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AGL Dalton Power Project Environmental Assessment

MP10-0035

Appendix C

Air Quality Impact Assessment

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Report

Air Quality Impact Assessment

AGL Gas-Fired Power Station at Dalton, NSW

20 OCTOBER 2009

Prepared for

AGL Energy Limited

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43217973

URS

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Abbreviations

Abbreviation	Description
AGL	AGL Energy Limited
agl	above ground level
Approved Methods	The Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (DEC 2005)
AAQ NEPM	Ambient Air Quality National Environment Protection Measure
AQIA	Air Quality Impact Assessment
AWS	Automatic Weather Station
CO	Carbon Monoxide
DEC	Department of the Environment and Conservation (formerly NSW EPA)
DECC	Department of the Environment and Climate Change (formerly DEC)
DECCW	Department of the Environment, Climate Change and Water (formerly DECC)
DLN	Dry Low NO_x
GT	Gas Turbine
HAP	Hazardous Air Pollutant
NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
NSW EPA	New South Wales Environmental Protection Authority
OCGT	Open Cycle Gas Turbine
PAHs	Polycyclic Aromatic Hydrocarbons
PMS	Performance Monitoring Station
PM_{10}	Particulate Matter less than 10 microns in aerodynamic diameter
ppm	Parts per million, by volume
SO_2	Sulphur dioxide
US EPA	United States Environmental Protection Authority
VOC	Volatile Organic Compound

Executive Summary

The potential air quality impact of the Dalton Power Project has been assessed using the Calpuff dispersion modelling package. The pollutants assessed included nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), particulate matter (PM_{10}) and formaldehyde. The dispersion modelling has used a largely conservative approach, in accordance with the DECCW (2005) *Approved Methods and Guidance for the Modelling and Assessment of Air Pollutants in NSW*. In order to assess the cumulative impact of the plant emissions on the local air quality, background concentrations of the criteria pollutants were obtained from the relevant DECCW and TMS monitoring stations.

The results of the dispersion modelling showed that the predicted impacts on ground level concentrations of NO_2, PM_{10}, CO and SO_2, when added to peak background concentrations, were within the DECCW regulatory criteria. In addition, the predicted incremental concentrations of formaldehyde were found to be within DECCW criteria. This analysis has also assumed that all oxides of nitrogen (NO_x) exist as nitrogen dioxide.

1 Introduction

1.1 Project Description

AGL Energy Limited (AGL) proposes the development of an Open Cycle Gas Turbine (OCGT) peaking power station (hereafter referred to as the Facility) to the north of Dalton, NSW. It is proposed that the Facility have a total generation capacity of up to 1500MW, consisting of up to six turbines, to be constructed in a two-staged approach:

- **Stage 1**: Power generation of between 250 MW and 780 MW comprising:
  - two to four E Class generators ranging from 125 MW to 200 MW (total power generation of 250 MW – 720 MW); or
  - two to three F Class generators ranging from 200 MW to 320 MW (total power generation of 400 MW – 780 MW).
- **Stage 2**: Power generation of up to a total of nominally 1500 MW comprising:
  - Any underbuild of Stage 1 plus additional E or F class turbines taking the maximum number of turbines to 6 with a total maximum generating capacity to nominally 1500MW.

It is proposed that the Facility be fuelled by natural gas, supplied via an off-take from the Moomba to Sydney gas pipeline. The Facility would include:

- A lay-down area;
- A connection to an electrical substation; and
- An underground gas pipeline.

Each gas turbine plot would consist of a main enclosure housing the air inlet and turbine, an exhaust stack and a transformer.

The Facility would typically operate for approximately 15% of the year or 1300 hours, during periods of peak demand. Peak demand is generally associated with the morning and evening periods, particularly at times of extreme temperatures, however, the facility may operate at any time during the day or night, and at any time of the year, when additional energy is required by the grid.

1.2 Process Description

In each gas turbine, air is drawn in through filters to remove ambient particulate matter. The air then passes into the compressor, where multiple rows of rotating blades raise the temperature and pressure of the air to between 15 and 30 atmospheres. After the compressor, the air flows into combustion chambers arranged around each gas turbine. In these combustors, the fuel is injected and burnt, increasing the temperature to approximately 1100-1200ºC. The combustors feature Dry Low NO_x (DLN) technology to produce very low levels of emissions when firing natural gas. The combustion products then enter the turbine section of the gas turbines and expand to atmospheric pressure, reducing in temperature to around 500-600ºC. As the gas expands, the gases drive the turbine, which in turn drives the compressor and an electrical generator. From the turbine, the heated exhaust gases pass through a silencer unit and are discharged to atmosphere through a stack.

1.3 Turbine Emissions

The primary atmospheric emissions from gas turbines are typical of gas combustion sources, and include nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2), water vapour (H_2O), oxides of nitrogen (NO_X) and carbon monoxide (CO).

1 Introduction

Other gaseous emissions include low concentrations of oxides of sulphur (SO_X), Particulate Matter (PM) as well as Hazardous Air Pollutants (HAPs) in trace concentrations. The various exhaust components and their respective sources are listed in **Table 1-1.**

Table 1-1 Gas turbine exhaust components and their sources

Component	Source/s
N_2, O_2,	Inlet Air
H_2O	Inlet Air, oxidation of hydrogen in fuel, water injection (where used)
NO_x	Oxidation of atmospheric nitrogen and nitrogen in the fuel
SO_x	Oxidation of sulphur in fuel
CO_2	Oxidation of carbon in fuel
CO	Incomplete oxidation of carbon in fuel
Particulate Matter	Particulate matter in air, incomplete oxidation of fuel, impurities in fuel
Hazardous Air Pollutants	Impurities in fuel and incomplete oxidation of fuel

Of these components, N_2, O_2 H_2O, CO_2 are not considered to impact air quality and have not been included in this assessment.

1.3.1 Oxides of Nitrogen

Oxides of nitrogen (NO_X) is the sum of nitric oxide (NO) and nitrogen dioxide (NO_2). In gas turbines the primary mechanism for NO_X formation is termed “thermal NO_X”. This occurs in the combustion zone, where high temperatures allow the dissociation of atmospheric nitrogen (N_2), after which the nitrogen may combine with excess oxygen. Generally, the NO_x emissions from a combustion source comprise approximately 90% NO and 10% NO_2 at the source.

In the atmosphere NO and NO_2 are linked in a circular reaction with oxidants such as ozone, which generate NO_2 from NO and sunlight which breaks NO_2 down to NO. Due to this reaction sequence, the exact amount of NO and NO_2 within emissions is often unknown, and consequently the sum emission of both species (i.e. NO_x) is quoted. The ambient concentration of NO_2 near to a NO_X source is dependent on the amount of oxidant and sunlight at the time.

In ambient concentrations usually found within the atmosphere, NO has no impact on either human health or the environment. Conversely, it is known that short term concentrations of NO_2 greater than 200ppb (411µg/m^3) (NEPC, 1998a), have the potential to cause irritation in certain individuals. To ensure that individuals are protected from potential health impacts of short term concentrations, maximum short term exposure is set within NSW at 246 µg/m^3 (120 ppb). The long term effects of NO_2 are less well known although some evidence suggests poor lung function of inhabitants of areas with high NO_2 concentrations. To address the potential long term effects of NO_2, an annual average limit of 62 µg/m^3 has been set by the DECCW.

1.3.2 Particulate Matter

Particulate matter is generally divided into three broad fractions:

- Total Suspended Particulate Matter (TSP);
- Particulate Matter of less than 10 µm in aerodynamic diameter (PM_{10}); and
- Particulate Matter of less than 2.5 µm in aerodynamic diameter ($PM_{2.5}$).

$PM_{2.5}$ is a sub-class of PM_{10}, which in itself is a sub-category of TSP. Whilst in definition, TSP includes the smaller size fractions, it is generically used to describe the larger fraction (between 10 µm and 30 µm diameter) that, because of its aerodynamic diameter and density, falls more rapidly from the air than smaller fractions. Given sufficient time, however, PM_{10} will also settle out of suspension in the atmosphere. The size of TSP means that the majority of this material will not enter the human body thorough inhalation, as it is stopped by the cilia in the nose and throat. Impacts of TSP are primarily limited nuisance, and may only affect health via annoyance reactions.

PM_{10} js acknowledged as a pollutant of concern due to its ability to be inhaled into the lungs. PM_{10} has been considered as part of this assessment. Gas turbine emissions operating on natural gas generally contain very low concentrations of particulate matter due to the fuel type and combustion process (US EPA 2000). The US EPA identifies that all particulate matter from gas combustion in gas turbines is less than 1 µm.

Major natural sources of background particulate levels include forest fires, pollen and wind-blown dust from exposed areas. Anthropogenic sources include stationary and mobile combustion sources, road dust, agriculture, mining, major fires and emissions from industrial processes. Background levels vary widely depending on location, meteorology and proximity of major sources.

1.3.3 Sulphur Dioxide

Emissions of sulphur dioxide are defined by the sulphur content of the fuel. The sources of sulphur within the natural gas are understood to be due to the addition of sulphur-containing odorants to the gas (for safety purposes), as well as potential trace amounts of sulphur carried through from the feedstock gas. The Natural gas supply to the site is regulated by the Australian Standard AS4564 - 2005 (Standards Australia, 2005), which specifies a concentration of less than 50mg/m^3 (1atm, 15°C).

1.3.4 Carbon Monoxide

Carbon monoxide (CO) is produced due to the incomplete combustion of any fuel containing carbon, where there is too little oxygen within the mix or the fuel. In gas turbines this occurs primarily during the Start Up phase of operation when combustion conditions are not optimized.

1.3.5 Hazardous Air Pollutants

Hazardous Air Pollutants (HAP's) emissions from gas turbines are lower than for other combustion sources e.g. internal combustion engines (USEPA, 2000). This is due to the combustion environment present, where high temperatures and high amounts of excess air promote more complete combustion of the fuel.

The US EPA (2000) identified the following HAP emissions from gas turbines:

- Acetaldehyde;
- Acrolein;
- Benzene;
- Ethylbenzene;
- Naphthalene
- Formaldehyde;
- Toluene;
- PAHs; and
- Xylenes.

Approximately 70% of the total mass HAP emissions were reported to be in the form of formaldehyde. In this assessment HAP's other than formaldehyde have not been directly assessed as the US EPA AP-42 emission factors, when considered in conjunction with DECCW air quality criteria, identify formaldehyde as the key HAP of interest for gas-fired turbines, where compliance with formaldehyde criteria subsequently demonstrates compliance of all other HAP's with the relevant DECCW criteria.

1.4 Emissions from Other Operational Sources

For the purposes of this report, it has been assumed that the stack emissions represent the primary emission source on site. Other air emission sources at the Facility may include:

- Drainage collection pond;
- Waste water pond;
- Evaporative cooler;
- Oil separator pit;
- Grey water tank; and
- Sanitary/foul water treatment.

Given the small scale of these sources and the lack of sensitive receptors in their immediate vicinity, these sources are not considered significant and were not included in the modelling.

2 Air Quality Criteria

2.1 General

There are three main types of regulatory criteria relevant to air emissions associated with the proposal. These are:

- **Emission Standards** – which specify maximum allowable in-stack pollutant concentrations specified for particular industrial activities and plant types;
- **Air Impact Assessment Criteria** – ambient criteria designed for use in air dispersion modelling and air quality impact assessments for new or modified emission sources; and
- **Ambient Air Quality Standards** – regional standards against which ambient air quality monitoring results may be assessed.

A combination of Emission Standards and Air Impact Assessment Criteria are typically used to evaluate the expected impact of air emissions on local air quality, and the effectiveness of plant design with any associated mitigation measures. The wider objective of these criteria is to ensure that the resulting local and regional ambient air quality meets the relevant Ambient Air Quality Standards.

2.1.1 Emission Standards

The *Protection of the Environment Operations (Clean Air) Regulation 2002* sets emission limits for air impurities from stationary plant and equipment. The current standards, taken from Schedule 3 (Electricity Generation) of the Regulation, relevant to the proposed Facility are presented in **Table 2-1.**

Table 2-1 Emission standards relevant to the proposal, sourced from Schedule 3, Protection of the Environment Operations (Clean Air) Regulation 2002

Air Impurity	Applicability	Regulatory Limit (Group 6)
Nitrogen dioxide (NO_2) or nitric oxide (NO) or both as NO_2 equivalent	Electricity generation – any turbine operating on gas being a turbine used in connection with an electricity generating system of 30 MW or more.	70 mg/m^3 (dry, 273K,15%O_2)

Note: An activity is designated to "Group 6"if it commenced to be carried on, or to operate, on or after 1 September 2005, as a result of an environment protection licence granted under the Protection of the Environment Operations Act 1997 pursuant to an application made on or after 1 September 2005.

2 Air Quality Criteria

2.1.2 Air Impact Assessment Criteria

In August 2005, the DECCW (NSW EPA) released the *Approved Methods and Guidance for the Modelling and Assessment of Air Pollutants in NSW*. This document specifies impact assessment criteria for a range of air pollutants. The impact assessment criteria for those pollutants associated with the Facility are shown in **Table 2-2.**

Table 2-2 DECCW Impact Assessment Criteria

Substance	Averaging Period	Impact Assessment Criteria	
		(ppm)	($\mu g/m^3$)
NO_2	1 hour	0.12	246
	Annual	0.03	62
CO	15 minutes	87	100,000
	1 hour	25	30,000
	8 hours	9	10,000
SO_2	10 minutes	0.25	712
	1 hour	0.20	570
	24 hours	0.08	228
	Annual	0.02	60
PM_{10}	24 hour	-	50
	Annual	-	30
Formaldehyde	1 hour	0.018	20

2.1.3 Ambient Air Quality Criteria

Ambient air quality criteria are provided in National Environmental Protection Measure (Ambient Air Quality) NEPC (1998). The guidelines contained in NEPC (1998) are designed for use in assessing regional air quality and are not intended for use as site boundary or atmospheric dispersion modelling criteria, hence the proposed peaking power plant emissions have not been assessed directly against these guidelines. It should be noted, however, that the maximum concentrations for NO_2, PM_{10}, SO_2 and CO are identical to the DEC (2005) criteria.

3 Existing Environment

3.1 Climate

Climate data was obtained for the closest Bureau of Meteorology (BoM) weather station located at Yass. This weather station is considered to be representative of the region, including the proposed development site. The data is presented in **Table 3-1** is a summary of records recorded between 1898 and 2009.

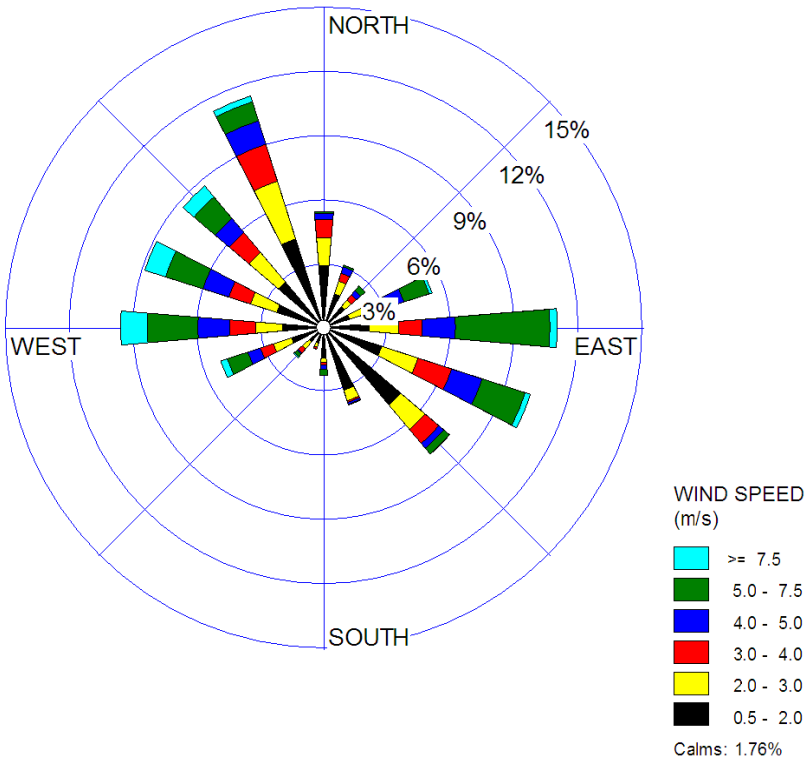
Being situated approximately 100km inland, the area experiences hot summers and cold winters. The mean daily maximum temperature is approximately 29^{0}C during summer and 12^{0}C during winter. Sub-zero temperatures have been recorded between April and November and are regularly recorded during winter with temperatures lower than -8^{0}C having been measured. The area receives moderate rainfall having a mean annual rainfall of 648.5 mm over an average of 93.5 rain days per year.

3.2 Meteorology

As site specific dispersion meteorology was not available, CSIRO's TAPM *(The Air Pollution Model* Hurley, 2005*)* meteorological model was used, with assimilation of wind data from Goulburn Airport which is understood to be the nearest Automatic Weather Station (AWS) and is located approximately 50 km east south east of the Facility. It is noted that whilst Yass weather station is closer to the Facility, only 9 am and 3 am observations are made, hence hourly data has been sourced from Goulburn. The methodology for developing site specific meteorological data is provided in **Appendix A** to this report.

The TAPM derived meteorological data is presented as an annual wind rose in **Figure 3-1** Wind in the region primarily blows from the north-west and south-east quadrants.

Figure 3-1 TAPM Generated Annual Wind rose for the proposed site (2006)



3 Existing Environment

Table 3-1 Summary of Climatic Data from Yass (Station 070091) (Bureau of Meteorology, 2009)

Statistic	January	February	March	April	May	June	July	August	September	October	November	December	Annual	Start Year	End Year
Mean maximum temperature (Degrees C)	29.4	29	25.8	21.2	16.4	12.6	11.6	13.4	16.6	20.5	24.2	27.7	20.7	1907	2009
Highest temperature (Degrees C)	41.2	41.1	38	33.9	24.6	20.5	22	25.8	28.9	32.7	38.9	40	41.2	1965	2009
Lowest maximum temperature (Degrees C)	13.3	14.5	13.3	8.8	3.9	4.3	2.9	5	7.3	8.7	10.2	13.6	2.9	1965	2009
Lowest temperature (Degrees C)	4	3.1	0	-3.5	-7	-7	-8.8	-7.5	-3.9	-1.8	-1.2	1.5	-8.8	1965	2009
Mean rainfall (mm)	50.5	43.9	46.8	48.8	50.2	57.9	59.4	59.2	56.3	64.5	56	54	647.5	1898	2009
Highest rainfall (mm)	176.2	187.6	254.1	205.5	219.8	174	178.8	141.3	149.4	157.6	201.5	201.1	1227.9	1898	2009
Lowest rainfall (mm)	0	0	0	0	0	3.6	5	2.6	11.7	0.6	1	0.3	211.5	1898	2009
Highest daily rainfall (mm)	90.4	63.2	141.3	95	82.3	63.5	94.7	53.6	45.4	99.8	69.6	77.2	141.3	1898	2009
Mean number of days of rain	6	4.9	5.4	6.1	7.3	10.1	11.3	10.7	9.4	8.7	7.2	6.4	93.5	1898	2009
Mean daily solar exposure (MJ/(m*m))	27.2	23.9	20.2	14.5	10.4	7.7	8.6	12	16.4	21.4	24.9	27.3	17.9	1990	2009
Mean number of clear days	10.3	8.2	9.4	8.8	6.6	4.3	5.1	6.7	7.4	7.9	7.5	10.4	92.6	1965	2009
Mean number of cloudy days	7.4	6.5	7.2	7.2	10.3	12.2	12.5	11.3	9.3	8.9	9	7.2	109	1965	2009
Mean 9am temperature (Degrees C)	19.9	19.3	17.1	12.9	8.6	5.8	4.7	6.5	10.2	14.1	16.1	18.7	12.8	1965	2009
Mean 9am wet bulb temperature (Degrees C)	15.9	16	14.3	10.9	7.6	5	3.9	5.4	8.4	11.2	13	14.6	10.5	1965	2009
Mean 9am dew point temperature (Degrees C)	12.9	13.3	11.6	8.9	6.4	4.1	3.1	3.8	6.2	7.6	9.8	11.5	8.3	1986	2009
Mean 9am relative humidity (%)	60	66	70	74	82	88	87	82	75	65	62	59	73	1909	2009
Mean 9am cloud cover (oktas)	3.3	3.6	3.4	3.5	4.6	5.2	5	4.4	3.9	3.8	3.8	3.3	4	1909	2009
Mean 9am wind speed (km/h) for years 1965 to 2009	7.8	7.3	7	5.8	4.8	4.9	5.1	7	8.2	9.5	9.5	8.4	7.1	1965	2009
Mean 3pm temperature (Degrees C)	27.9	27.4	24.5	19.9	15.2	11.6	10.6	12.3	15.3	19	22.3	25.8	19.3	1965	2009
Mean 3pm wet bulb temperature (Degrees C)	18.3	18.4	16.8	13.9	11.2	8.8	7.8	8.8	11	13.3	15.3	16.7	13.4	1965	2009
Mean 3pm dew point temperature (Degrees C)	11.3	11.5	10.3	8.1	7.3	6	4.8	4.9	6.4	7.2	8.9	9.6	8	1986	2009
Mean 3pm relative humidity (%)	41	41	44	49	60	70	68	62	57	50	46	40	52	1986	2009
Mean 3pm cloud cover (oktas)	3.9	4	4	3.9	4.4	4.7	4.6	4.5	4.4	4.3	4.3	3.9	4.2	1965	2009
Mean 3pm wind speed (km/h) for years 1965 to 2009	14.2	12.4	11.7	10.9	9.1	9.2	10.2	12.5	13.6	13.7	14.8	15.1	12.3	1965	2009

3.3 Background Air Quality

DEC (2005) require that the highest background concentration of a pollutant, as measured by an appropriate monitoring station, is used to represent the background concentration of that pollutant for the region throughout the period assessed. It is necessary to incorporate the background concentrations of air pollutants as they provide a baseline level, to which the predicted impact of the development can be added, thus producing a cumulative air quality impact that is suitable for comparison against regulatory criteria. Short-term concentrations of the pollutants considered in this assessment vary significantly throughout the year, hence the use of the maximum background value for all conditions provides a conservative estimate of short-term cumulative pollutant levels.

The area being assessed is a relatively sparsely populated rural area, with the density of emissions such as NO_x, CO, SO_2 and PM_{10} being low, and primarily limited to those from wood combustion in domestic heaters, open fires and agricultural burning. The region is also expected to experience elevated level PM_{10} from both locally and regionally generated wind blown dust.

Given that there are no site-specific background monitoring data available for this assessment, background concentrations of NO_2, CO, SO_2 and PM_{10} have been adopted from areas which have a greater pollution potential as a function of population, industrial emissions, meteorology and topography. Whilst this is unsuitable for predicting the actual scale of cumulative air quality impacts of the proposed Facility, it is conservative, and appropriate for the purposes of this assessment in demonstrating compliance with regulatory criteria.

In accordance with the *Approved Methods*, formaldehyde has not been assessed in a cumulative manner, hence background data for formaldehyde has not been included in this section.

The background data for this assessment were sourced from two government monitoring stations which undertake monitoring as part of the National Environment Protection Measure for Ambient Air Quality (AAQ NEPM) these are:

- Monash (ACT); and
- Chullora (NSW).

