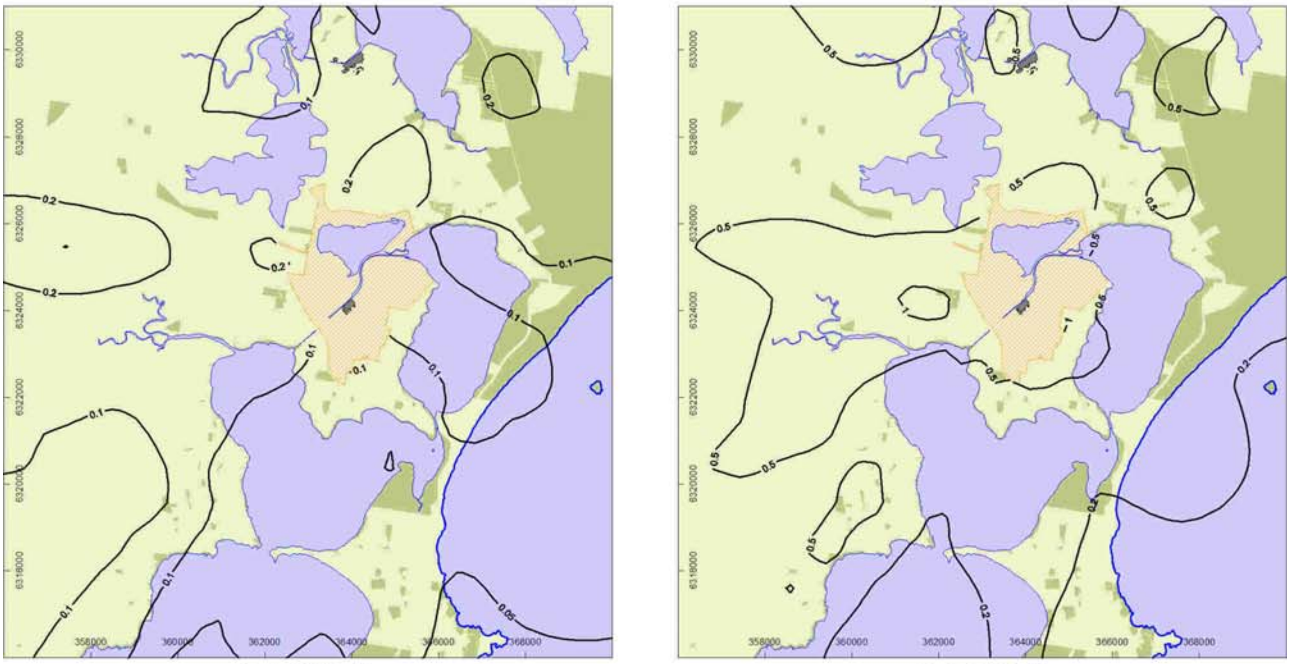
Predicted maximum 1-hour average SO_2 concentrations at ground-level due to OCGT - $\mu g/m^3$