Further discussion of these data is provided in the following sections.

3.3.1 Monash Air Quality Monitoring

Background concentrations of NO_2 and PM_{10} were taken from the ACT Government Territory & Municipal Services Performance Monitoring Station (PMS), (TMS, 2007), located at Monash in the Australian Capital Territory which is located approximately 82km south of the proposed site.

The PMS has been located in accordance with AAQ NEPM protocol, which specifies the implementation of a monitoring program on the basis of a range of factors, including population. The population in the area of the PMS is 324,000, hence a single station has been commissioned at a site that is considered "*generally representative of the upper bound*"[1] of pollutant concentrations for the region. The monitoring data collected by the PMS is considered to provide a conservative representation of the background concentrations required for this assessment for the following reasons:

- Siting of the PMS in an area of greater population density and magnitude (324,000 people) ; and
- Siting of the PMS within valley topography where wood fired heaters are commonly used.

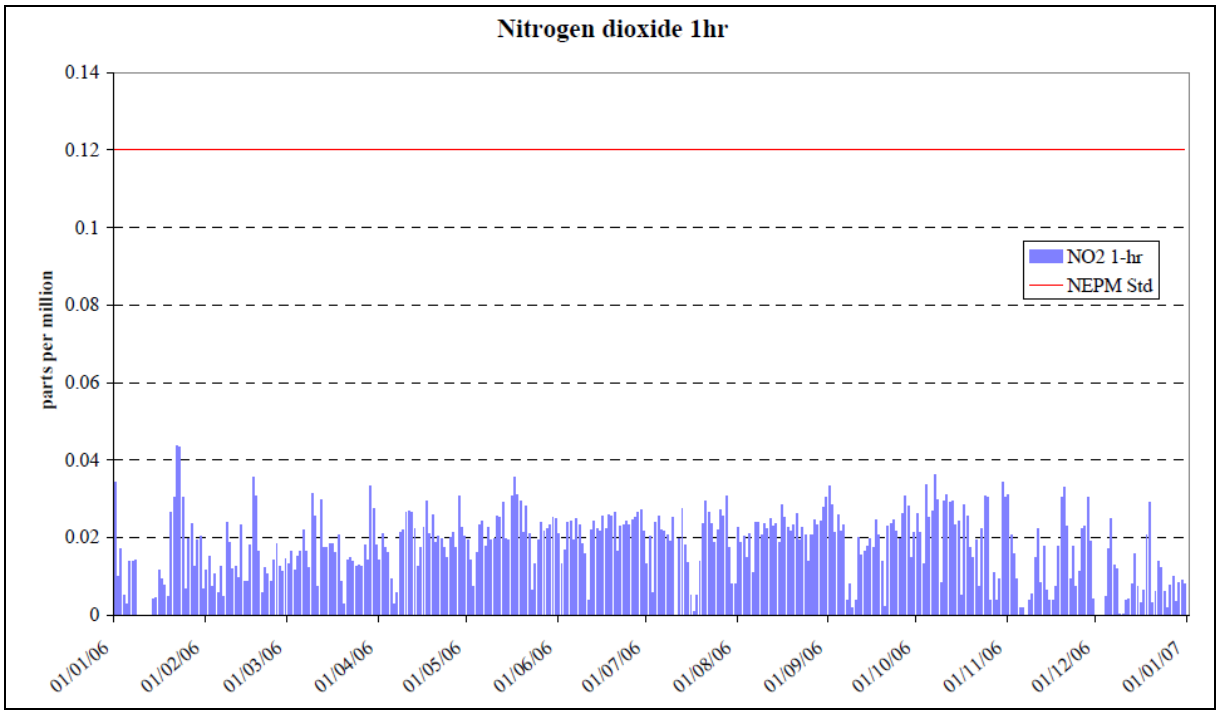
[1]Australian Capital Territory Ambient Air Quality Report 2007
http://www.ephc.gov.au/sites/default/files/AAQ_MntRpt__2007_ACT_Report_Final_0.pdf

3 Existing Environment

Nitrogen Dioxide

Figure 3-2 shows the hourly NO_2 levels that were recorded at Monash in 2006. Levels appear fairly consistent throughout the year, with the peak occurring in late January, and being below the DECCW and NEPM goal concentrations (which are identical) of 0.12 ppm.

Figure 3-2 Hourly Nitrogen Dioxide Levels at Monash, ACT 2006



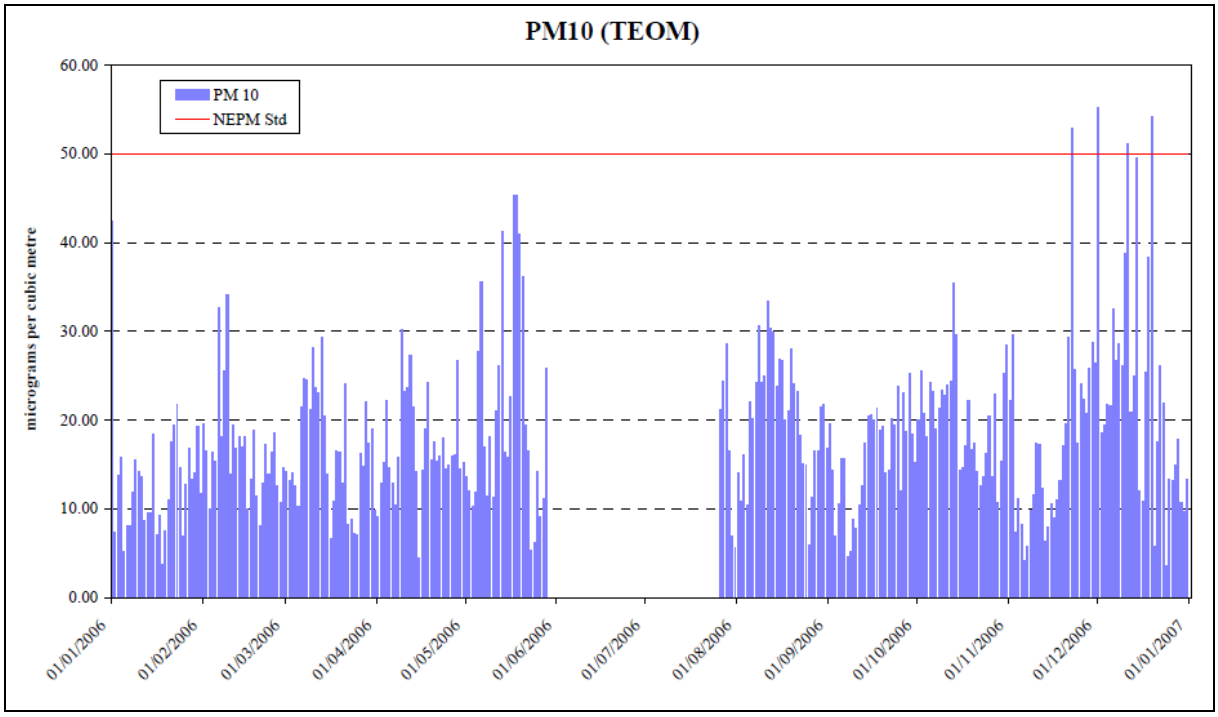
(Source: TMS, 2007)

Particulate Matter (as PM_{10})

Figure 3-3 shows the daily PM_{10} levels that were recorded at Monash in 2006. The peak PM_{10} measurements (~55 µg/m^3) occurred during late November and early December, which corresponded to periods of bushfire activity in northern Victoria and southern NSW (TMS, 2007), and have thus been excluded from this assessment. The annual average of 16.9 µg/m^3 indicates that in general, regional PM_{10} levels are low.

3 Existing Environment

Figure 3-3 24 Hour PM_{10} Levels at Monash, 2006



(Source: TMS, 2007)

As can be seen in Figure 3-3 data for the winter months is incomplete, due to vandalism of the monitoring station. Data recovery in 2006 at the Monash PMS was 84.1%. It is noted that PM_{10} concentrations had potential to increase during this winter period due to wood combustion in domestic heaters. The Facility is situated away from consolidated urban and residential development, hence the potential for elevated concentrations of PM_{10}, resulting from domestic wood burning, is considered to be low. Consequently, the value of 45.3 µg/m^3 has been adopted for this assessment.

3.3.2 Chullora Monitoring Data

Background levels of CO and SO_2 are not measured at Monash. The background data for these pollutants were taken from the DECCW monitoring station at Chullora, located in Sydney's south west. It should be noted that the Chullora monitoring station is located in within Sydney's south west and is surrounded by industry, residential areas and heavily trafficked roads, consequently the background SO_2 and CO concentrations used in this assessment are considered conservative as the proposed development site is situated away from such sources. Whilst the incorporation of these data is unsuitable for predicting the actual scale of cumulative air quality impacts of the proposed Facility, it is conservative, and appropriate for the purposes of this assessment in demonstrating compliance with regulatory criteria.

3.3.3 Estimation of pollutant concentrations for averaging periods less than 1 hour

Where pollutant concentrations were required to be assessed for averaging times less than one hour, namely for sulphur dioxide and carbon monoxide, **Equation 1** was used (Victorian EPA, 2005).

$$C_t = C_{60}\left[\frac{60}{t}\right]^{0.2} \qquad \text{(Equation 1)}$$

Where:

C_t = concentration of pollutant at time t

C_{60} = concentration of pollutant based on averaging time of 60 minutes;

t = time (in minutes)

3.4 Summary of Background Pollutant Concentrations

The concentrations listed in **Table 3-2** have been incorporated into this assessment for the purpose of estimating cumulative concentrations.

Table 3-2 Summary of Background Pollutant Concentrations

Substance	Averaging Period	Monitoring Source	Background Concentration (µg/m³)	DECCW Criteria (µg/m³)
NO_2	1 hour	Monash, ACT	90[A]	246
	Annual	Monash, ACT	37[A]	62
CO	15 minutes	Chullora, NSW	6270[B]	100,000
	1 hour	Chullora, NSW	4752	30,000
	8 hours	Chullora, NSW	2876	10,000
SO_2	10 minutes	Chullora, NSW	61[B]	712
	1 hour	Chullora, NSW	43	570
	24 hours	Chullora, NSW	11	228
	Annual	Chullora, NSW	3	60
PM_{10}	24 hour	Monash, ACT	45.3	50
	Annual	Monash, ACT	16.9	30
Formaldehyde	1 hour	NA[C]	NA[C]	20

Notes:
A: Values reported in TMS (2007) as ppm have been converted assuming 273K and 1 atm.
B: Sub hourly concentration estimated from peak hourly concentration based on power law discussed in Section 3.3.3.
C: Not Applicable: The *Approved Methods* stipulate that only the incremental impact be evaluated.

- Monash data sourced from: TMS (2007), *The Australian Capital Territory 2006 Ambient Air Quality Report against the Ambient Air Quality National Environment Protection Measure.*
- Chullora data sourced from: DECCW (2007), *National Environmental Protection (Ambient Air Quality) Measure Compliance Report New South Wales.*

4

Assessment Methodology

This section provides detail of the methodologies employed in the AQIA, including dispersion model selection, modelling configurations, assessment scenarios, plume merging and emissions data.

4.1 Dispersion Model

Three dispersion models are generally endorsed by NSW EPA for development approvals, namely AUSPLUME, TAPM and Calpuff. This section provides a background of the model selection process for this assessment.

4.1.1 Plume Behaviour

An open cycle gas turbine plume differs to those from other large scale power generation technologies, in that the plume also contains the waste heat from the power cycle, thus making the emissions more buoyant than those from other technologies. For example, around five times more waste heat will be emitted from an open cycle turbine exhaust, than would be emitted from the boiler stack of a steam power plant of the same electrical generating capacity[2], in which the vast majority of waste heat would be emitted separately via cooling towers. Subsequently, buoyancy flux, which is the dominant parameter in the estimation of plume rise, and is linearly related to the rate of heat emissions, is also significantly higher for these plumes. When coupled with the scale of the proposed facility, this implies that the turbine emissions are amongst the most buoyant of industrial emissions which are assessed using dispersion modelling. In addition, open cycle gas turbines have high stack exit velocities in the vicinity of 40 m/s (~150km/h). This high velocity affects the behaviour of the plume in the early stages of development, where the high momentum plume constitutes a buoyant jet, which is less prone to near-stack effects such as building downwash and stack tip downwash. These factors mean that emissions from the Facility will rise high up into the atmosphere under a range of meteorological conditions. Consequently, plume transport and dispersion in the upper air is considered to be of high importance to the modelling assessment.

Given the inland location of the Facility and the highly buoyant emissions, the following dispersion mechanisms are considered to be of importance:

- Fumigation of the upper atmosphere in the presence of low wind speeds associated with a high pressure zone / fumigation of a subsidence inversion;
- Inversion breakup fumigation;
- Plume grounding during highly convective conditions; and
- Recirculation of emissions when the atmosphere is stratified.

[2] Based on a comparison provided in the "*Generator Efficiency Standards -Technical Guidelines"* AGO(2006).

4.1.2 Model Selection

Three dispersion models are generally endorsed by DECCW for development approvals, namely Ausplume, TAPM and Calpuff. As identified above, the behaviour of the plumes in the upper atmosphere are considered to be of prime importance. Ausplume was dismissed as a potential model for the following reasons:

- Peak impacts will potentially occur outside of the range at which Ausplume predictions are valid (i.e. > 10km);
- Fumigation impacts (which include the accumulation of pollutants over several hours) are not adequately represented, as emissions are deleted after each hour in Ausplume;
- The treatment of the upper atmosphere is too simplistic in Ausplume where:
  - A single wind direction is used for all levels of the atmosphere;
  - Wind speed increases with height.

More realistic predictions are generally made with the non-steady-state models, which incorporate more sophisticated treatment of dispersion in convective and complex flow conditions.

The TAPM and Calpuff models both incorporate site-specific factors such as terrain influences, regional-scale winds and inversions to predict ground-level concentrations. Given the need to conduct a large range of modelling runs, Calpuff was selected for this assessment.

In Calpuff a plume is modelled as a series of "puffs" that are individually tracked in three dimensions during the modelling run. The use of a puff approach allows the model to incorporate variations in land use, elevation and meteorology throughout the modelling domain, as well as variations in meteorology (e.g. change in wind direction) with time.

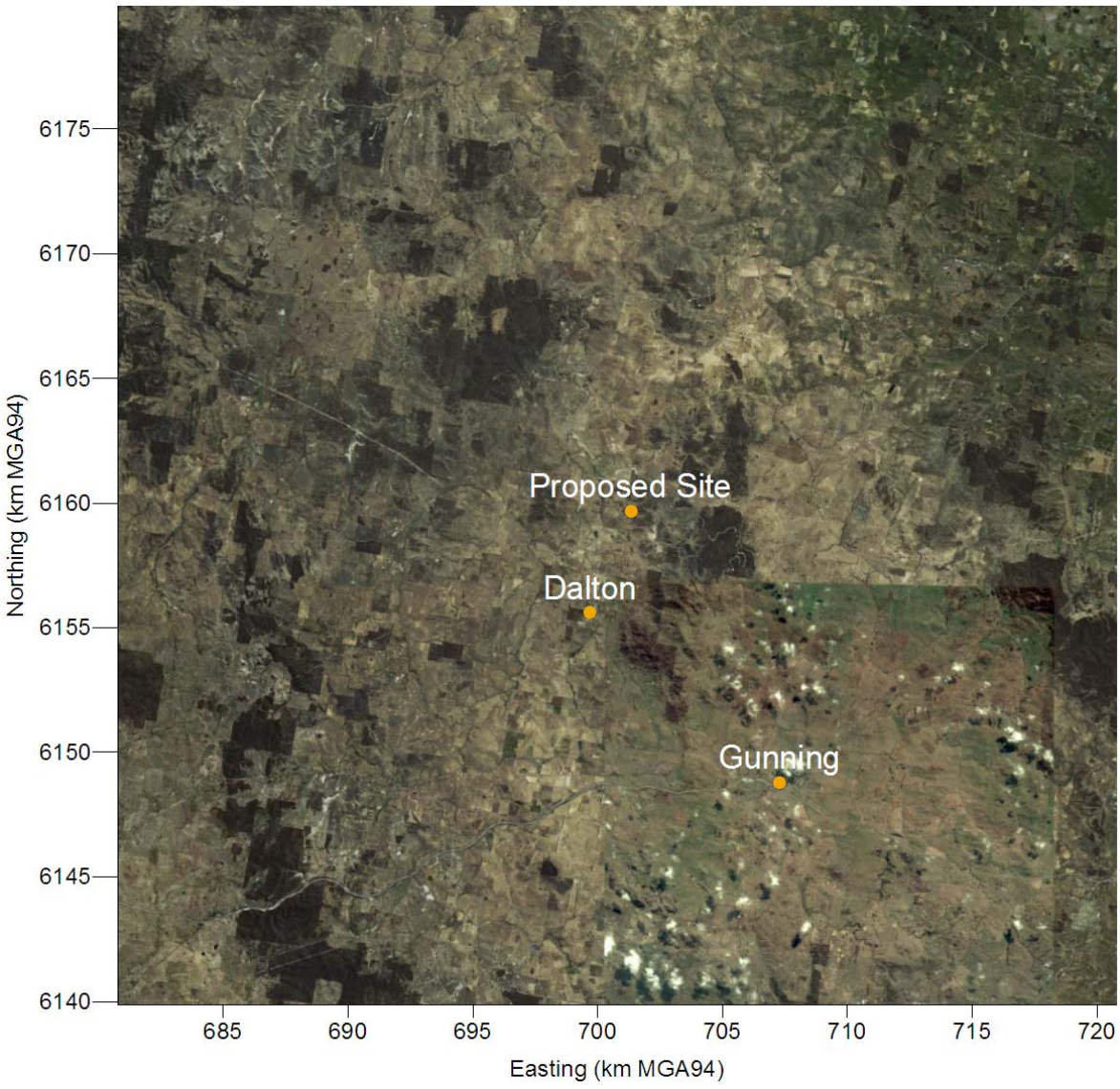
4.2 Model Configuration

This section provides details on the configuration of the dispersion model used to conduct the AQIA.

4.2.1 Modelling Domain

Modelling was performed of a 40 x 40 km modelling domain. From previous modelling assessments of open cycle gas turbine facilities, peak impacts have occurred at a distance of up to 10 km from the emission source. The modelling domain has been selected to include the region where the peak impact might be predicted to occur.

Figure 4-1 Aerial view of calpuff modelling domain showing the site location and nearby townships



(Image sourced from Google Earth Pro)

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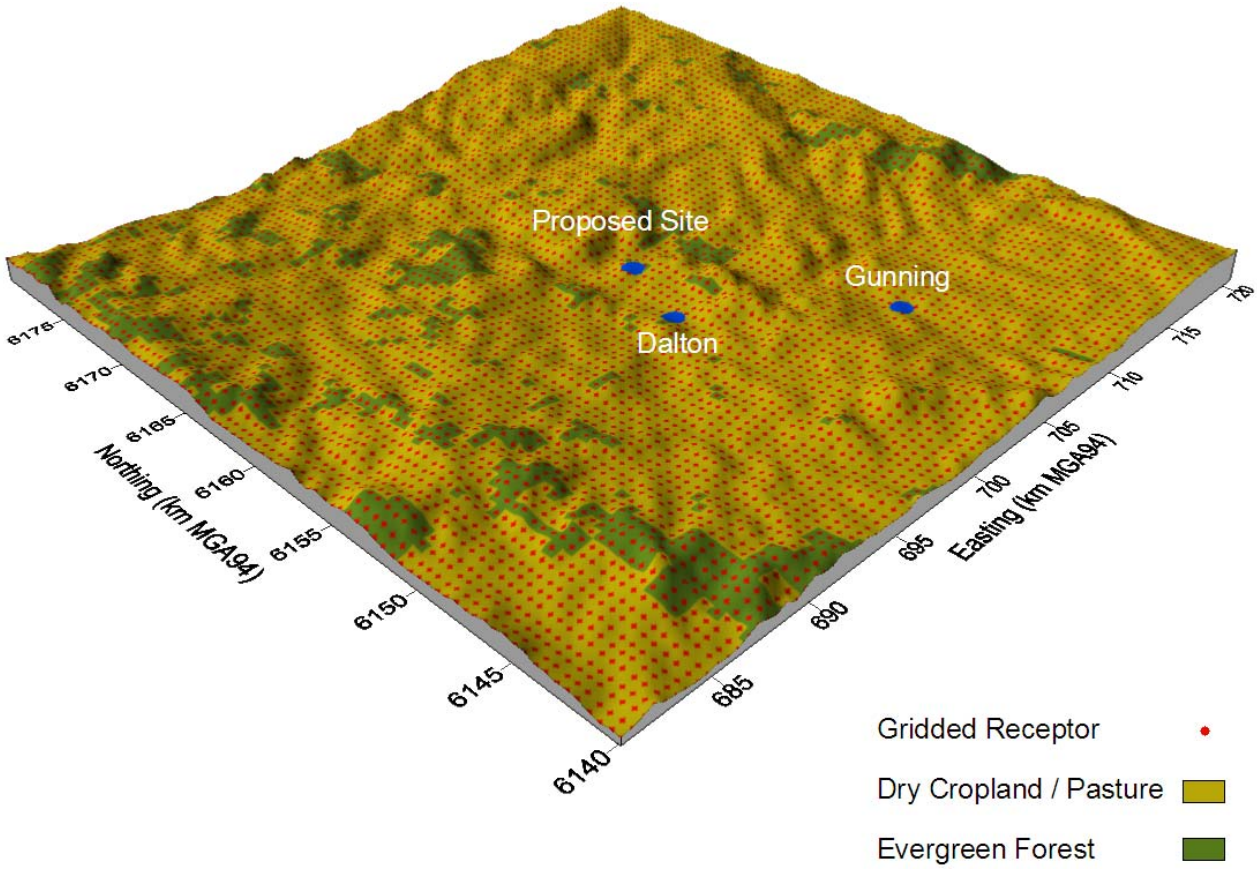
4.2.2 Gridded Receptor Locations

Due to the large 40 x 40 km modelling domain, a grid spacing was of 500m was used, which consists of 81 x 81 gridded receptor points. A visualisation of the dispersion modelling grid is shown in **Figure 4-2**, which incorporates terrain features and land use categories.

Figure 4-2 Calpuff modelling domain showing gridded receptors, land use type and terrain features



4.2.3 Building Wake Effects

Due to the high amount of momentum flux in the early stages of plume development as well as the lack of buildings within proximity to the development, building wake effects are considered to be negligible and have not been incorporated into the model.

4.2.4 Plume Merging

The proposed plant consists of a single line of turbine exhaust stacks located at a distance of around 50m from one another. Each of these stacks vent approximately 1100 m^3/s (E Class) and 1700 m^3/s (F Class) of exhaust gases at a speed of around 150 km/h, and a temperature of around 500 to 600ºC. During the operation of multiple turbine units, plumes from adjacent stacks will merge, resulting in enhanced plume rise, where once merged, the increased ratio of plume volume to entrainment area acts to increase the effect of the buoyancy flux to accelerate the plume, resulting in greater plume rise.

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Given the potential mechanisms under which peak impacts are expected to occur (see **Section 4.1.1**), this effect is considered important, as it ultimately defines how high emissions rise into the atmosphere, and subsequently which direction, and at what rate these emissions are transported. Steady-state Gaussian dispersion modelling approaches typically ignore plume merging on the basis that the associated underestimation of net buoyancy flux is considered conservative for the purpose of estimating ground level concentrations. This is due to the use of winds that are composed of a single wind direction, with speed that increases with height according to a power law. Given the desire to investigate potential fumigation events in the upper atmosphere, underestimation of buoyancy flux is not considered conservative for this assessment. Hence this assessment has incorporated the approach of Briggs (1975) in order to estimate the degree of plume merging that occurs for each hour of each model run, and subsequently allow the enhancement in plume rise to be incorporated into the dispersion model. Further discussion of this methodology is provided in **Appendix D**.

4.2.5 Summary of Model Setup

Further presentation and analysis of the TAPM and Calmet meteorological modelling is included in **Appendix A**.

TAPM (Meteorological Model)

TAPM Version 4 was configured in accordance with the following:

- 4 modelling grids (at 30, 10, 3 and 1km resolution), 31 x 31 grid points, with 25 vertical levels;
- Grid centre coordinates: 149º11’30’’E, -34º41’00’’S, (MGA94: 94700778 mE, 6159887 mN);
- Assimilation of meteorological data from Goulburn Airport Automatic Weather Station on a 60 km radius of influence, configured to affect the two lowest vertical levels (10 and 25m);
- Data exported at grid centre as surface and upper air files for incorporation into Calmet;

Calmet (Meteorological pre-processor for Calpuff)

Calmet V6.326 was configured as detailed below:

- 81 x 81 grid points at 500 m resolution;
- Grid origin: 680.528 kmE 6139.637 kmN MGA, Zone 55 (South)
- Terrain information sourced from the USGS 3 second (~90 m) terrain database;
- Land use data manually generated from aerial photography;
- 12 cell face levels at 0, 20, 40, 60, 80, 100, 140 180, 260, 400, 500, 1500, 3000 mAGL;
- Temperature from surface and upper air stations;
- Diagnostic wind module used:
  - No Surface wind extrapolation;
  - Horizontally and vertically varying winds with divergence minimisation. Froude number adjustment and slope flows incorporated with a terrain radius of influence (TERRAD) of 2km; and
  - No calculation of kinematic effects.

Further presentation and analysis of the meteorological modelling is included in **Appendix A**.

Calpuff (Dispersion Module)

Calpuff V6.263 was configured as detailed below:

- 81 x 81 gridded receptors at 500 m resolution;
- Inversion strength computed from temperature gradients ;
- Transitional plume rise modelled;
- Stack tip downwash was included;
- Briggs rise for point sources not subject to downwash;
- Partial plume penetration of elevated inversions was used;
- Terrain effects were incorporated using the partial plume adjustment method;
- ISC rural wind speed profile was used; and
- Pasquill Gifford dispersion coefficients were used.

4.3 Emissions During Construction

The construction phase is anticipated to take approximately 18 months and will involve the construction of concrete footings for the generator units, the formation of unsealed site roads, installation of the turbine units, construction of a switchyard and transmission connection, installation of the gas pipeline and gas receiving station, fencing, commissioning and other minor works.

During the construction phase, there is the potential for dust to be generated due to the excavation and handling of soils, site grading activities and vehicles movements. Given the undeveloped nature of the site, there is considered to be no significant potential for any dust emissions from construction activities to contain contaminants, or for the works to give rise to odorous emissions, consequently emissions during construction have not been quantified.

The distance to the nearest residential dwelling is approximately 2 km, which is considered to provide a sufficient buffer zone between the main work area to prevent nuisance dust impacts. The minimisation and control of dust emissions during the construction period will be implemented using procedures contained in the Construction Environmental Management Plan (CEMP) for the Project.

4.4 Emissions During Operation

This section of the report details the emission scenarios and emission parameters that were used in the atmospheric dispersion modelling in this assessment.

4.4.1 Assessment Scenarios

This assessment has considered a total of eight scenarios. These are:

- Stage 1, E Class Plant, Startup;
- Stage 1, E Class Plant, Operation;
- Stage 1, F Class Plant, Startup;
- Stage 1, F Class Plant, Operation;
- Stage 2, E Class Plant, Startup;
- Stage 2, E Class Plant, Operation;
- Stage 2, F Class Plant, Startup; and
- Stage 2, F Class Plant, Operation.

For modelling purposes it has been assumed that all turbines will operate continuously for all hours of the year, under all meteorological conditions. Given the use of a Lagrangian puff model, where emissions from sequential hours are tracked and have the potential to co-contribute to ground level concentrations within a single hour, the assumption of continuous operation is considered conservative, particularly for startup scenarios where, in reality, the Facility will not startup in sequential hours.

4.4.2 Emissions Data Sources

The emissions inventory for this assessment has utilised a combination of data sources which include the following:

- Manufacturers' specifications, guarantees and estimates;
- Emission factors which specify emissions on the basis of fuel consumed; and
- Fuel standards.

Manufacturer's emissions data has been sourced for the following turbine types:

- **E Class Turbine**: Alstom GT13E2 -, Nominal Capacity ~ 160 MW; and
- **F Class Turbine**: General Electric (GE) 9FA -, Nominal Capacity ~ 235 MW.

These two turbine types are considered to be representative of E and F Class technologies (respectively). It should be noted that for the purposes of this assessment, the GE9FA emissions have been scaled upward by 10% in order to allow for the potential installation of F Class units with a capacity of up to 250 MW per turbine unit. Further discussion of emission rates is provided in **Section 4.4.4**.

Oxides of Nitrogen and Carbon Monoxide Emissions

E Class emission rates for NO_x and CO for both startup and operation have been sourced from vendor information as well as information documented in the AQIA for the AGL Leafs Gully Power Project (URS, 2008) which also assessed an E Class turbine. F Class emission rates for NO_x and CO for both startup and operation have been sourced from vendor information. Further information on startup emissions of these compounds is provided in **Appendix B** and **Section 4.4.3**.

Sulphur Dioxide Emissions

Sulphur dioxide emission rates were based on the pipeline limit of 50mg/m^3 as specified in the Australian Standard AS4564 - 2005 concentration 50mg/m^3 (1atm, 15°C), in conjunction with calculated fuel consumption. Despite the lower rate of fuel consumption under startup conditions, it has been assumed that sulphur dioxide emissions are the same under startup, as under operation. The emission calculations for sulphur dioxide are shown in **Appendix B**.

Particulate Matter (PM_{10}) Emissions

PM_{10} emissions have been estimated base on a supplier estimate of 7mg/Nm^3, dry@15%O_2. In the absence of any information on startup emissions of PM_{10} it has been assumed that PM_{10} emissions are the same under startup, as under operation. Given that there is no short term (e.g. 1 hour averaged) criteria for PM_{10}, any short term (15 minute) fluctuations under startup will have minimal contribution to the 24 hour average, and are hence considered to be of little importance. The emission calculations for particulate matter are shown in **Appendix B**.

Formaldehyde Emissions

The method used to calculate formaldehyde emissions during operation was based on the relationship between fuel consumption and emissions provided in the US EPA AP-42 Emissions Factors. Due to the different operating conditions during startup, fuel consumption was not deemed to be an appropriate factor to estimate formaldehyde emissions. The method used to calculate formaldehyde emissions during startup was based on the relationship between Volatile Organic Compounds (VOC) produced during startup and operation for a similar E Class turbine operating on natural gas, as documented in El Segundo Power (ESPII LLC, 2007). **Table A.1.6** of El Segundo Power (2007) states that startup emissions of VOC to be 13.0 lbs per 12 minute event, equating to 65.0 lbs/hr. The normal operation VOC emission rate was stated to be 5.4 lbs/hr, thus giving a surrogate VOC scaling factor of 12.04. This scaling factor of 12.04 was applied to the formaldehyde emission rates calculated for the normal operation scenario to generate formaldehyde emission rates during startup.

The emission calculations for formaldehyde are shown in **Appendix B**.

4.4.3 Turbine Startup

During operation, gas turbine generators are designed to oxidise fuel into carbon dioxide and water in a highly efficient manner with minimal occurrence of incomplete combustion. This differs from the startup period, where lower combustion temperatures and transient changes in combustion parameters increase the amount of incomplete combustion present whilst lower flow rates also impede the stable operation of DLN emission controls. This results in increased emissions of NO_x, CO and HAP's for a short period prior to operation of the turbine.

In general, startup is referred as the period from which the turbine startup sequence is initiated, until the turbine is operating at full load. For the turbine types that AGL are considering, the total start-up sequence takes between 15 and 45 minutes. **Figure 4-3** shows a generic startup sequence for an industrial turbine.

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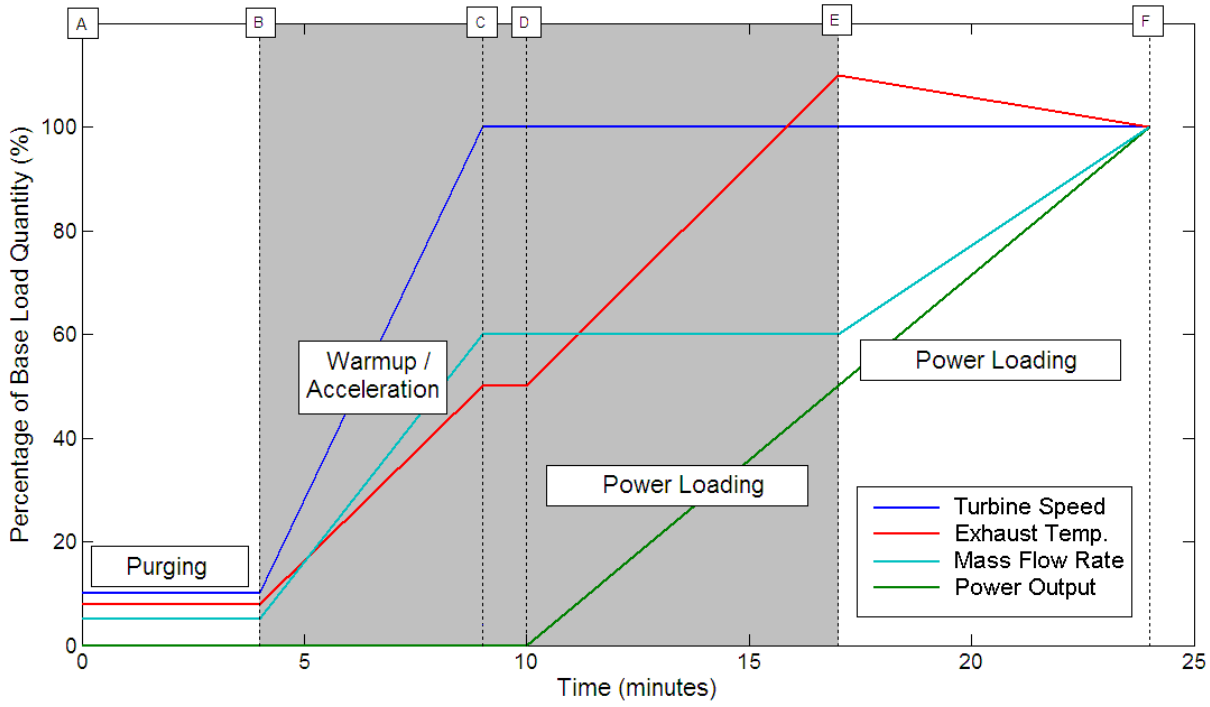
Figure 4-3 Generic Turbine Startup Sequence



To begin the start sequence, the gas turbine generators use an electric starter motor to establish a flow of air through the turbine and to purge the turbine (shown as section A-B in **Figure 4-3**). After this process fuel is introduced into the combustors and ignited with spark plugs (B) and the generator is then run up to 3000 revolutions per minute (rpm) on its own power (B-C) and the starter motor is switched off. At this stage, the unit is synchronised to the electricity grid, thus allowing the export of power (C-D). Fuel flow is further increased (D-F) and the export of power increased until the unit is at operating load (F). For turbines which use DLN emissions controls, at around 50% load (point E), the emission controls become effective, and NO_x, CO and HAP emissions are typical of those that occur under operation.

For the purposes of this assessment, startup has been defined as the period between the ignition, until the point at which emission controls become effective and emissions are representative of those that would occur under normal operation. This period (B-E) is shaded in grey in **Figure 4-3**. Under this definition, for the turbine types that AGL are considering, the start-up sequence takes around 10 to 20 minutes.

Table 4-1 and **Table 4-2** provide details of startup emission quantities for E Class and F Class turbines, respectively.

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Table 4-1 Startup Emissions per Startup Event - E Class

Stage	Sequence	Duration (mins)	NOx (kg)	CO (kg)
Ignition to Full Load	B-F	21	49	659
Operation to Full Load	E-F	6	6	1
Startup	**B-E**	**15**	**43**	**658**

Table 4-2 Startup Emissions per Startup Event - F Class

Stage	Sequence	Duration (mins)	NOx (kg)	CO (kg)
Ignition to Full Speed No Load	B-C	10	12	150
Synchronisation	C-D	1	1	16
No Load to Operation	D-E	5	9	28
Startup	**B-E**	**16**	**22**	**194**

4.4.4 Source Parameters

The Facility will consist of up to six turbine stacks, each separated by a distance of 50 m. **Table 4-3** shows each of the stack locations, as well as which stacks are present for each plant type and stage.

Table 4-3 Gas turbine exhaust stack locations

Stack	Location (MGA94)		Base Elevation (mAHD)	Stage 1		Stage 2	
				E Class	F Class	E Class	F Class
Stack 1	701228 mE	6159700 mN	575	X	X	X	X
Stack 2	701277 mE	6159705 mN	575	X	X	X	X
Stack 3	701326 mE	6159710 mN	575	X	X	X	X
Stack 4	701376 mE	6159716 mN	575	X	-	X	X
Stack 5	701427 mE	6159721 mN	575	-	-	X	X
Stack 6	701475 mE	6159728 mN	575	-	-	X	X

"X" denotes that a turbine is constructed at the location for a given plant configuration

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Table 4-4 shows the emission parameters used in this assessment.

Table 4-4 Gas turbine emission parameters

Parameter	E Class		F Class	
	Startup	Operation	Startup	Operation
Stack Height (m)	35	35	46	46
Stack Diameter (m)	6.0	6.0	6.7	6.7
Exit Temperature (ºC)	365	532	435	610
Exit Velocity (m/s)	20	40	13	45
Duration (min)	15	-	20*	-
Emission Rates (g/s)	Startup	Operation	Startup	Operation
NO_x	48.1	19.3	26.3	30.6
CO	730.7	4.6	179.6	9.1
SO_2	1.3	1.3	2.0	2.0
PM_{10}	3.0	3.0	3.8	3.8
Formaldehyde	1.79	0.15	2.88	0.24

Note: The stack parameters for the F Class startup are the average over a 16 minute startup, however emission rates have been weighted with an additional 4 minutes of operating emissions, such that the net emissions flux is representative of that which would occur over the 20 minutes after ignition.

The modelling of startup scenarios has been performed such that net emissions flux for the Facility includes the startup of each turbine, with subsequent operation of each turbine through the remainder of the hour. This has been achieved by using the parameters in **Table 4-4** and weighting the stack numbers in accordance with the duration of startup. For example, for the Stage 1, E Class plant, a single stack has been modelled as starting up for the entire hour, whilst the other three stacks have been modelled as operational for the entire hour. Under this representation, the net emissions flux is correct, and startup emissions are emitted out of a stack which has parameters equal to those present under startup. The one exception to this rule is the Stage 2, E Class plant, where the Startup emission rates have been re-weighted to a 20 minute startup duration, such that two stacks can be modelled at startup for the entire hour, with the remaining four stacks operational for the entire hour. **Table 4-5** shows the weighting of stacks for each of the startup scenarios.

Table 4-5 Weighting of startup stacks for startup scenarios

Air Impurity	Startup Stacks	Operating Stacks
Stage 1, E Class Plant, Startup	1	3
Stage 1, F Class Plant, Startup	1	2
Stage 2, E Class Plant, Startup	2	4
Stage 2, F Class Plant, Startup	2	4

4.5 Photochemical and Interregional Impacts

Photochemical smog occurs as a result of reactions involving precursor pollutants which include NO_x and non-methane hydrocarbons (NMHCs). These reactions occur on time scales ranging from several hours to several days, and produce compounds which include ozone, nitric oxide, peroxyacetyl nitrate and aldehydes. As part of this process, aerosols are also formed which result in visible orange-brown hazes.

Photochemical smog is typically produced during extended periods of light winds accompanied by higher temperatures and strong sunlight, in places where anthropogenic emissions of precursor pollutants are significant on a regional basis, and where terrain features and/or meteorological patterns promote the trapping or recirculation of pollutants.

The proposed Facility is located around 200 km from Sydney and over 100 km from the south-western extremities of the Sydney airshed[3], in a rural region where there are few significant sources of precursor emissions. In addition, relative to existing power generation in NSW the scale of proposed precursor emission rates are small. For example, it is noted that at peak load, the proposed NO_x emission rates are around 10%-25% of those emitted by a coal-fired power station of the same capacity[4], and the proposed emissions are intermittent unlike those from base load generation.

Given the remote nature of the site, the comparatively small scale of emissions, and the intermittent operation of the facility, the potential for photochemical smog and/or interregional impacts is considered to be negligible. Subsequently no further assessment of these issues has been undertaken.

4.6 NO/NO_2 Conversion Calculations

The emission rates of oxides of nitrogen from the generators are modelled as total NO_X, which includes nitrogen dioxide (NO_2), nitric oxide (NO) and traces of nitrous oxide (N_2O). The principal species of concern, in terms of human health effects, is NO_2 and it is this compound which has relevant ground level guidelines. While NO_2 will only make up a small proportion of the total NO_X emitted by the generators at the point of discharge, the NO_2/NO_x ratio will increase as the plume travels downwind as NO in the plume is oxidised to form additional NO_2.

The *Approved Methods* propose three methods for assessing NO_x impacts, which are listed in order of increasing complexity. A summary of the methods is discussed below.

- **Method 1**: 100% Conversion of NO to NO_2. This method assumes all NO_x emissions are emitted as NO_2 and that the highest recorded background NO_2 level is constant;
- **Method 2**: NO to NO_2 conversion limited by ambient ozone concentration (OLM). This method presumes all available ambient ozone (O_3) will react with NO to form NO_2.
- **Method 3**: NO to NO_2 conversion using empirical relationship. (The Janssen Method). In the paper "*A Classification of NO Oxidation Rates in Power Plant Plumes Based on Atmospheric Conditions*", Janssen et al. (1988) state that more than 95% of the NO_x from plant emissions will be in the form of NO and less than 5% is in the form of NO_2.

In this assessment it has conservatively been assumed that all emitted NO_x exists in the form of NO_2.

[3] As defined in DECC (2009) *Interim DECC Nitrogen Oxide Policy for Cogeneration in Sydney and the Illawarra*, Department of the Environment and Climate Change, February 2009.
[4] See **Appendix B** for a comparison of NO_x emissions from large NSW generators.

5

Results

5.1 Summary of Air Quality Predictions

Table 5-1 provides the results of the dispersion modelling. All predictions were below regulatory criteria. The one result that is shown to be approaching criteria is the Stage 2 F Class operation scenario NO_2 prediction. It should be acknowledged that this result has been calculated in a conservative manner, and had it been found to be above criteria, would have been subject to further level/s of refinement, in accordance with the *Approved Methods*. Further discussion of this result is provided in **Section 5.2.1.**

Contour isopleths for nitrogen dioxide across the modelling domain have been provided in the **Figures** section at the end of this report. Isopleths for other compounds have not been presented due to the low levels predicted.

5.2 Comparison Against Emission Limits

The turbines proposed for the Facility comply with the relevant emission limits specified in the *Protection of the Environment Operations (Clean Air) Regulation 2002*. The proposed use of DLN emission controls guarantee the turbine emissions to less than 25 ppmvd (parts per million volumetric dry) at the 15% oxygen reference condition.

Table 5-1 Proposed in-stack emission limit for oxides of nitrogen

Air Impurity	In-Stack Concentration (mg/m^3 dry, 273K,15%O_2)	Regulatory Limit (Group 6) (mg/m^3 dry, 273K,15%O_2)
Nitrogen dioxide (NO_2) or nitric oxide (NO) or both as NO_2 equivalent	51	70

5 Results

Table 5-1 Summary of maximum dispersion modelling results with comparison against regulatory criteria (All results are in µg/m³)

Substance	Averaging Period	Stage 1				Stage 2				Background	Maximum Cumulative*	DECCW Criteria
		E Class		F Class		E Class		F Class				
		Startup	Operation	Startup	Operation	Startup	Operation	Startup	Operation			
NO_2	1 hour	71.8	87.3	46.5	64.6	96.9	92.0	100.8	150.7	90	240.7	246
	Annual	0.3	0.1	0.2	0.1	0.4	0.2	0.3	0.2	37	37.4	62
CO	15 minute	1439	27	282	25	1717	29	798	59	6270	7987	100,000
	1 hour	1091	21	214	19	1301	22	605	45	4750	6051	30,000
	8 hour	320	5	29	3	420	7	64	8	2880	3300	10,000
SO_2	10 Minute	6.3	8.4	4.4	6.0	6.8	8.9	9.9	14.1	61	75.1	712
	1 hour	4.4	5.9	3.1	4.2	4.8	6.2	6.9	9.8	43	52.8	570
	24 hour	0.4	0.5	0.4	0.2	0.6	0.7	0.7	0.6	11	11.7	228
	Annual	0.01	0.01	0.01	0.01	0.02	0.01	0.02	0.01	3	3.0	60
PM_{10}	24 hour	1.0	1.2	0.8	0.5	1.3	1.6	1.4	1.1	45.3	46.9	50
	Annual	0.03	0.02	0.03	0.01	0.04	0.03	0.05	0.02	16.9	16.9	30
Formaldehyde	1 hour	0.9	0.2	1.5	0.1	1.3	0.20	3.2	0.1	NA	3.2	20

*Cumulative results presented for all compounds except formaldehyde, which has been assessed on an incremental basis in accordance with the *Approved Methods*.

5.3 Discussion of Results

The predicted impact of nitrogen dioxide, carbon monoxide, sulphur dioxide, particulate matter and formaldehyde emissions from the Facility were shown to be below DECCW criteria, hence on the basis of these predictions, no adverse impacts on local air quality are expected as a result of the intermittent discharge of these pollutants from the proposed Facility.

The intent of this document is to investigate the compliance of the proposal with air quality criteria. Whilst assessment methods such adding the 100th percentile background (e.g. the highest hourly background reading recorded for the year) to the peak impact will lead to overestimation of actual impacts, as stipulated by the *Approved Methods*, this is appropriate for the purpose of investigating compliance with regulatory criteria.

5.3.1 Nitrogen Dioxide

The peak all NO_x as NO_2 prediction, when added to the peak NO_2 background from ACT Monash station, was found to be below regulatory criteria. Of the eight scenarios, the Stage 2, F Class Operation scenario was shown to be approaching criteria. The peak impact area was predicted to occur 10 km south south-west of the Facility, as shown in the **Figure 9** of the **Figures** Section. It should be acknowledged that this result has been calculated in accordance with the *Approved Methods* using conservative assumptions, yet ones which are adequate to demonstrate compliance with criteria. Should it have been required, additional refinement in accordance with the *Approved Methods* would potentially include:

- Resolving the amount of NO_X present as NO_2;
- Refinement of background concentration which could include:
  - Analysis of peak results at the Monash monitoring station for external events;
  - Collection of monitoring data that is representative of the modelling region; and
  - Use of a time varying background concentration instead of the annual maximum.