FIGURE 18



Fuel: Natural Gas
Normal operation

Fuel: Natural Gas
Start-up, worst case

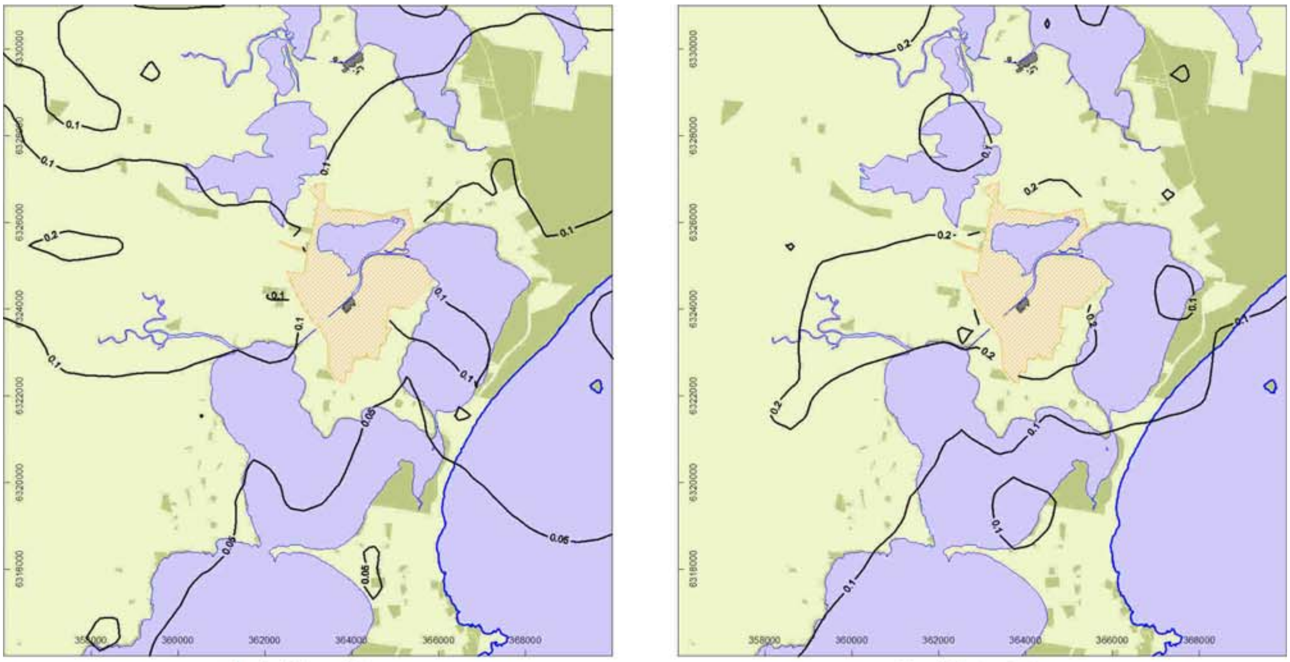


Fuel: Oil fired
Normal operation

Fuel: Oil fired
Start-up, worst case

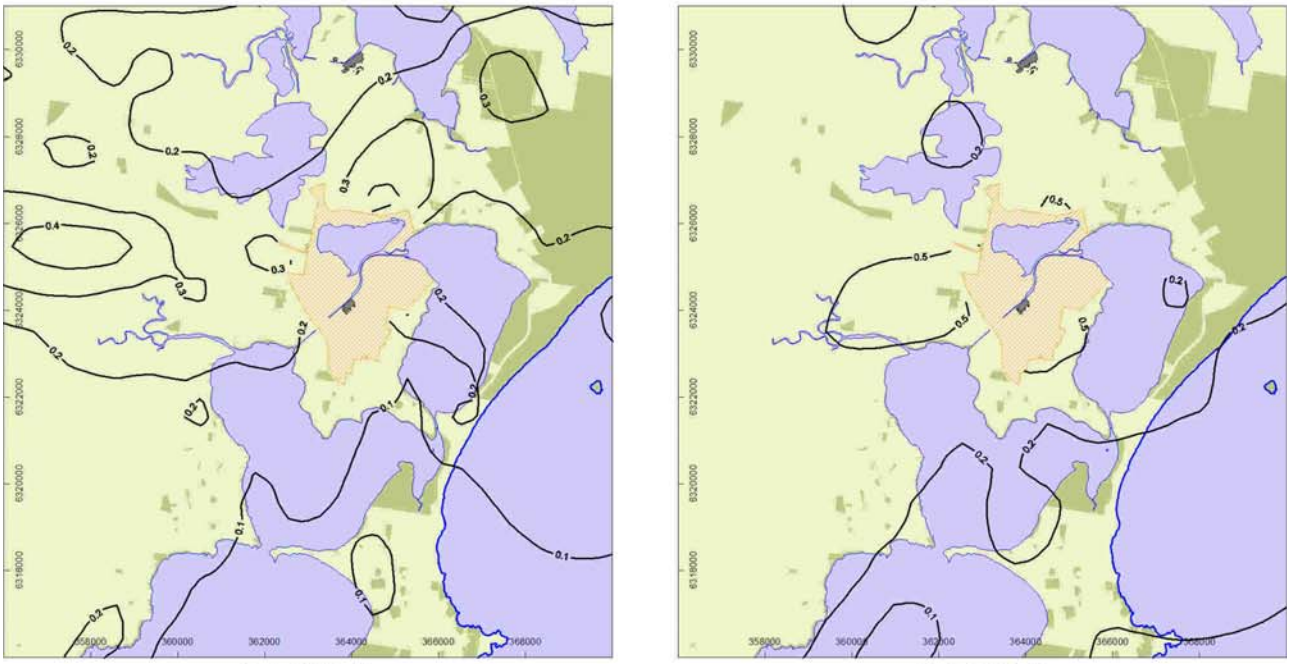
Predicted maximum 24-hour average SO_2 concentrations at ground-level due to OCGT - µg/m^3

FIGURE 19



Fuel: Natural Gas
Normal operation

Fuel: Natural Gas
Start-up, worst case



Fuel: Oil fired
Normal operation

Fuel: Oil fired
Start-up, worst case

Predicted maximum 24-hour average PM_{10} concentrations at ground-level due to OCGT - µg/m^3

FIGURE 20