The additional refinement would produce lower concentrations of NO_2, hence show a lesser impact.

5.3.2 Carbon Monoxide, Sulphur Dioxide, Particulate Matter (PM_{10}) and Formaldehyde

The predicted impact of carbon monoxide, sulphur dioxide, particulate matter (PM_{10}) and formaldehyde from the Facility were shown to be below criteria, hence no adverse impacts on local air quality are expected as a result of the intermittent discharge of these pollutants from the proposed peaking power plant.

6

Conclusions

The potential air quality impact of the Dalton Power Project has been assessed using the Calpuff dispersion modelling package. The pollutants assessed included nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), particulate matter (PM_{10}) and formaldehyde. The dispersion modelling has used a largely conservative approach, in accordance with the DEC (2005) *Approved Methods and Guidance for the Modelling and Assessment of Air Pollutants in NSW*. In order to assess the cumulative impact of the plant emissions on the local air quality, background concentrations of the criteria pollutants were obtained from the relevant DECCW and TMS monitoring stations.

The results of the dispersion modelling showed that the predicted impacts on ground level concentrations of NO_2, PM_{10}, CO and SO_2, when added to peak background concentrations, were within the DECCW regulatory criteria. In addition, the predicted incremental concentrations of formaldehyde were found to be within DECCW criteria. This analysis has also assumed that all oxides of nitrogen (NO_x) exist as nitrogen dioxide.

7

References

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8

Limitations

URS Australia Pty Ltd (URS) has prepared this report in accordance with the usual care and thoroughness of the consulting profession for the use of AGL Pty Ltd and only those third parties who have been authorised in writing by URS to rely on the report. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report. It is prepared in accordance with the scope of work and for the purpose outlined in the Proposal dated 19th December, 2008.

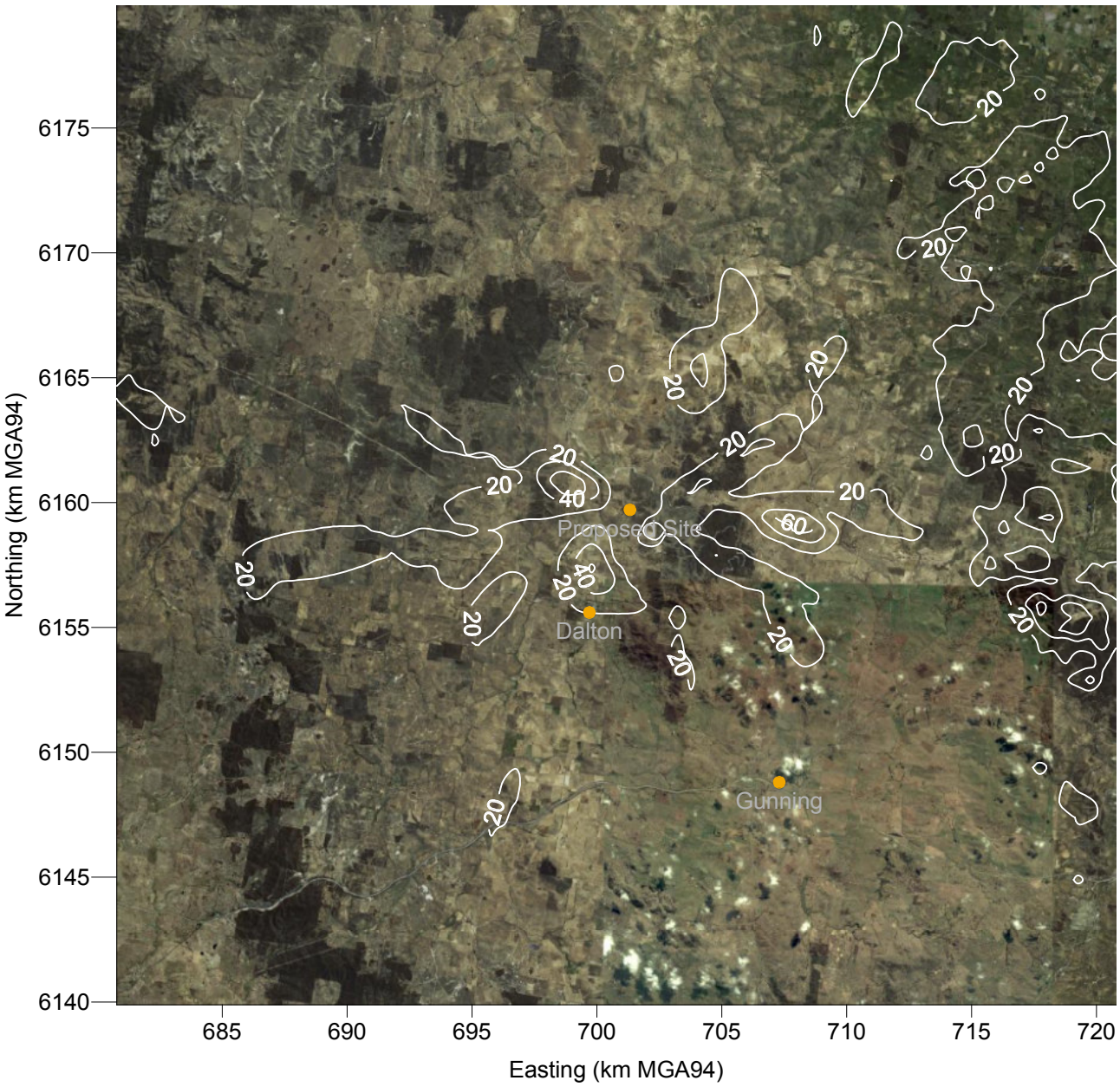
The methodology adopted and sources of information used by URS are outlined in this report. URS has made no independent verification of this information beyond the agreed scope of works and URS assumes no responsibility for any inaccuracies or omissions. No indications were found during our investigations that information contained in this report as provided to URS was false.

This report was prepared between March and October 2009, and is based on the conditions encountered and information reviewed at the time of preparation. URS disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

9

Figures



Maximum Incremental Impact Shown
Contours in µg/m^3
(Image sourced from GoogleEarth)

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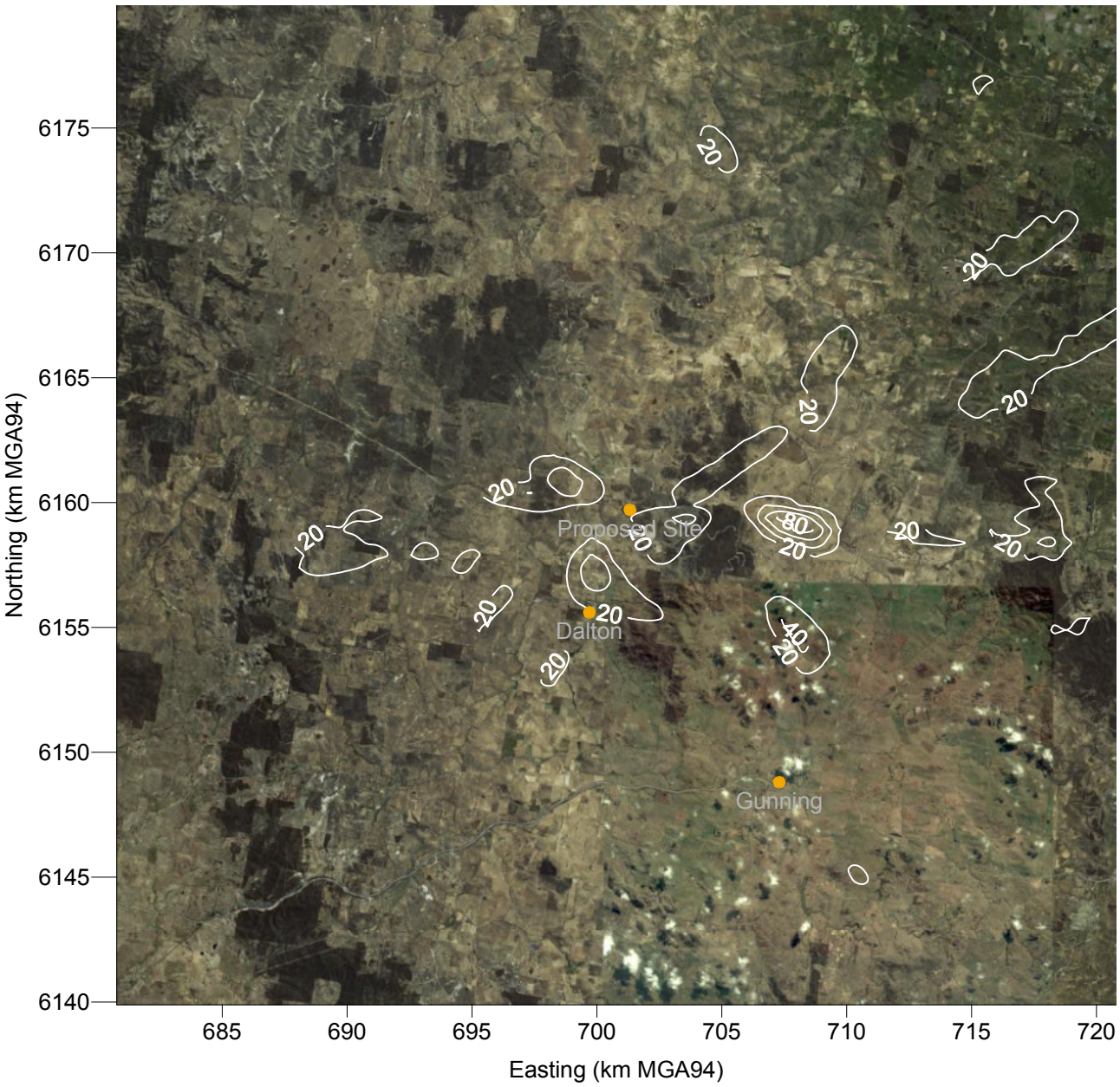

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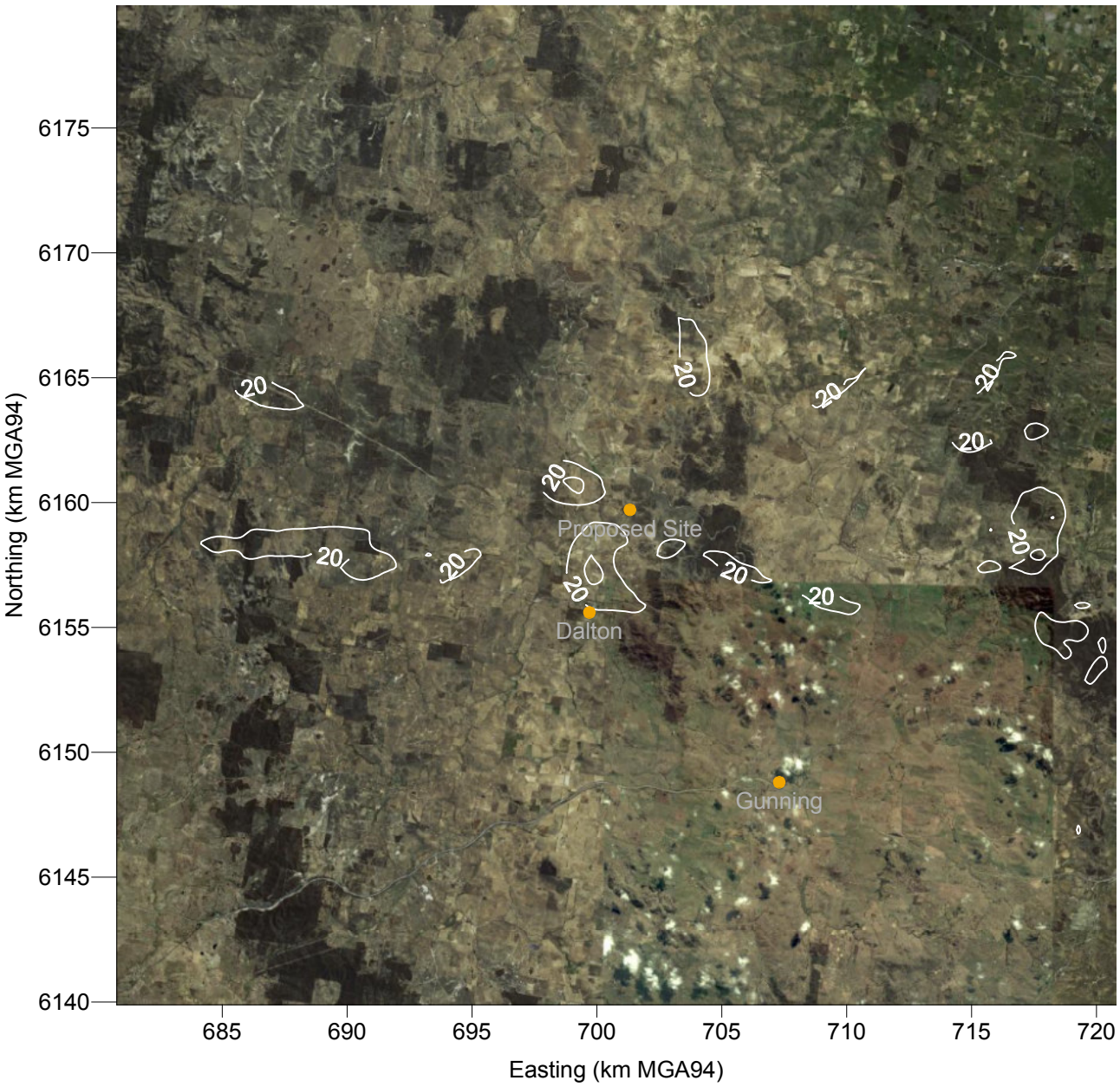

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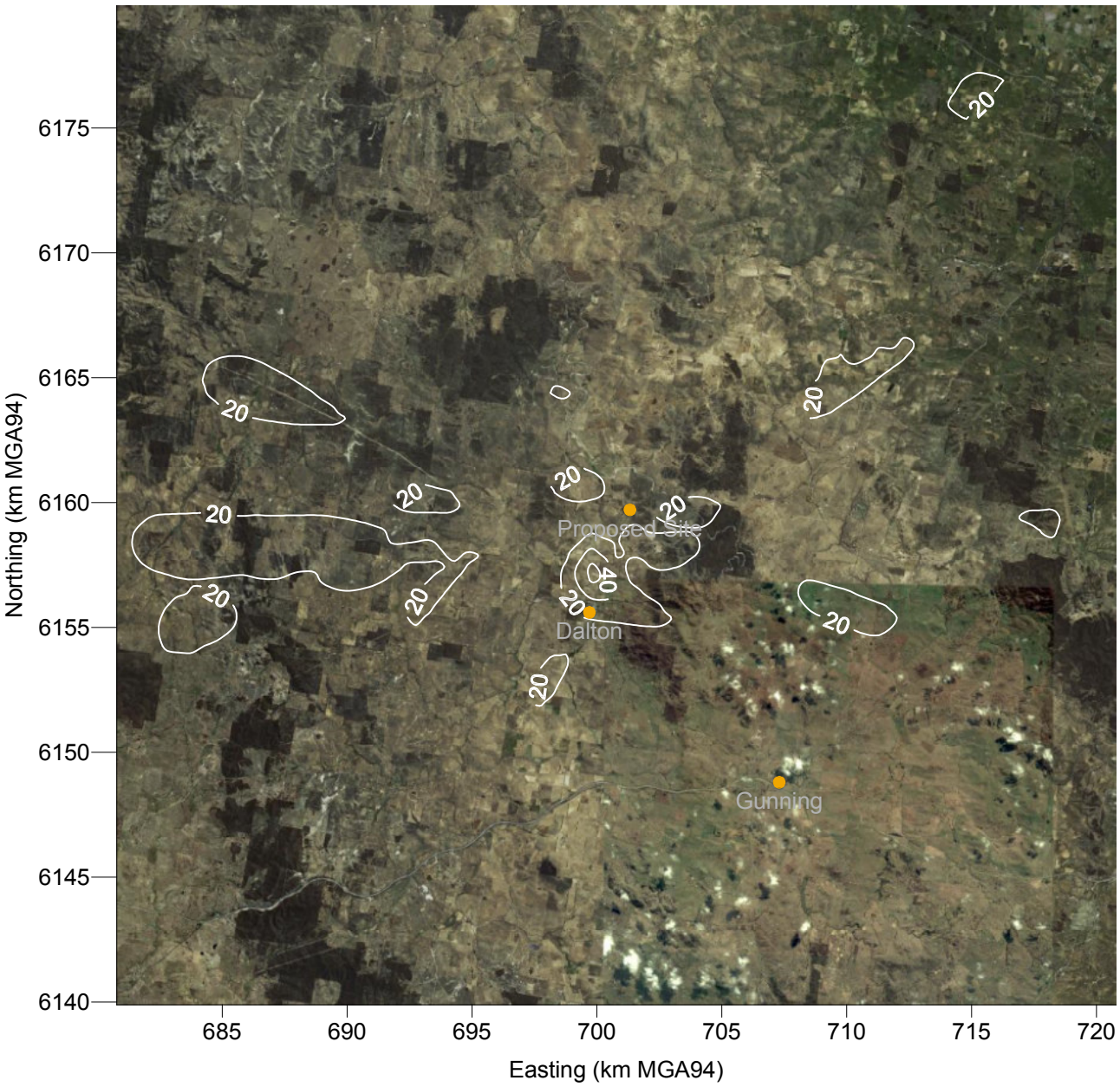

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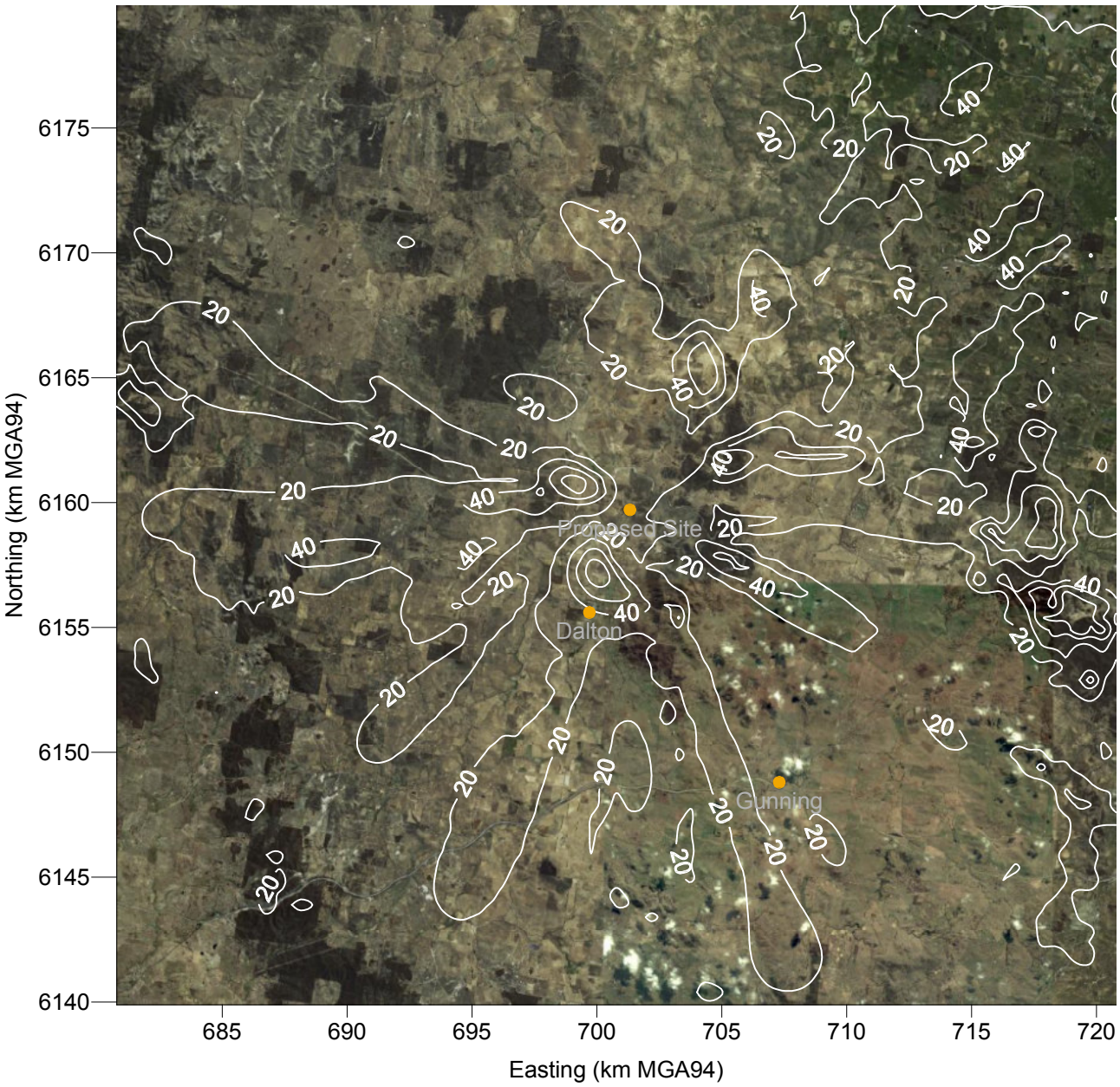

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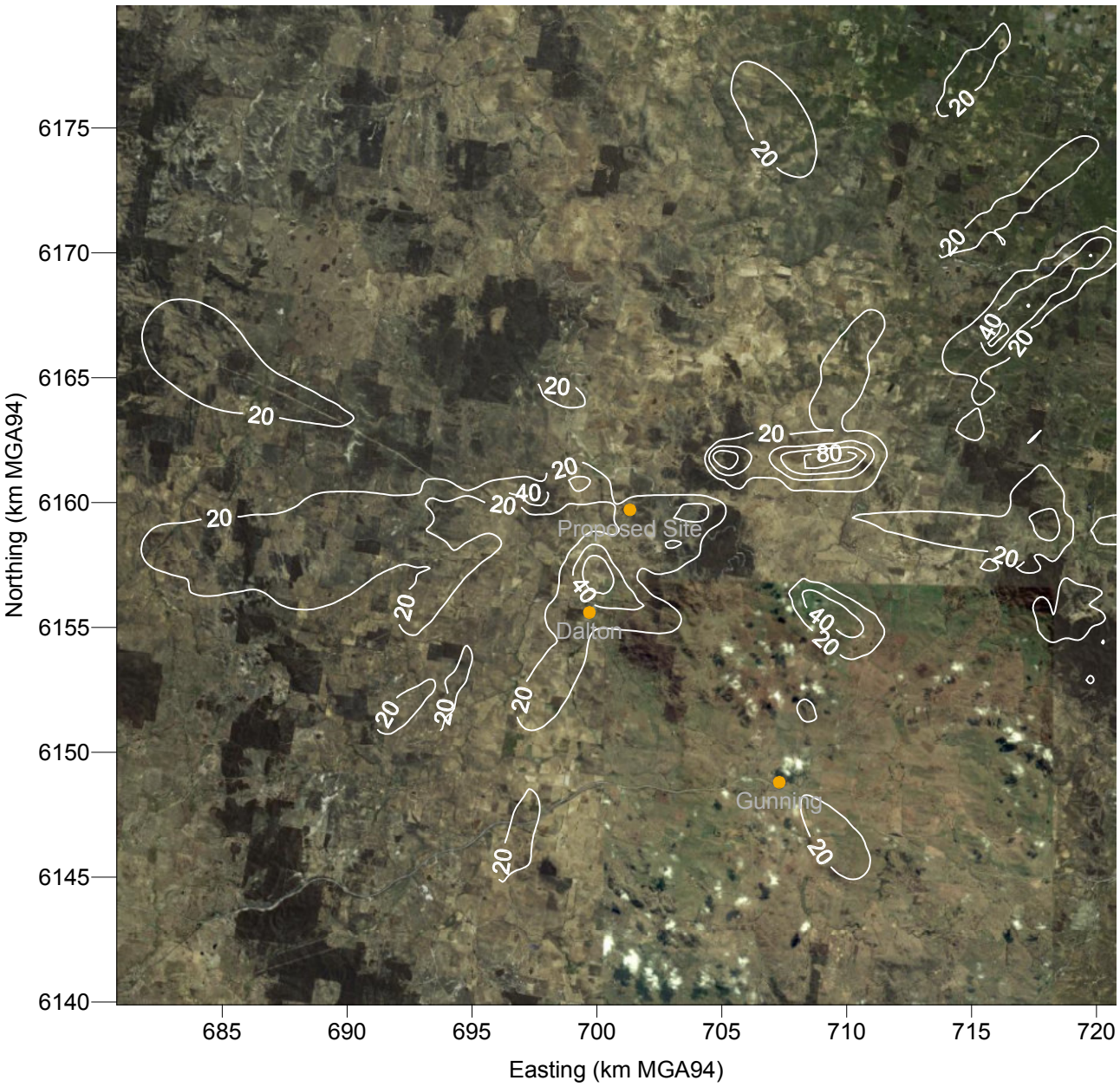

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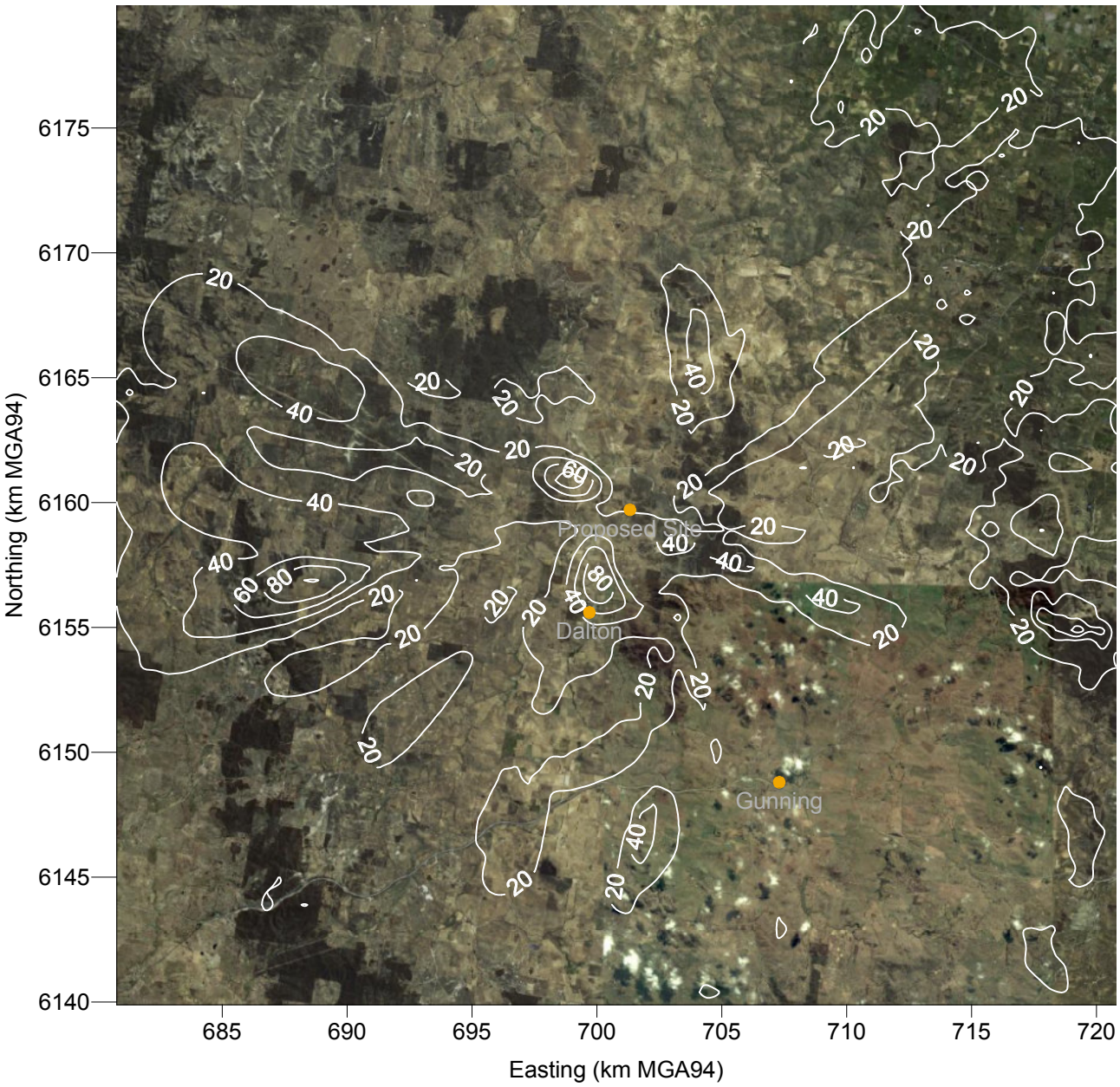

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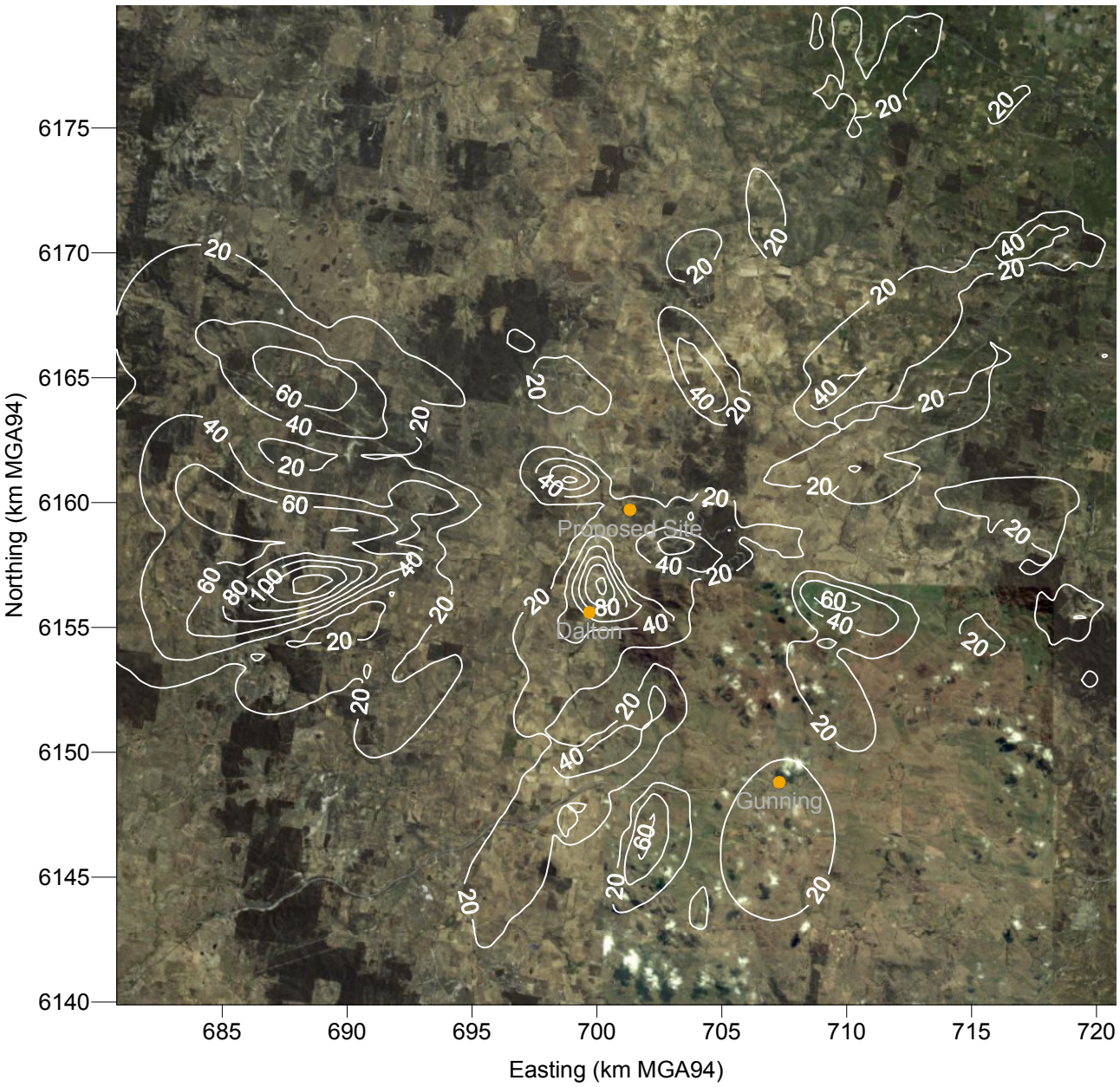

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Contours in µg/m^3
(Image sourced from GoogleEarth)

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URS	Drawn: SWB | Approved: DRAFT | Date: November 2009	Figure: 8 | Rev: A
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A

Appendix A Meteorological Data Discussion

Appendix A

A.1 Assessment of Meteorological Data 2001 - 2006

The meteorological data needed for dispersion modelling is required to be site representative. As URS is not aware of meteorological data being collected on site, the closest weather stations were assessed. The closest weather station sites were found to be the Goulburn Airport (50 km south-south-east of the site) and Yass (30km south west of the site).

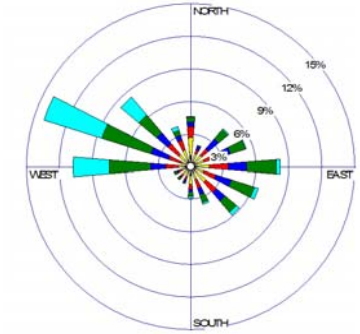
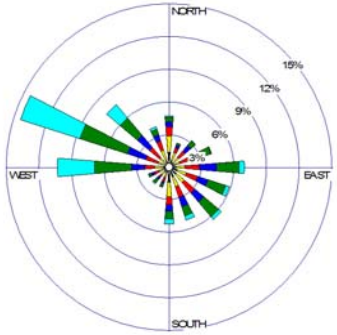
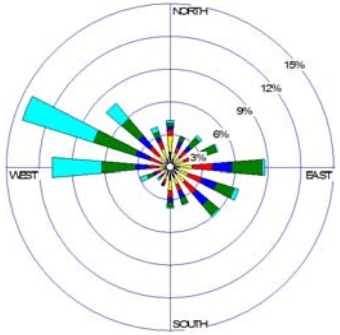
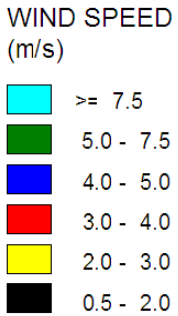
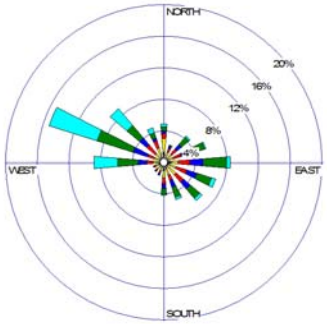
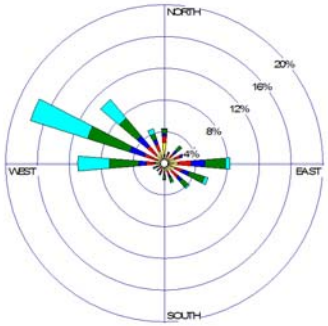
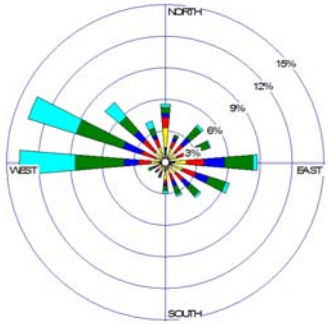
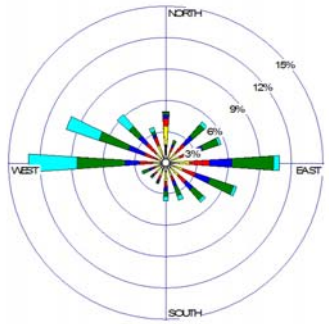
Given that Yass weather station only reports wind at 9am and 3pm, URS examined six years from Goulburn Airport which reports hourly. Goulburn was used for comparison against synthetic TAPM meteorological data compiled for the project site.

This methodology is consistent with the requirements contained in DEC (2005) *Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales.* The Goulburn Airport wind roses for 2000–2006 (inclusive) are shown in **Figure A-1**. The wind roses for the individual years appear to be fairly consistent, showing winds from the west and north-west to be dominant. The average wind speed showed little difference from year to year, with a range between 4.02 m/s in 2001 to 4.39 m/s in 2003. Similarly, the calms showed minor variation, ranging from 9.63% in 2003 to 15.46% in 2004. The most recent year, 2006, is consistent with other years and does not show anomalous patterns in terms of wind directions or average wind speeds.

When generating site representative metrological files for use in the dispersion models, it is preferred to incorporate data from local meteorological stations. Given the distance of the Goulburn AWS from the site direct incorporation into dispersion modelling was considered unsuitable. However, the Goulburn data was utilised in the TAPM meteorological modelling to allow a synthetic met file to be developed that included correlation with observed weather conditions.

Appendix A

Figure A-1 Goulburn Airport Windroses 2000 – 2006

2000	2001	2002	
Average wind speed: 4.06 m/s Calms: 14.26 %	Average wind speed: 4.02 m/s Calms: 13.83 %	Average wind speed: 4.28 m/s Calms: 12.57 %	
			
2003	**2004**	**2005**	**2006**
Average wind speed: 4.39 m/s Calms: 9.63 %	Average wind speed: 4.35 m/s Calms: 15.46 %	Average wind speed: 4.22 m/s Calms: 13.01 %	Average wind speed: 4.09m/s Calms 11.88%
			

A.2 Meteorological modelling

The meteorology used in the dispersion modelling was generated with the inclusion of weather observations at Goulburn for 2006. The CSIRO's prognostic meteorological model TAPM was used to prepare the surface data available given the absence of suitable AWS in proximity to the site.

A.2.1 TAPM

The Air Pollution Model (TAPM) was utilised to create site specific surface meteorological and upper air files for use in CALMET. TAPM Version 4 was run to generate the meteorology for use in the dispersion modelling. TAPM has been identified as a suitable model of choice to simulate meteorological fields in a number of situations[5].

TAPM is an incompressible, non-hydrostatic, primitive equation model with a terrain-following vertical co-ordinate for three-dimensional simulations. It includes parameterisations for cloud/rain micro-physical processes, turbulence closure, urban/vegetative canopy and soil, and radiative fluxes.

TAPM, with the use of the input databases provided by CSIRO, was used to generate a meteorological dataset for the year 2006 based on actual synoptic data. The following TAPM settings and input files were used to generate the meteorological file for the Dalton site for the year 2006. TAPM was configured as detailed below:

- Grid centre coordinates 149º11'30''E, -34º41'00''S, (MGA94: 94700778 mE, 6159887 mN);
- Meteorological grid consisting of four nests of 31 x 31 grid points at 30, 10, 3, and 1km spacing, with 25 vertical grid levels from 10 to 8000 m;
- Terrain at 9 arc-second (approximately 270m) resolution from the Geoscience Australia terrain database. Land characterisation data at approximately 1km resolution, sourced from the US geological Survey, Earth Resources Observation System (EROS) Data Centre Distributed Active Archive Centre (EDC DAAC). Sea surface temperature data at 100 km grid intervals from the US National Centre for Atmospheric Research (NCAR);
- Six hourly synoptic scale meteorology from the BoM on a 75 to 100 km grid. This data is derived from the BoM LAPS (Limited Area Prediction System) output;
- Wind data assimilation was used with the model configured to utilise Goulburn Airport AWS data to influence meteorological conditions affect the two lowest vertical levels (10 and 25m) on a radius of influence of 60 km (AWS Location: 749839mE, 6144793mN, MGA94, Zone 55); and
- Data was exported at grid centre as surface and upper air files for incorporation into Calmet.

[5] CSIRO (2005). *The Air Pollution Model (TAPM) Version 3. Part 2: Summary of Some Verification Studies. CSIRO Atmospheric Research Technical Paper 72*, 2005.

Appendix A

A.2.2 Calmet

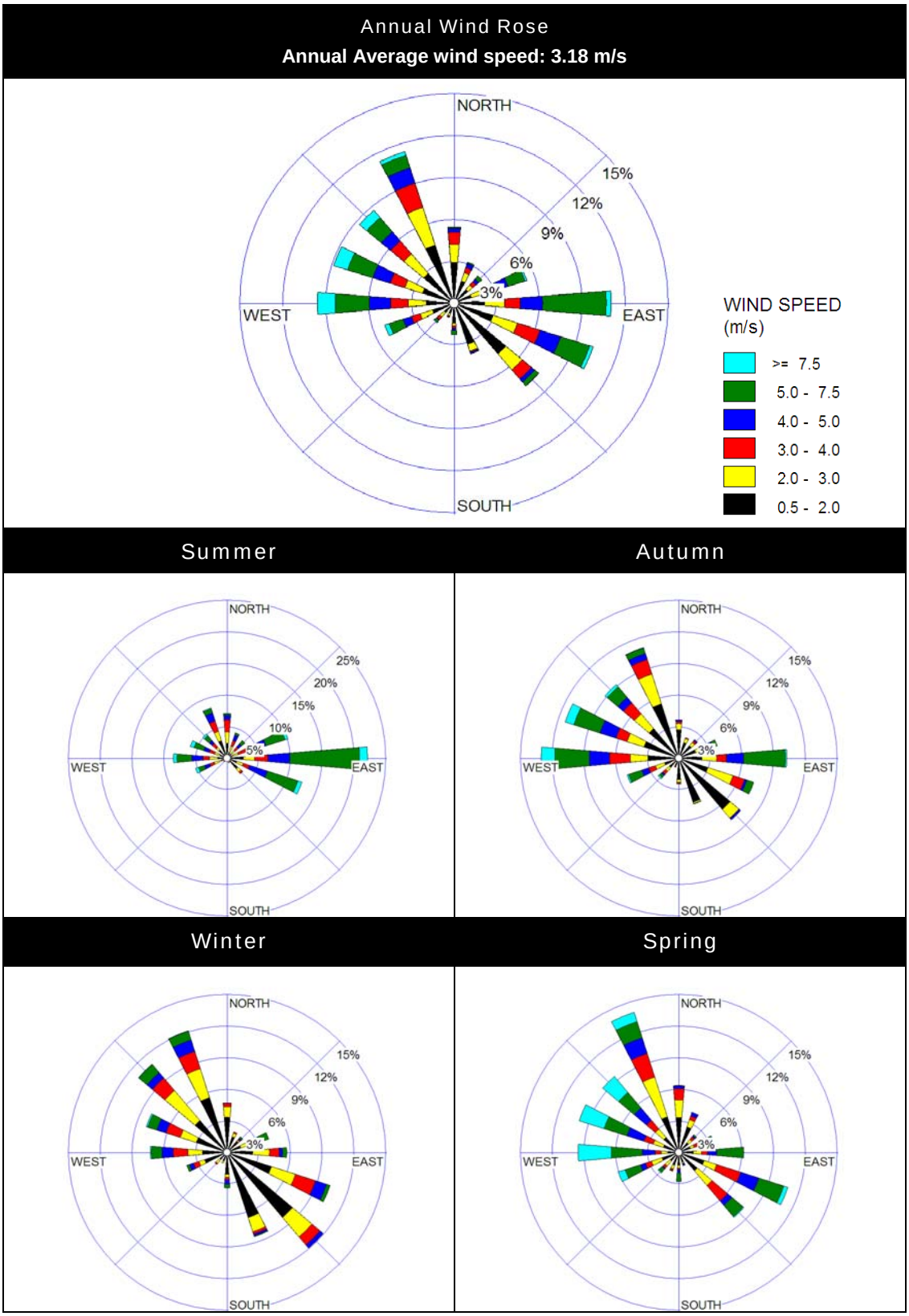
Calmet is a three dimensional meteorological simulation package included within the Calpuff suite of programs. Calmet predicts three dimensional wind profiles and atmospheric parameters for use in predicting dispersion conditions through Calpuff. Surface and upper air files generated by TAPM were used in predicting wind profiles over the modelling domain with Calmet. Calmet was configured as detailed below:

- 81 x 81 grid points at 500 m resolution;
- Grid origin: 680.528 kmE 6139.637 kmN MGA, Zone 55 (South)
- Terrain information sourced from the USGS 3 second (~90 m) terrain database;
- Land use data manually generated from aerial photography;
- 12 cell face levels at 0, 20, 40, 60, 80, 100, 140 180, 260, 400, 500, 1500, 3000 m above ground level;
- Temperature from surface and upper air stations;
- Diagnostic wind module used:
    - No Surface wind extrapolation;
    - Horizontally and vertically varying winds with divergence minimisation. Froude number adjustment and slope flows incorporated with a terrain radius of influence (TERRAD) of 2km;
    - No calculation of kinematic effects;

A.3 Results

The annual and seasonal windroses for the Calmet generated meteorological data are provided in **Figure A-2**. These wind roses show the dominance of winds from the north-west and south-east. Summer shows winds to be primarily from the east, with autumn and winter showing a distinct westerly and south easterly component. Spring, however, shows the presence of a more uniform spread of winds, however, the dominance of westerly winds is still present.

Figure A-2 Annual and Seasonal Calmet generated wind roses for the Project Site in 2006.

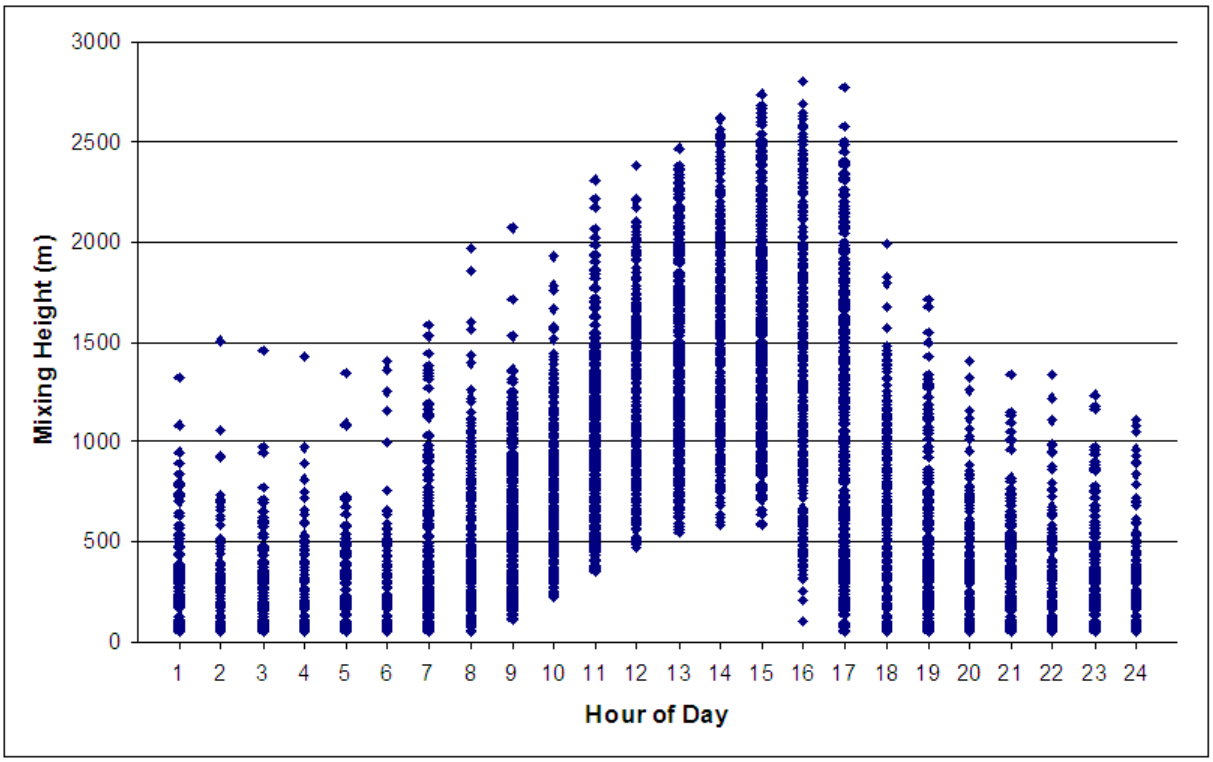


Appendix A

A.4 Mixing Height

Figure A-3 shows the mixing height against the hour of the day as generated by Calmet. The figure shows that the predicted mixing height increases with increasing solar radiation as a function of time of day. This is consistent with general atmospheric processes that show increased vertical mixing during the daytime associated with the increasing thermal radiation. Night time conditions are cooler, more stable and, as expected, winds are generally lighter thus vertical mixing is reduced leading to a lower mixing height.

Figure A-3: Calmet Generated Mixing Height vs Hour of Day



A.5 Atmospheric Stability

Stability class is used as an indicator of atmospheric turbulence for use in meteorological models. The class of atmospheric stability generally used in these types of assessments is based on the Pasquill-Gifford-Turner scheme where six categories are used (A to F) which represent atmospheric stability from extremely unstable to moderately stable conditions. The stability class of the atmosphere is based on three main characteristics, these being:

- Static stability (vertical temperature profile/structure);
- Convective turbulence (caused by radiative heating of the ground); and
- Mechanical turbulence (caused by surface roughness).

The Pasquill Gifford Stability classes are provided in **Table A-1**.

The stability classes for the site have been extracted from the TAPM generated meteorological file and are shown in **Table A-2**.

Table A-9-1 Modified Pasquill-Gifford Stability Classes (adapted from Turner, 1994[6])

Surface Wind Speed at 10m (m/s)	Insolation			Night-time cloud (Oktas)	
	Strong	Moderate	Slight	Thinly overcast of > 4/8 low cloud	< 3/8 Cloud
≤ 2	A	A-B	B	-	-
2 - 3	A-B	B	C	E	F
3 - 5	B	B-C	C	D	E
5 - 6	C	C-D	D	D	D
> 6	C	D	D	D	D

The Pasquill Gifford Stability Classes, shown in **Table A-2** shows moderately stable atmospheric conditions (Stability Class D) is the most prevalent Stability Class of the area, with the Extremely Unstable conditions (Stability Class A) being the least prevalent.

Table A-2: Site Representative Pasquill-Gifford Stability Classes

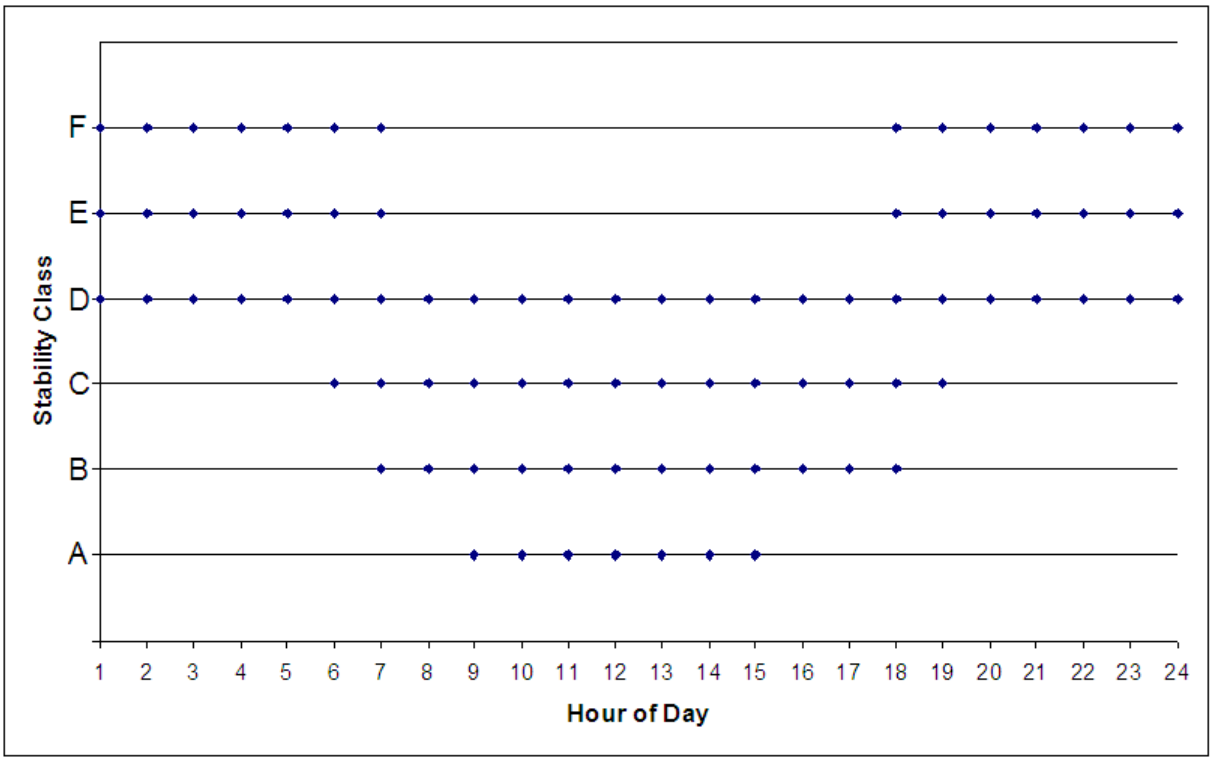
Stability Class	Frequency
A (Extremely Unstable)	1.2%
B (Moderately Unstable)	11.2%
C (Slightly Unstable)	20.2%
D (neutral)	20.2%
E (Slightly Stable)	8.0%
F (Moderately Stable)	39.2%

[6] Turner B (1994) *Workbook of Atmospheric Dispersion Estimates: An Introduction to Dispersion Modelling.* 2nd Edition. CRC Press Inc.

Appendix A

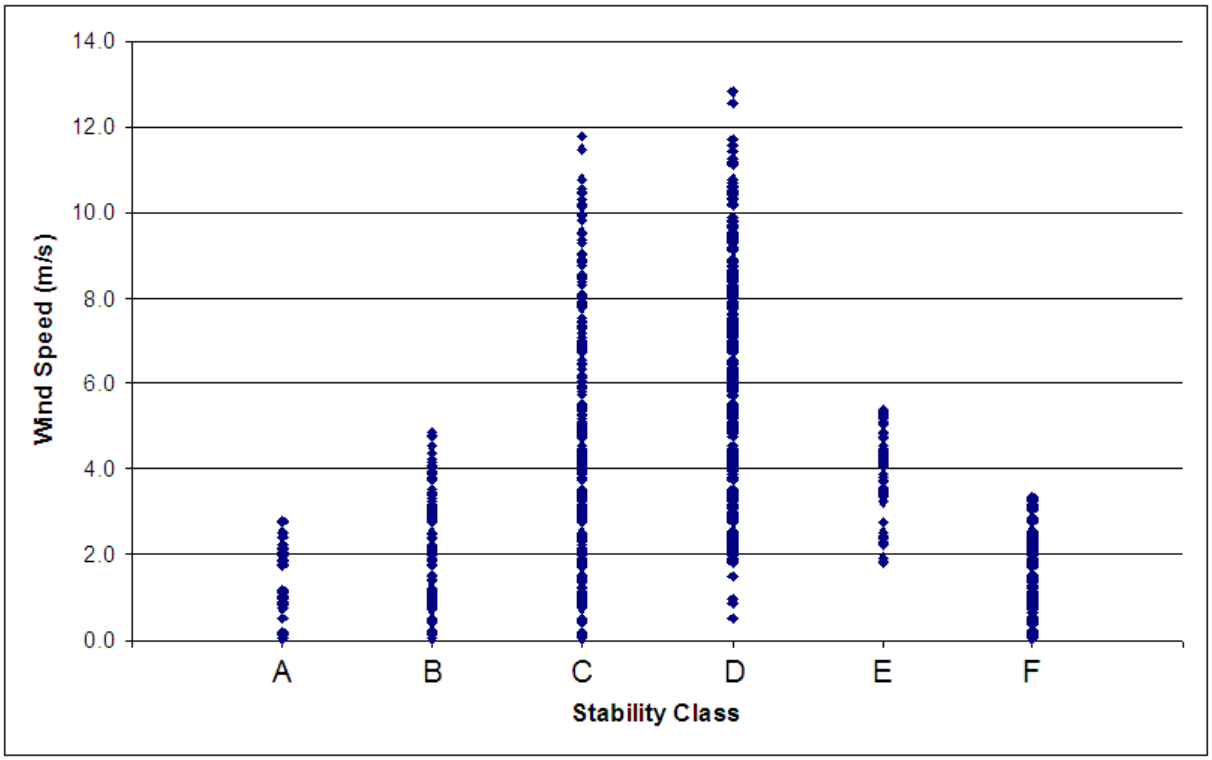
In addition to their composition, Stability Classes were also predicted as a function of time of day, as shown in **Figure A-4**. As expected, there is a tendency for the unstable classes (Stability Classes A, B and C) to occur during daytime, whilst the more stable conditions (Stability Classes D,E and F) are shown to occur primarily during night time. This is consistent with the values contained in **Table A-2**.

Figure A-4: Calmet Generated Stability Class vs Hour of Day



Stability Classes were also plotted against wind speed, as shown in **Figure A5**. As expected, the highest wind speeds are associated with stable or neutral stability classes (Stability Classes C and D). The more unstable conditions (Stability Classes A and B) have lower wind speeds due to vertical mixing, and the more stable conditions (Stability Classes E and F) also have low wind speeds as a result of stable night time atmospheric conditions. These data are consistent with the values contained in **Table-A2.**

Figure A-5: Calmet generated wind speed vs stability class



A.6 Conclusion

Where site specific meteorological data does not exist, as is the case for the Dalton Power Project, the predicted meteorological data used in the dispersion modelling is required to be representative of the surrounding area. It is accepted standard Australian practice, that in situations where adequate site-specific meteorological data does not exist, local meteorological station data can be incorporated into TAPM to synthetically generate meteorological data. Meteorological data for the Goulburn Airport AWS for the year 2006 was incorporated into the TAPM run. TAPM is a sophisticated, 3D meteorological model that has been extensively validated and is considered appropriate for this purpose.

The assessment of the predicted meteorology at the Site was discussed and was shown to be consistent with general atmospheric parameters. It is therefore considered that the meteorological data used in dispersion modelling is appropriate.

B

Appendix B Stack Emissions Calculations

Appendix B

Sulphur Dioxide

Sulphur dioxide emissions were calculated from fuel consumption and the Australian Standard specification for general purpose natural gas. **Table B-1** presents fuel properties and **Table B-2** presents the emission calculations.

Table B-1 Sulphur dioxide emission calculations - fuel properties

Parameter	Value	Units	Ref.
Fuel-bound Sulphur[1]	50	mg/m³	15ºC, 1atm
Fuel-bound Sulphur[2]	66.23	mg/kg	-
Energy density of fuel[3]	51.4	MJ/kg (HHV)	-

[1]Limit as specified by Australian Standard AS4564-2005. [2]Assuming density of natural gas of 0.755kg/m³ at 15°C and 1atm (AGL, 1995, *Natural Gas Technical Data Handbook*). [3]AGL(1995), *Natural Gas Technical Data Handbook;*

Table B-2 Sulphur dioxide emission calculations

Parameter	E Class	F Class
Fuel consumption (GJ/hr)	1756	2825
Fuel consumption (kg/s)	9.5	15.3
Sulphur emission rate (mg/s)	628	1011
Sulphur dioxide emission rate[1] (g/s)	**1.3**	**2.0**

[1]Assuming all fuel bound sulphur is oxidised to sulphur dioxide.

Formaldehyde

Formaldehyde emissions were calculated from fuel consumption and the USEPA AP-42 emission factors, in conjunction with the ratio derived from ESP(2007). **Table B-3** presents the emission calculations.

Table B-3 Formaldehyde emission calculations

Parameter	E Class		F Class	
	Operation	Startup	Operation	Startup
Fuel Consumption (GJ/hr)	1756	-	2825	-
Fuel Consumption (MMBTU/hr)	1665	-	2679	-
Emission Factor (lb formaldehyde/MMBTU)	7.10E-04			
HAP Scaling Factor[1]	1	12.04	1	12.04
Formaldehyde (g/s)	**0.15**	**1.79**	**0.24**	**2.88**

[1]from ESP(2007).

Particulate Matter (PM_{10})

PM_{10} emissions have been calculated from a vendor estimate provided by Alstom for the GT13E2 turbine of 7 mg/Nm^3, dry at 15% O_2. This has been adopted for both the E Class and the F Class PM_{10} emission rates. **Table B-4** presents the emission calculations.

Table B-4 Particulate matter emission calculations

Parameter	E Class	F Class
Mass flow rate (kg/s)	537	684
Flow rate (Nm^3/s,wet) [1]	425	541
PM_{10} Concentration (mg/Nm^3, dry, 273K, 1 Atm) [2]	7	7
PM_{10} dioxide emission rate (g/s) [3]	**3.0**	**3.8**

[1]Assuming that stack emissions have a molecular weight equal to that of dry air which has a density of $1.293kg/m^3$ at 273K,1 Atm.
[2]PM_{10} concentration provided by Alstom and assumed to be representative of an F Class turbine. [3]In the absence of in-stack moisture content and oxygen content, the dry 15%O_2 concentration has simply been multiplied by the wet flow rate. Typical DLN gas turbine moisture contents are ~7% and oxygen contents are typically 15%O_2 (dry) hence the estimation is slightly conservative.

NO_x Emissions relative to large NSW generators

In order to provide context on the scale of NO_x emissions from the Facility, a brief comparison has been prepared against other large generators in NSW (both proposed and existing). In addition, comparison against National Pollution Inventory (NPI) emission factors has also been made. **Table B-5** presents the results of this comparison.

Table B-5 Comparison of NO_x Emission rates from the recent Development Applications and National Pollution Inventory Emission Factors against the Proposal

Facility	Capacity (MW)	NO_x Emissions (kg/hr)	NO_x Emissions (kg/MWh)
AGL Dalton DLN GT (proposed)	Up to 1500	661	0.4
Mt Piper (existing)[1]	1320	5,120	3.9
Mt Piper (proposed)[1]	2000	3,745	1.9
Eraring (existing)[2]	2640	12,621	4.8
Eraring (proposed)[2]	3000	9,835	3.3
Bayswater (proposed)[3]	2000	3,262	1.6
NPI Emission factor for DLN GT	NA	NA	0.4*
NPI Emission factor for new coal	NA	NA	1.9**

Notes:
- NPI Emission Factors sourced from: DEH (2005) *National Pollution Inventory Emission Estimation Technique Manual for Fossil Fuel Electric Generation Version 2.4,* Department of the Environment and Heritage, March 2005.
- *Assuming a thermal efficiency of 35% (HHV).
- **Assuming Ultra-Super Critical Coal plant with a thermal efficiency of 40% (HHV) using a Low NO_x boiler, producing 4.9kg NO_x/t of coal (DEH,2005), the coal having a gross calorific value of 23.4 GJ/t.
- [1]Sourced from: SKM (2009) *Mt Piper Power Station Extension Environmental Assessment, Air Quality Assessment*, SKM, September 2009.
- [2]Sourced from: HLA (2007) *Air Quality Impact Assessment Proposed 750 MW Upgrade Eraring Power Station*, HLA, 2007.
- [3]Sourced from: Katestone (2009) *Air Quality Impact Assessment for the Proposed Bayswater B Power Station Project*, Katestone Environmental, 2009.

C

Appendix C Sample Modelling Files

```
---------------- Run title (3 lines)
------------------------------------------

                    CALPUFF MODEL CONTROL FILE
                    --------------------------

-------------------------------------------------------------------------------
----

INPUT GROUP: 0 -- Input and Output File Names

--------------
Default Name  Type           File Name
------------  ----           ---------
CALMET.DAT    input    * METDAT =             *
    or
ISCMET.DAT    input    * ISCDAT =             *
    or
PLMMET.DAT    input    * PLMDAT =             *
    or
PROFILE.DAT   input    * PRFDAT =             *
SURFACE.DAT   input    * SFCDAT =             *
RESTARTB.DAT  input    * RSTARTB=             *
-------------------------------------------------------------------------------
-----
CALPUFF.LST   output   ! PUFLST =S1ALSU1D.LIS  !
CONC.DAT      output   ! CONDAT =S1ALSU1D.CON    !
DFLX.DAT      output   * DFDAT  =             *
WFLX.DAT      output   * WFDAT  =             *

VISB.DAT      output   * VISDAT =             *
TK2D.DAT      output   * T2DDAT =             *
RHO2D.DAT     output   * RHODAT =             *
RESTARTE.DAT  output   * RSTARTE=             *
-------------------------------------------------------------------------------
-----
Emission Files
--------------
PTEMARB.DAT   input    ! PTDAT  =E:\CALPUFF\DALPUF\S1ALSU1D.PTE  !
VOLEMARB.DAT  input    * VOLDAT =             *
BAEMARB.DAT   input    * ARDAT  =             *
LNEMARB.DAT   input    * LNDAT  =             *
-------------------------------------------------------------------------------
-----
Other Files
-----------
OZONE.DAT     input    * OZDAT  =             *
VD.DAT        input    * VDDAT  =             *
CHEM.DAT      input    * CHEMDAT=             *
H2O2.DAT      input    * H2O2DAT=             *
HILL.DAT      input    * HILDAT=              *
HILLRCT.DAT   input    * RCTDAT=              *
COASTLN.DAT   input    * CSTDAT=              *
FLUXBDY.DAT   input    * BDYDAT=              *
BCON.DAT      input    * BCNDAT=              *
DEBUG.DAT     output   * DEBUG =              *
MASSFLX.DAT   output   * FLXDAT=              *
MASSBAL.DAT   output   * BALDAT=              *
FOG.DAT       output   * FOGDAT=              *
RISE.DAT      output   * RISDAT=              *
-------------------------------------------------------------------------------
-----
All file names will be converted to lower case if LCFILES = T
Otherwise, if LCFILES = F, file names will be converted to UPPER CASE
         T = lower case      ! LCFILES = F !
         F = UPPER CASE
NOTE: (1) file/path names can be up to 70 characters in length


Provision for multiple input files
```



```
-----------------------------------

     Number of CALMET.DAT files for run (NMETDAT)
                                   Default: 1       ! NMETDAT =   12   !

     Number of PTEMARB.DAT files for run (NPTDAT)
                                   Default: 0       ! NPTDAT =  0  !

     Number of BAEMARB.DAT files for run (NARDAT)
                                   Default: 0       ! NARDAT =  0  !

     Number of VOLEMARB.DAT files for run (NVOLDAT)
                                   Default: 0       ! NVOLDAT =  0  !

!END!

-------------
Subgroup (0a)
-------------

  The following CALMET.DAT filenames are processed in sequence if NMETDAT>1

Default Name  Type           File Name
------------  ----           ---------
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM01.MET     !  !END!
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM02.MET     !  !END!
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM03.MET     !  !END!
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM04.MET     !  !END!
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM05.MET     !  !END!
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM06.MET     !  !END!
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM07.MET     !  !END!
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM08.MET     !  !END!
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM09.MET     !  !END!
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM10.MET     !  !END!
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM11.MET     !  !END!
 none         input    ! METDAT=E:\CALPUFF\DALMET\DALM12.MET     !  !END!


-------------------------------------------------------------------------------
-----

INPUT GROUP: 1 -- General run control parameters
--------------

    Option to run all periods found
    in the met. file     (METRUN)   Default: 0       ! METRUN =   0  !

        METRUN = 0 - Run period explicitly defined below
        METRUN = 1 - Run all periods in met. file

    Starting date:    Year   (IBYR)  --    No default   ! IBYR  =  2006  !
                      Month  (IBMO)  --    No default   ! IBMO  =  1  !
                      Day    (IBDY)  --    No default   ! IBDY  =  1  !
    Starting time:    Hour   (IBHR)  --    No default   ! IBHR  =  0  !
                      Minute (IBMIN) --    No default   ! IBMIN =  0  !
                      Second (IBSEC) --    No default   ! IBSEC =  0  !

    Ending date:      Year   (IEYR)  --    No default   ! IEYR  =  2007  !
                      Month  (IEMO)  --    No default   ! IEMO  =  1  !
                      Day    (IEDY)  --    No default   ! IEDY  =  1  !
    Ending time:      Hour   (IEHR)  --    No default   ! IEHR  =  0  !
                      Minute (IEMIN) --    No default   ! IEMIN =  0  !
                      Second (IESEC) --    No default   ! IESEC =  0  !

    (These are only used if METRUN = 0)

    Base time zone        (XBTZ) -- No default       ! XBTZ= -10.0  !
    The zone is the number of hours that must be
    ADDED to the time to obtain UTC (or GMT)
    Examples: PST = 8., MST = 7.
              CST = 6., EST = 5.

    Length of modeling time-step (seconds)
```



```
    Equal to update period in the primary
    meteorological data files, or an
    integer fraction of it (1/2, 1/3 ...)
    Must be no larger than 1 hour
    (NSECDT)                      Default:3600     ! NSECDT =  3600  !
                                  Units: seconds

    Number of chemical species (NSPEC)
                                  Default: 5       ! NSPEC =  4   !

    Number of chemical species
    to be emitted  (NSE)          Default: 3       ! NSE =  0   !

    Flag to stop run after
    SETUP phase (ITEST)           Default: 2       ! ITEST =  2   !
    (Used to allow checking
    of the model inputs, files, etc.)
          ITEST = 1 - STOPS program after SETUP phase
          ITEST = 2 - Continues with execution of program
                      after SETUP

    Restart Configuration:

       Control flag (MRESTART)    Default: 0       ! MRESTART =  0   !

          0 = Do not read or write a restart file
          1 = Read a restart file at the beginning of
              the run
          2 = Write a restart file during run
          3 = Read a restart file at beginning of run
              and write a restart file during run

       Number of periods in Restart
       output cycle (NRESPD)      Default: 0       ! NRESPD =  0   !

          0 = File written only at last period
         >0 = File updated every NRESPD periods

    Meteorological Data Format (METFM)
                                  Default: 1       ! METFM =  1   !

          METFM = 1 - CALMET binary file (CALMET.MET)
          METFM = 2 - ISC ASCII file (ISCMET.MET)
          METFM = 3 - AUSPLUME ASCII file (PLMMET.MET)
          METFM = 4 - CTDM plus tower file (PROFILE.DAT) and
                      surface parameters file (SURFACE.DAT)
          METFM = 5 - AERMET tower file (PROFILE.DAT) and
                      surface parameters file (SURFACE.DAT)

    Meteorological Profile Data Format (MPRFFM)
           (used only for METFM = 1, 2, 3)
                                  Default: 1       ! MPRFFM =  1   !

          MPRFFM = 1 - CTDM plus tower file (PROFILE.DAT)
          MPRFFM = 2 - AERMET tower file (PROFILE.DAT)

    PG sigma-y is adjusted by the factor (AVET/PGTIME)**0.2
    Averaging Time (minutes) (AVET)
                                  Default: 60.0    ! AVET = 60. !
    PG Averaging Time (minutes) (PGTIME)
                                  Default: 60.0    ! PGTIME = 60. !


!END!


-------------------------------------------------------------------------------
----

INPUT GROUP: 2 -- Technical options
--------------
```



```
    Vertical distribution used in the
    near field (MGAUSS)           Default: 1     ! MGAUSS =  1   !
       0 = uniform
       1 = Gaussian

    Terrain adjustment method
    (MCTADJ)                      Default: 3     ! MCTADJ =  3   !
       0 = no adjustment
       1 = ISC-type of terrain adjustment
       2 = simple, CALPUFF-type of terrain
           adjustment
       3 = partial plume path adjustment

    Subgrid-scale complex terrain
    flag (MCTSG)                  Default: 0     ! MCTSG =  0   !
       0 = not modeled
       1 = modeled

    Near-field puffs modeled as
    elongated slugs? (MSLUG)      Default: 0     ! MSLUG =  0   !
       0 = no
       1 = yes (slug model used)

    Transitional plume rise modeled?
    (MTRANS)                      Default: 1     ! MTRANS =  1   !
       0 = no  (i.e., final rise only)
       1 = yes (i.e., transitional rise computed)

    Stack tip downwash? (MTIP)    Default: 1     ! MTIP =  1  !
       0 = no  (i.e., no stack tip downwash)
       1 = yes (i.e., use stack tip downwash)

    Method used to compute plume rise for
    point sources not subject to building
    downwash? (MRISE)             Default: 1     ! MRISE =  1  !
       1 = Briggs plume rise
       2 = Numerical plume rise

    Method used to simulate building
    downwash? (MBDW)              Default: 1     ! MBDW =  1  !
       1 = ISC method
       2 = PRIME method

    Vertical wind shear modeled above
    stack top? (MSHEAR)           Default: 0     ! MSHEAR =  0  !
       0 = no  (i.e., vertical wind shear not modeled)
       1 = yes (i.e., vertical wind shear modeled)

    Puff splitting allowed? (MSPLIT)  Default: 0     ! MSPLIT =  0  !
       0 = no (i.e., puffs not split)
       1 = yes (i.e., puffs are split)

    Chemical mechanism flag (MCHEM)   Default: 1     ! MCHEM =  0   !
       0 = chemical transformation not
           modeled
       1 = transformation rates computed
           internally (MESOPUFF II scheme)
       2 = user-specified transformation
           rates used
       3 = transformation rates computed
           internally (RIVAD/ARM3 scheme)
       4 = secondary organic aerosol formation
           computed (MESOPUFF II scheme for OH)

    Aqueous phase transformation flag (MAQCHEM)
    (Used only if MCHEM = 1, or 3)    Default: 0     ! MAQCHEM =  0
    !
       0 = aqueous phase transformation
           not modeled
       1 = transformation rates adjusted
           for aqueous phase reactions

    Wet removal modeled ? (MWET)      Default: 1     ! MWET =  0   !
```

```
        0 = no
        1 = yes

     Dry deposition modeled ? (MDRY)       Default: 1     ! MDRY =  0   !
        0 = no
        1 = yes
        (dry deposition method specified
         for each species in Input Group 3)


     Gravitational settling (plume tilt)
     modeled ? (MTILT)                     Default: 0     ! MTILT =  0   !
        0 = no
        1 = yes
        (puff center falls at the gravitational
         settling velocity for 1 particle species)

     Restrictions:
         - MDRY  = 1
         - NSPEC = 1  (must be particle species as well)
         - sg    = 0  GEOMETRIC STANDARD DEVIATION in Group 8 is
                      set to zero for a single particle diameter

     Method used to compute dispersion
     coefficients (MDISP)                  Default: 3     ! MDISP =  3   !

        1 = dispersion coefficients computed from measured values
            of turbulence, sigma v, sigma w
        2 = dispersion coefficients from internally calculated
            sigma v, sigma w using micrometeorological variables
            (u*, w*, L, etc.)
        3 = PG dispersion coefficients for RURAL areas (computed using
            the ISCST multi-segment approximation) and MP coefficients in
            urban areas
        4 = same as 3 except PG coefficients computed using
            the MESOPUFF II eqns.
        5 = CTDM sigmas used for stable and neutral conditions.
            For unstable conditions, sigmas are computed as in
            MDISP = 3, described above.  MDISP = 5 assumes that
            measured values are read

     Sigma-v/sigma-theta, sigma-w measurements used? (MTURBVW)
     (Used only if MDISP = 1 or 5)         Default: 3     ! MTURBVW =  3  !
        1 = use sigma-v or sigma-theta measurements
            from PROFILE.DAT to compute sigma-y
            (valid for METFM = 1, 2, 3, 4, 5)
        2 = use sigma-w measurements
            from PROFILE.DAT to compute sigma-z
            (valid for METFM = 1, 2, 3, 4, 5)
        3 = use both sigma-(v/theta) and sigma-w
            from PROFILE.DAT to compute sigma-y and sigma-z
            (valid for METFM = 1, 2, 3, 4, 5)
        4 = use sigma-theta measurements
            from PLMMET.DAT to compute sigma-y
            (valid only if METFM = 3)

     Back-up method used to compute dispersion
     when measured turbulence data are
     missing (MDISP2)                      Default: 3     ! MDISP2 =  3  !
     (used only if MDISP = 1 or 5)
        2 = dispersion coefficients from internally calculated
            sigma v, sigma w using micrometeorological variables
            (u*, w*, L, etc.)
        3 = PG dispersion coefficients for RURAL areas (computed using
            the ISCST multi-segment approximation) and MP coefficients in
            urban areas
        4 = same as 3 except PG coefficients computed using
            the MESOPUFF II eqns.

     [DIAGNOSTIC FEATURE]
     Method used for Lagrangian timescale for Sigma-y
     (used only if MDISP=1,2 or MDISP2=1,2)
     (MTAULY)                              Default: 0     ! MTAULY =  0  !
```



```
        0 = Draxler default 617.284 (s)
        1 = Computed as Lag. Length / (.75 q) -- after SCIPUFF
       10 < Direct user input (s)             -- e.g., 306.9


     [DIAGNOSTIC FEATURE]
     Method used for Advective-Decay timescale for Turbulence
     (used only if MDISP=2 or MDISP2=2)
     (MTAUADV)                             Default: 0     ! MTAUADV =  0  !
        0 = No turbulence advection
        1 = Computed (OPTION NOT IMPLEMENTED)
       10 < Direct user input (s)   -- e.g., 800


     Method used to compute turbulence sigma-v &
     sigma-w using micrometeorological variables
     (Used only if MDISP = 2 or MDISP2 = 2)
     (MCTURB)                              Default: 1     ! MCTURB =  1  !
        1 = Standard CALPUFF subroutines
        2 = AERMOD subroutines

     PG sigma-y,z adj. for roughness?      Default: 0     ! MROUGH =  0  !
     (MROUGH)
        0 = no
        1 = yes

     Partial plume penetration of          Default: 1     ! MPARTL =  1  !
     elevated inversion modeled for
     point sources?
     (MPARTL)
        0 = no
        1 = yes

     Partial plume penetration of          Default: 1     ! MPARTLBA =  0
     !
     elevated inversion modeled for
     buoyant area sources?
     (MPARTLBA)
        0 = no
        1 = yes

     Strength of temperature inversion     Default: 0     ! MTINV =  0  !
     provided in PROFILE.DAT extended records?
     (MTINV)
        0 = no (computed from measured/default gradients)
        1 = yes

     PDF used for dispersion under convective conditions?
                                           Default: 0     ! MPDF =  0  !
     (MPDF)
        0 = no
        1 = yes

     Sub-Grid TIBL module used for shore line?
                                           Default: 0     ! MSGTIBL = 0  !
     (MSGTIBL)
        0 = no
        1 = yes

     Boundary conditions (concentration) modeled?
                                           Default: 0     ! MBCON = 0  !
     (MBCON)
        0 = no
        1 = yes, using formatted BCON.DAT file
        2 = yes, using unformatted CONC.DAT file

     Note:  MBCON > 0 requires that the last species modeled
            be 'BCON'.  Mass is placed in species BCON when
            generating boundary condition puffs so that clean
            air entering the modeling domain can be simulated
            in the same way as polluted air.  Specify zero
            emission of species BCON for all regular sources.
```



```
     Individual source contributions saved?
                                           Default: 0     ! MSOURCE = 0  !
     (MSOURCE)
        0 = no
        1 = yes


     Analyses of fogging and icing impacts due to emissions from
     arrays of mechanically-forced cooling towers can be performed
     using CALPUFF in conjunction with a cooling tower emissions
     processor (CTEMISS) and its associated postprocessors.  Hourly
     emissions of water vapor and temperature from each cooling tower
     cell are computed for the current cell configuration and ambient
     conditions by CTEMISS. CALPUFF models the dispersion of these
     emissions and provides cloud information in a specialized format
     for further analysis. Output to FOG.DAT is provided in either
     'plume mode' or 'receptor mode' format.

     Configure for FOG Model output?
                                           Default: 0     ! MFOG =  0   !
     (MFOG)
        0 = no
        1 = yes  - report results in PLUME Mode format
        2 = yes  - report results in RECEPTOR Mode format


     Test options specified to see if
     they conform to regulatory
     values? (MREG)                        Default: 1     ! MREG =  0   !

        0 = NO checks are made
        1 = Technical options must conform to USEPA
            Long Range Transport (LRT) guidance
                        METFM    1 or 2
                        AVET     60. (min)
                        PGTIME   60. (min)
                        MGAUSS   1
                        MCTADJ   3
                        MTRANS   1
                        MTIP     1
                        MRISE    1
                        MCHEM    1 or 3 (if modeling SOx, NOx)
                        MWET     1
                        MDRY     1
                        MDISP    2 or 3
                        MPDF     0 if MDISP=3
                                 1 if MDISP=2
                        MROUGH   0
                        MPARTL   1
                        MPARTLBA 0
                        SYTDEP   550. (m)
                        MHFTSZ   0
                        SVMIN    0.5 (m/s)


     !END!


     ----------------------------------------------------------------------------
     ----

     INPUT GROUP: 3a, 3b -- Species list
     -----------------

     ------------
     Subgroup (3a)
     ------------

       The following species are modeled:

     ! CSPEC =          NOX !         !END!
     ! CSPEC =           CO !         !END!
     ! CSPEC = FORMALDEHYDE !         !END!
```



```
     ! CSPEC =       TRACER !         !END!

                                                          Dry
                                                          OUTPUT GROUP
         SPECIES          MODELED          EMITTED       DEPOSITED
         NUMBER
          NAME         (0=NO, 1=YES)    (0=NO, 1=YES)    (0=NO,
           (0=NONE,
        (Limit: 12                                         1=COMPUTED-GAS
        1=1st CGRUP,
         Characters                                        2=COMPUTED-PARTICLE
         2=2nd CGRUP,
         in length)                                       3=USER-SPECIFIED)
         3= etc.)

     !          NOX  =         1,               0,           0,
     0   !
     !           CO  =         1,               0,           0,
     0   !
     ! FORMALDEHYDE  =         1,               0,           0,
     0   !
     !       TRACER  =         1,               0,           0,
     0   !

     !END!

       Note:  The last species in (3a) must be 'BCON' when using the
              boundary condition option (MBCON > 0).  Species BCON should
              typically be modeled as inert (no chem transformation or
              removal).


     -------------
     Subgroup (3b)
     -------------
       The following names are used for Species-Groups in which results
       for certain species are combined (added) prior to output.  The
       CGRUP name will be used as the species name in output files.
       Use this feature to model specific particle-size distributions
       by treating each size-range as a separate species.
       Order must be consistent with 3(a) above.


     ----------------------------------------------------------------------------
     ----


     INPUT GROUP: 4 -- Map Projection and Grid control parameters
     --------------

          Projection for all (X,Y):
          -------------------------

          Map projection
          (PMAP)                     Default: UTM    ! PMAP = UTM  !

              UTM :  Universal Transverse Mercator
              TTM :  Tangential Transverse Mercator
              LCC :  Lambert Conformal Conic
               PS :  Polar Stereographic
               EM :  Equatorial Mercator
             LAZA :  Lambert Azimuthal Equal Area

          False Easting and Northing (km) at the projection origin
          (Used only if PMAP= TTM, LCC, or LAZA)
          (FEAST)                    Default=0.0     ! FEAST  = 0.000  !
          (FNORTH)                   Default=0.0     ! FNORTH = 0.000  !

          UTM zone (1 to 60)
          (Used only if PMAP=UTM)
          (IUTMZN)                   No Default      ! IUTMZN =  55   !
```

```
     Hemisphere for UTM projection?
     (Used only if PMAP=UTM)
     (UTMHEM)                  Default: N      ! UTMHEM = S  !
         N   :  Northern hemisphere projection
         S   :  Southern hemisphere projection

     Latitude and Longitude (decimal degrees) of projection origin
     (Used only if PMAP= TTM, LCC, PS, EM, or LAZA)
     (RLAT0)                   No Default      ! RLAT0 = 0N  !
     (RLON0)                   No Default      ! RLON0 = 0E  !

         TTM :  RLON0 identifies central (true N/S) meridian of projection
                RLAT0 selected for convenience
         LCC :  RLON0 identifies central (true N/S) meridian of projection
                RLAT0 selected for convenience
         PS  :  RLON0 identifies central (grid N/S) meridian of projection
                RLAT0 selected for convenience
         EM  :  RLON0 identifies central meridian of projection
                RLAT0 is REPLACED by 0.0N (Equator)
         LAZA:  RLON0 identifies longitude of tangent-point of mapping
         plane
                RLAT0 identifies latitude of tangent-point of mapping plane

     Matching parallel(s) of latitude (decimal degrees) for projection
     (Used only if PMAP= LCC or PS)
     (XLAT1)                   No Default      ! XLAT1 = 0N  !
     (XLAT2)                   No Default      ! XLAT2 = 0N  !

         LCC :  Projection cone slices through Earth's surface at XLAT1 and
         XLAT2
         PS  :  Projection plane slices through Earth at XLAT1
                (XLAT2 is not used)

     ----------
     Note:  Latitudes and longitudes should be positive, and include a
            letter N,S,E, or W indicating north or south latitude, and
            east or west longitude.  For example,
            35.9  N Latitude  =  35.9N
            118.7 E Longitude = 118.7E


     Datum-region
     ------------

     The Datum-Region for the coordinates is identified by a character
     string.  Many mapping products currently available use the model of
     the
     Earth known as the World Geodetic System 1984 (WGS-84).  Other local
     models may be in use, and their selection in CALMET will make its
     output
     consistent with local mapping products.  The list of Datum-Regions
     with
     official transformation parameters is provided by the National Imagery
     and
     Mapping Agency (NIMA).

     NIMA Datum - Regions(Examples)

     ------------------------------------------------------------------------
     --------
     WGS-84    WGS-84 Reference Ellipsoid and Geoid, Global coverage
     (WGS84)
     NAS-C     NORTH AMERICAN 1927 Clarke 1866 Spheroid, MEAN FOR CONUS
     (NAD27)
     NAR-C     NORTH AMERICAN 1983 GRS 80 Spheroid, MEAN FOR CONUS (NAD83)
     NWS-84    NWS 6370KM Radius, Sphere
     ESR-S     ESRI REFERENCE 6371KM Radius, Sphere

     Datum-region for output coordinates
     (DATUM)                   Default: WGS-84    ! DATUM = WGS-84  !

METEOROLOGICAL Grid:
```



```
     Rectangular grid defined for projection PMAP,
     with X the Easting and Y the Northing coordinate

            No. X grid cells (NX)      No default     ! NX =  81   !
            No. Y grid cells (NY)      No default     ! NY =  81   !
         No. vertical layers (NZ)      No default     ! NZ =  12   !

           Grid spacing (DGRIDKM)      No default     ! DGRIDKM = .5 !
                                       Units: km

                Cell face heights
                    (ZFACE(nz+1))      No defaults
                                       Units: m
    ! ZFACE = .0, 20.0, 40.0, 60.0, 80.0, 100.0, 140.0, 180.0, 260.0, 400.0,
               500.0, 1500.0, 3000.0 !

             Reference Coordinates
            of SOUTHWEST corner of
                 grid cell(1, 1):

             X coordinate (XORIGKM)    No default     ! XORIGKM = 680.528 !
             Y coordinate (YORIGKM)    No default     ! YORIGKM = 6139.637
             !
                                       Units: km

COMPUTATIONAL Grid:

     The computational grid is identical to or a subset of the MET. grid.
     The lower left (LL) corner of the computational grid is at grid point
     (IBCOMP, JBCOMP) of the MET. grid.  The upper right (UR) corner of the
     computational grid is at grid point (IECOMP, JECOMP) of the MET. grid.
     The grid spacing of the computational grid is the same as the MET.
     grid.

        X index of LL corner (IBCOMP)      No default     ! IBCOMP =  1   !
                  (1 <= IBCOMP <= NX)

        Y index of LL corner (JBCOMP)      No default     ! JBCOMP =  1   !
                  (1 <= JBCOMP <= NY)


        X index of UR corner (IECOMP)      No default     ! IECOMP =  81
        !
                  (1 <= IECOMP <= NX)

        Y index of UR corner (JECOMP)      No default     ! JECOMP =  81
        !
                  (1 <= JECOMP <= NY)


SAMPLING Grid (GRIDDED RECEPTORS):

     The lower left (LL) corner of the sampling grid is at grid point
     (IBSAMP, JBSAMP) of the MET. grid.  The upper right (UR) corner of the
     sampling grid is at grid point (IESAMP, JESAMP) of the MET. grid.
     The sampling grid must be identical to or a subset of the
     computational
     grid.  It may be a nested grid inside the computational grid.
     The grid spacing of the sampling grid is DGRIDKM/MESHDN.

        Logical flag indicating if gridded
        receptors are used (LSAMP)         Default: T     ! LSAMP = T !
        (T=yes, F=no)

        X index of LL corner (IBSAMP)      No default     ! IBSAMP =  1   !
         (IBCOMP <= IBSAMP <= IECOMP)

        Y index of LL corner (JBSAMP)      No default     ! JBSAMP =  1   !
         (JBCOMP <= JBSAMP <= JECOMP)
```



```
        X index of UR corner (IESAMP)      No default     ! IESAMP =  81
        !
          (IBCOMP <= IESAMP <= IECOMP)

        Y index of UR corner (JESAMP)      No default     ! JESAMP =  81
        !
          (JBCOMP <= JESAMP <= JECOMP)


       Nesting factor of the sampling
        grid (MESHDN)                      Default: 1     ! MESHDN =  1  !
        (MESHDN is an integer >= 1)

!END!

------------------------------------------------------------------------------
----


INPUT GROUP: 5 -- Output Options
--------------
                                        *                          *
     FILE                       DEFAULT VALUE             VALUE THIS RUN
     ----                       -------------             --------------

   Concentrations (ICON)              1                   !  ICON =  1   !
   Dry Fluxes (IDRY)                  1                   !  IDRY =  0   !
   Wet Fluxes (IWET)                  1                   !  IWET =  0   !
   2D Temperature (IT2D)              0                   !  IT2D =  0   !
   2D Density (IRHO)                  0                   !  IRHO =  0   !
   Relative Humidity (IVIS)           1                   !  IVIS =  0   !
    (relative humidity file is
     required for visibility
     analysis)
   Use data compression option in output file?
   (LCOMPRS)                          Default: T          ! LCOMPRS = T !

   *
    0 = Do not create file, 1 = create file


    QA PLOT FILE OUTPUT OPTION:

       Create a standard series of output files (e.g.
       locations of sources, receptors, grids ...)
       suitable for plotting?
       (IQAPLOT)                      Default: 1          !  IQAPLOT =  1
       !
         0 = no
         1 = yes

    DIAGNOSTIC MASS FLUX OUTPUT OPTIONS:

       Mass flux across specified boundaries
       for selected species reported?
       (IMFLX)                        Default: 0          ! IMFLX =  0  !
         0 = no
         1 = yes (FLUXBDY.DAT and MASSFLX.DAT filenames
                  are specified in Input Group 0)

       Mass balance for each species
       reported?
       (IMBAL)                        Default: 0          ! IMBAL =  0  !
         0 = no
         1 = yes (MASSBAL.DAT filename is
              specified in Input Group 0)


    NUMERICAL RISE OUTPUT OPTION:

       Create a file with plume properties for each rise
```



```
       increment, for each model timestep?
       This applies to sources modeled with numerical rise
       and is limited to ONE source in the run.
       (INRISE)                       Default: 0          ! INRISE =  0  !
         0 = no
         1 = yes (RISE.DAT filename is
                  specified in Input Group 0)


    LINE PRINTER OUTPUT OPTIONS:

       Print concentrations (ICPRT)   Default: 0          ! ICPRT =  0   !
       Print dry fluxes (IDPRT)       Default: 0          ! IDPRT =  0   !
       Print wet fluxes (IWPRT)       Default: 0          ! IWPRT =  0   !
       (0 = Do not print, 1 = Print)

       Concentration print interval
       (ICFRQ) in timesteps           Default: 1          ! ICFRQ =  1   !
       Dry flux print interval
       (IDFRQ) in timesteps           Default: 1          ! IDFRQ =  1   !
       Wet flux print interval
       (IWFRQ) in timesteps           Default: 1          ! IWFRQ =  1   !

       Units for Line Printer Output
       (IPRTU)                        Default: 1          ! IPRTU =  3   !
                        for             for
                   Concentration    Deposition
          1 =         g/m**3          g/m**2/s
          2 =        mg/m**3         mg/m**2/s
          3 =        ug/m**3         ug/m**2/s
          4 =        ng/m**3         ng/m**2/s
          5 =       Odour Units

       Messages tracking progress of run
       written to the screen ?
       (IMESG)                        Default: 2          ! IMESG =  2   !
         0 = no
         1 = yes (advection step, puff ID)
         2 = yes (YYYYJJJHH, # old puffs, # emitted puffs)


       SPECIES (or GROUP for combined species) LIST FOR OUTPUT OPTIONS

                    ---- CONCENTRATIONS ----    ------ DRY FLUXES ------
                    ------ WET FLUXES ------    -- MASS FLUX --
     SPECIES
     /GROUP         PRINTED?  SAVED ON DISK?   PRINTED?  SAVED ON DISK?
     PRINTED?  SAVED ON DISK?    SAVED ON DISK?
     --------       ----------------------     ----------------------
     ------------------------   ----------------
!       TRACER =     0,           1,           0,           0,           0,
0,           0   !
!          NOX =     0,           1,           0,           0,           0,
0,           0   !
!           CO =     0,           1,           0,           0,           0,
0,           0   !
! FORMALDEHYDE =     0,           1,           0,           0,           0,
0,           0   !

  Note:  Species BCON (for MBCON > 0) does not need to be saved on disk.


       OPTIONS FOR PRINTING "DEBUG" QUANTITIES (much output)

         Logical for debug output
         (LDEBUG)                                 Default: F     ! LDEBUG = F
         !

         First puff to track
         (IPFDEB)                                 Default: 1     ! IPFDEB =
         1  !

         Number of puffs to track
```

```
       (NPFDEB)                                Default: 1     ! NPFDEB =
       1  !

       Met. period to start output
       (NN1)                                   Default: 1     ! NN1 =  1
       !

       Met. period to end output
       (NN2)                                   Default: 10    ! NN2 =  10
       !

!END!


------------------------------------------------------------------------------
----


INPUT GROUP: 6a, 6b, & 6c -- Subgrid scale complex terrain inputs
-------------------------

(excluded from sample file due to size)


------------------------------------------------------------------------------
----


INPUT GROUP: 7 -- Chemical parameters for dry deposition of gases
--------------

(excluded from sample file due to size)


------------------------------------------------------------------------------
----


INPUT GROUP: 8 -- Size parameters for dry deposition of particles
--------------

(excluded from sample file due to size)


------------------------------------------------------------------------------
----


INPUT GROUP: 9 -- Miscellaneous dry deposition parameters
--------------

(excluded from sample file due to size)


------------------------------------------------------------------------------
----


INPUT GROUP: 10 -- Wet Deposition Parameters
---------------

(excluded from sample file due to size)


------------------------------------------------------------------------------
----


INPUT GROUP: 11 -- Chemistry Parameters

(excluded from sample file due to size)

------------------------------------------------------------------------------
----
```



```
INPUT GROUP: 12 -- Misc. Dispersion and Computational Parameters
---------------

     Horizontal size of puff (m) beyond which
     time-dependent dispersion equations (Heffter)
     are used to determine sigma-y and
     sigma-z (SYTDEP)                        Default: 550.   ! SYTDEP =
     5.5E02 !

     Switch for using Heffter equation for sigma z
     as above (0 = Not use Heffter; 1 = use Heffter
     (MHFTSZ)                                Default: 0      ! MHFTSZ =
     0   !

     Stability class used to determine plume
     growth rates for puffs above the boundary
     layer (JSUP)                            Default: 5      ! JSUP =  5
     !

     Vertical dispersion constant for stable
     conditions (k1 in Eqn. 2.7-3)  (CONK1)  Default: 0.01   ! CONK1 =
     .01 !

     Vertical dispersion constant for neutral/
     unstable conditions (k2 in Eqn. 2.7-4)
     (CONK2)                                 Default: 0.1    ! CONK2 =
     .1 !

     Factor for determining Transition-point from
     Schulman-Scire to Huber-Snyder Building Downwash
     scheme (SS used for Hs < Hb + TBD * HL)
     (TBD)                                   Default: 0.5    ! TBD = .5
     !
        TBD < 0   ==> always use Huber-Snyder
        TBD = 1.5 ==> always use Schulman-Scire
        TBD = 0.5 ==> ISC Transition-point

     Range of land use categories for which
     urban dispersion is assumed
     (IURB1, IURB2)                          Default: 10     ! IURB1 =
     10  !
                                                             19     ! IURB2 =
                                                             19  !

     Site characterization parameters for single-point Met data files
     ---------
     (needed for METFM = 2,3,4,5)

        Land use category for modeling domain
        (ILANDUIN)                           Default: 20     ! ILANDUIN
        =  20  !

        Roughness length (m) for modeling domain
        (Z0IN)                               Default: 0.25   ! Z0IN =
        .25 !

        Leaf area index for modeling domain
        (XLAIIN)                             Default: 3.0    ! XLAIIN =
        3.0 !

        Elevation above sea level (m)
        (ELEVIN)                             Default: 0.0    ! ELEVIN =
        .0 !

        Latitude (degrees) for met location
        (XLATIN)                             Default: -999.  ! XLATIN =
        -999.0 !

        Longitude (degrees) for met location
        (XLONIN)                             Default: -999.  ! XLONIN =
        -999.0 !
```



```
     Specialized information for interpreting single-point Met data files
     -----

        Anemometer height (m) (Used only if METFM = 2,3)
        (ANEMHT)                             Default: 10.    ! ANEMHT =
        10.0 !

        Form of lateral turbulance data in PROFILE.DAT file
        (Used only if METFM = 4,5 or MTURBVW = 1 or 3)
        (ISIGMAV)                            Default: 1      ! ISIGMAV =
        1  !
            0 = read sigma-theta
            1 = read sigma-v

        Choice of mixing heights (Used only if METFM = 4)
        (IMIXCTDM)                           Default: 0      ! IMIXCTDM
        =  0  !
            0 = read PREDICTED mixing heights
            1 = read OBSERVED mixing heights

     Maximum length of a slug (met. grid units)
     (XMXLEN)                                Default: 1.0    ! XMXLEN =
     1.0 !

     Maximum travel distance of a puff/slug (in
     grid units) during one sampling step
     (XSAMLEN)                               Default: 1.0    ! XSAMLEN =
     1.0 !

     Maximum Number of slugs/puffs release from
     one source during one time step
     (MXNEW)                                 Default: 99     ! MXNEW =
     99   !

     Maximum Number of sampling steps for
     one puff/slug during one time step
     (MXSAM)                                 Default: 99     ! MXSAM =
     99   !

     Number of iterations used when computing
     the transport wind for a sampling step
     that includes gradual rise (for CALMET
     and PROFILE winds)
     (NCOUNT)                                Default: 2      ! NCOUNT =
     2   !

     Minimum sigma y for a new puff/slug (m)
     (SYMIN)                                 Default: 1.0    ! SYMIN =
     1.0  !

     Minimum sigma z for a new puff/slug (m)
     (SZMIN)                                 Default: 1.0    ! SZMIN =
     1.0  !

     Maximum sigma z (m) allowed to avoid
     numerical problem in calculating virtual
     time or distance.  Cap should be large
     enough to have no influence on normal events.
     Enter a negative cap to disable.
     (SZCAP_M)                               Default: 5.0e06 ! SZCAP_M =
     5.0E06 !

     Default minimum turbulence velocities sigma-v and sigma-w
     for each stability class over land and over water (m/s)
     (SVMIN(12) and SWMIN(12))

                    ----------  LAND  ----------       ---------  WATER
                    ----------
        Stab Class :  A    B    C    D    E    F         A    B    C    D
        E    F
                    ---  ---  ---  ---  ---  ---       ---  ---  ---  ---
                    ---  ---
```



```
     Default SVMIN : .50, .50, .50, .50, .50, .50,      .37, .37, .37, .37,
     .37, .37
     Default SWMIN : .20, .12, .08, .06, .03, .016,     .20, .12, .08, .06,
     .03, .016

           ! SVMIN = 0.500, 0.500, 0.500, 0.500, 0.500, 0.500, 0.370,
           0.370, 0.370, 0.370, 0.370, 0.370!
           ! SWMIN = 0.200, 0.120, 0.080, 0.060, 0.030, 0.016, 0.200,
           0.120, 0.080, 0.060, 0.030, 0.016!

     Divergence criterion for dw/dz across puff
     used to initiate adjustment for horizontal
     convergence (1/s)
     Partial adjustment starts at CDIV(1), and
     full adjustment is reached at CDIV(2)
     (CDIV(2))                               Default: 0.0,0.0  ! CDIV =
     .0, .0 !

     Search radius (number of cells) for nearest
     land and water cells used in the subgrid
     TIBL module
     (NLUTIBL)                               Default: 4      ! NLUTIBL =
     4  !

     Minimum wind speed (m/s) allowed for
     non-calm conditions. Also used as minimum
     speed returned when using power-law
     extrapolation toward surface
     (WSCALM)                                Default: 0.5    ! WSCALM =
     .5 !

     Maximum mixing height (m)
     (XMAXZI)                                Default: 3000.  ! XMAXZI =
     3000.0 !

     Minimum mixing height (m)
     (XMINZI)                                Default: 50.    ! XMINZI =
     50.0 !

     Default wind speed classes --
     5 upper bounds (m/s) are entered;
     the 6th class has no upper limit
     (WSCAT(5))                    Default   :
                                   ISC RURAL : 1.54, 3.09, 5.14, 8.23,
                                   10.8 (10.8+)

                                Wind Speed Class :  1     2     3     4     5
                                                    ---   ---   ---   ---
                                                    ---
                                     ! WSCAT = 1.54, 3.09, 5.14, 8.23,
                                     10.80 !

     Default wind speed profile power-law
     exponents for stabilities 1-6
     (PLX0(6))                     Default   : ISC RURAL values
                                   ISC RURAL : .07, .07, .10, .15, .35,
                                   .55
                                   ISC URBAN : .15, .15, .20, .25, .30,
                                   .30

                                 Stability Class :  A     B     C     D     E
                                 F
                                                    ---   ---   ---   ---
                                                    ---   ---
                                     ! PLX0 = 0.07, 0.07, 0.10, 0.15,
                                     0.35, 0.55 !

     Default potential temperature gradient
     for stable classes E, F (degK/m)
     (PTG0(2))                     Default: 0.020, 0.035
                                      ! PTG0 = 0.020,   0.035 !

     Default plume path coefficients for
```

```
     each stability class (used when option
     for partial plume height terrain adjustment
     is selected -- MCTADJ=3)
     (PPC(6))                    Stability Class :  A     B     C     D     E
     F
                                 Default  PPC : .50,  .50,  .50,  .50,
                                 .35,  .35
                                              ---   ---   ---   ---
                                              ---   ---
                                       !  PPC = 0.50, 0.50, 0.50, 0.50,
                                       0.35, 0.35 !

     Slug-to-puff transition criterion factor
     equal to sigma-y/length of slug
     (SL2PF)                              Default: 10.        ! SL2PF =
     10.0 !

     Puff-splitting control variables ------------------------

       VERTICAL SPLIT
       --------------

       Number of puffs that result every time a puff
       is split - nsplit=2 means that 1 puff splits
       into 2
       (NSPLIT)                           Default:   3        ! NSPLIT =
       3  !

       Time(s) of a day when split puffs are eligible to
       be split once again; this is typically set once
       per day, around sunset before nocturnal shear develops.
       24 values: 0 is midnight (00:00) and 23 is 11 PM (23:00)
       0=do not re-split    1=eligible for re-split
       (IRESPLIT(24))                     Default:  Hour 17 = 1
       !  IRESPLIT = 0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,1,0,0,0,0,0,0 !

       Split is allowed only if last hour's mixing
       height (m) exceeds a minimum value
       (ZISPLIT)                          Default: 100.       ! ZISPLIT =
       100.0 !

       Split is allowed only if ratio of last hour's
       mixing ht to the maximum mixing ht experienced
       by the puff is less than a maximum value (this
       postpones a split until a nocturnal layer develops)
       (ROLDMAX)                          Default: 0.25       ! ROLDMAX =
       0.25 !


       HORIZONTAL SPLIT
       ----------------

       Number of puffs that result every time a puff
       is split - nsplith=5 means that 1 puff splits
       into 5
       (NSPLITH)                          Default:   5        ! NSPLITH =
       5  !

       Minimum sigma-y (Grid Cells Units) of puff
       before it may be split
       (SYSPLITH)                         Default:  1.0       ! SYSPLITH =
       1.0 !

       Minimum puff elongation rate (SYSPLITH/hr) due to
       wind shear, before it may be split
       (SHSPLITH)                         Default:  2.        ! SHSPLITH =
       2.0 !

       Minimum concentration (g/m^3) of each
       species in puff before it may be split
       Enter array of NSPEC values; if a single value is
       entered, it will be used for ALL species
       (CNSPLITH)                         Default:  1.0E-07   ! CNSPLITH =
```



```
       1.0E-07 !

     Integration control variables ------------------------

       Fractional convergence criterion for numerical SLUG
       sampling integration
       (EPSSLUG)                          Default:   1.0e-04  ! EPSSLUG =
       1.0E-04 !

       Fractional convergence criterion for numerical AREA
       source integration
       (EPSAREA)                          Default:   1.0e-06  ! EPSAREA =
       1.0E-06 !

       Trajectory step-length (m) used for numerical rise
       integration
       (DSRISE)                           Default:   1.0      ! DSRISE =
       1.0 !

       Boundary Condition (BC) Puff control variables
       ----------------------

       Minimum height (m) to which BC puffs are mixed as they are emitted
       (MBCON=2 ONLY).  Actual height is reset to the current mixing height
       at the release point if greater than this minimum.
       (HTMINBC)                          Default:   500.     ! HTMINBC =
       500.0 !

       Search radius (km) about a receptor for sampling nearest BC puff.
       BC puffs are typically emitted with a spacing of one grid cell
       length, so the search radius should be greater than DGRIDKM.
       (RSAMPBC)                          Default:   10.      ! RSAMPBC =
       10.0 !

       Near-Surface depletion adjustment to concentration profile used when
       sampling BC puffs?
       (MDEPBC)                           Default:   1        ! MDEPBC =
       1  !
          0 = Concentration is NOT adjusted for depletion
          1 = Adjust Concentration for depletion

!END!


------------------------------------------------------------------------
----


INPUT GROUPS: 13a, 13b, 13c, 13d -- Point source parameters
---------------------------------

---------------
Subgroup (13a)
---------------

     Number of point sources with
     parameters provided below      (NPT1)  No default  !  NPT1 =  0  !

     Units used for point source
     emissions below                (IPTU)  Default: 1  !  IPTU =   1  !
           1 =         g/s
           2 =        kg/hr
           3 =        lb/hr
           4 =      tons/yr
           5 =      Odour Unit * m**3/s  (vol. flux of odour compound)
           6 =      Odour Unit * m**3/min
           7 =      metric tons/yr

     Number of source-species
     combinations with variable
     emissions scaling factors
     provided below in (13d)        (NSPT1) Default: 0  !  NSPT1 =  0  !
```



```
     Number of point sources with
     variable emission parameters
     provided in external file      (NPT2)  No default  !  NPT2 =  4  !

     (If NPT2 > 0, these point
     source emissions are read from
     the file: PTEMARB.DAT)

!END!


(remainder of file excluded from sample file due to size)
```

```
PTEMARB.DAT     2.1            Comments, times with seconds, time zone, coord
info
   2
The digit above denotes how many lines of comments will follow.
Alstom 4 Stack Run - with variable merging
UTM
  55S
WGS-84
KM
UTC+1000
 2006 1 0 0 2007 1 0 3600
 4   4
'NOX' 'CO' 'FORMALDEHYDE' 'TRACER'
      29.0       29.0       29.0       29.0
'T1'      701.228 6159.700 35.0 9.9 575.0  0.0       1.0 0.0
'T2'      701.277 6159.705 35.0 9.9 575.0  0.0       1.0 0.0
'T3'      701.326 6159.710 35.0 9.9 575.0  0.0       1.0 0.0
'T4'      701.373 6159.716 35.0 9.4 575.0  0.0       1.0 0.0
    2006 1 0 0 2006 1 0 3600
'T1'  2192.0 18.7 1.4 1.4 19.30 4.60 0.15 1.00
'T2'  2192.0 18.7 1.4 1.4 19.30 4.60 0.15 1.00
'T3'  2192.0 18.7 1.4 1.4 19.30 4.60 0.15 1.00
'T4'  1556.0 8.2 1.4 1.4 48.10 730.70 1.79 1.00
    2006 1 1 0 2006 1 1 3600
'T1'  2192.0 18.3 1.4 1.4 19.30 4.60 0.15 1.00
'T2'  2192.0 18.3 1.4 1.4 19.30 4.60 0.15 1.00
'T3'  2192.0 18.3 1.4 1.4 19.30 4.60 0.15 1.00
'T4'  1556.0 8.1 1.4 1.4 48.10 730.70 1.79 1.00
    2006 1 2 0 2006 1 2 3600
'T1'  2192.0 18.4 1.4 1.4 19.30 4.60 0.15 1.00
'T2'  2192.0 18.4 1.4 1.4 19.30 4.60 0.15 1.00
'T3'  2192.0 18.4 1.4 1.4 19.30 4.60 0.15 1.00
'T4'  1556.0 8.2 1.4 1.4 48.10 730.70 1.79 1.00
    2006 1 3 0 2006 1 3 3600
'T1'  2192.0 18.8 1.4 1.4 19.30 4.60 0.15 1.00
'T2'  2192.0 18.8 1.4 1.4 19.30 4.60 0.15 1.00
'T3'  2192.0 18.8 1.4 1.4 19.30 4.60 0.15 1.00
'T4'  1556.0 8.2 1.4 1.4 48.10 730.70 1.79 1.00
    2006 1 4 0 2006 1 4 3600
'T1'  2192.0 18.8 1.4 1.4 19.30 4.60 0.15 1.00
'T2'  2192.0 18.8 1.4 1.4 19.30 4.60 0.15 1.00
'T3'  2192.0 18.8 1.4 1.4 19.30 4.60 0.15 1.00
'T4'  1556.0 8.2 1.4 1.4 48.10 730.70 1.79 1.00
    2006 1 5 0 2006 1 5 3600
'T1'  2192.0 18.7 1.4 1.4 19.30 4.60 0.15 1.00
'T2'  2192.0 18.7 1.4 1.4 19.30 4.60 0.15 1.00
'T3'  2192.0 18.7 1.4 1.4 19.30 4.60 0.15 1.00
'T4'  1556.0 8.2 1.4 1.4 48.10 730.70 1.79 1.00
    2006 1 6 0 2006 1 6 3600
'T1'  2192.0 19.7 1.4 1.4 19.30 4.60 0.15 1.00
'T2'  2192.0 19.7 1.4 1.4 19.30 4.60 0.15 1.00
'T3'  2192.0 19.7 1.4 1.4 19.30 4.60 0.15 1.00
'T4'  1556.0 9.5 1.4 1.4 48.10 730.70 1.79 1.00
    2006 1 7 0 2006 1 7 3600
'T1'  2192.0 23.6 1.4 1.4 19.30 4.60 0.15 1.00
'T2'  2192.0 23.6 1.4 1.4 19.30 4.60 0.15 1.00
'T3'  2192.0 23.6 1.4 1.4 19.30 4.60 0.15 1.00
'T4'  1556.0 10.6 1.4 1.4 48.10 730.70 1.79 1.00
    2006 1 8 0 2006 1 8 3600
'T1'  2192.0 25.8 1.4 1.4 19.30 4.60 0.15 1.00
'T2'  2192.0 25.8 1.4 1.4 19.30 4.60 0.15 1.00
'T3'  2192.0 25.8 1.4 1.4 19.30 4.60 0.15 1.00
'T4'  1556.0 10.8 1.4 1.4 48.10 730.70 1.79 1.00
    2006 1 9 0 2006 1 9 3600
'T1'  2192.0 25.7 1.4 1.4 19.30 4.60 0.15 1.00
'T2'  2192.0 25.7 1.4 1.4 19.30 4.60 0.15 1.00
'T3'  2192.0 25.7 1.4 1.4 19.30 4.60 0.15 1.00
'T4'  1556.0 10.5 1.4 1.4 48.10 730.70 1.79 1.00
```

D

Appendix D Plume Merging Methodology

This assessment has incorporated the approach of Briggs (1975) in order to estimate the degree of plume merging that occurs for each hour of each model run, and subsequently allow the enhancement in plume rise to be incorporated into the dispersion model. The product of the Briggs methodology is a parameter called the *Number of Effective Stacks* (N_E) which equates to the factor by which the single stack buoyancy flux is effectively increased by neighbouring plumes.

Equation 1 and **Equation 2** define Briggs' separation factor (S) and number of effective stacks (N_E) respectively.

$$S = 6.\left(\frac{(N-1)s}{N^{1/3}.\Delta h_1}\right)^{3/2} \qquad \text{(Equation 1)}$$

Where: Δh_1 = Plume rise of a single stack (m above stack top)

s = Physical stack separation (m)

$$N_E = \frac{N+S}{1+S} \qquad \text{(Equation 2)}$$

Where: N_E = Number of effective stacks

N = Number of stack sources

S = Separation factor

The plume merging estimation process requires the calculation of plume rise heights for a single stack source. In Calpuff, single stack model runs were performed for both E and F Class turbines, under both startup and operating conditions. These model runs were configured to use the numerical plume rise module, and to produce plume rise outputs at a resolution of 5 metres from the point of release, until the plume stabilizes in the atmosphere. These files were subsequently processed to provide a single stack plume rise termination heights suitable for incorporation into **Equation 2** for each stack type, and for each hour of each modelling run.

The resulting N_E was then used to scale the buoyancy flux of each individual stack, as shown in **Equation 3**.

$$F_{EFF} = N_E \times F_0 \qquad \text{(Equation 3)}$$

Where: F_{EFF} = Effective buoyancy flux

F_0 = Buoyancy flux of a single stack

Calculation of Exit Parameters for Modelling

As Calpuff does not include the functionality to scale buoyancy flux independently of other stack parameters, and the Calpuff time varying point source emission file does not allow stack diameter to

Appendix D

be varied with time[7], a time varying stack velocity was used to regulate the buoyancy flux to be consistent with **Equation 3** on an hour by hour basis.

For a given stack type, effective stack parameters were derived by taking the hour at which the highest N_E occurred during the year, and calculating a set of effective stack parameters. The effective stack temperature and diameter were derived using **Equation 4** and **Equation 5.**

$$T_{EFF} = \frac{T_a\left(F_{EFF} \diagup G_0\right) + g}{g} \qquad \text{(Equation 4)}$$

Where:

T_{EFF} = Effective stack temperature

T_a = Ambient temperature at stack elevation

F_{EFF} = Effective buoyancy flux

G_0 = Volume flux of a single stack

g = Gravitational acceleration

$$D_{EFF} = \sqrt{\frac{4.G_0}{\left(T_a \diagup T_{EFF}\right) \times V_0}} \qquad \text{(Equation 5)}$$

Where:

D_{EFF} = Effective stack diameter

V_0 = Stack velocity (actual)

The stack velocity for other hours was derived using **Equation 7.**

$$V_{EFF(i)} = \frac{4.F_{EFF(i)}}{g \times V_0^2\left(1 - T_{a(i)} \diagup T_{EFF}\right)} \qquad \text{(Equation 6)}$$

Where:

$V_{EFF(i)}$ = Effective stack velocity for hour = *i*

$T_{a(i)}$ = Ambient temperature at stack elevation for hour = *i*

F_{EFF} = Effective buoyancy flux for hour = *i*

G_0 = Volume flux of a single stack

g = Gravitational acceleration

The resulting parameters ensure that the buoyancy flux is estimated in accordance with **Equation 1** and **Equation 3**, and that momentum flux is not overestimated. Whilst the contribution of momentum flux to final plume rise height is considered to be near to negligible, any underestimation considered slightly conservative.

[7] A necessary requirement to derive virtual stack parameters which allow the single stack momentum and volume flux to be unaffected, whilst allowing the modification of buoyancy flux in accordance with **Equation 3**.

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