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AGL Dalton Power Project Environmental Assessment

MP10-0035

Appendix D

Plume Rise Assessment

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Report

Plume Rise Assessment

AGL Gas-Fired Power Station at Dalton, NSW

28 OCTOBER 2009

Prepared for

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Introduction

1.1 Introduction

AGL Australia Pty Ltd (AGL) proposes to build an open cycle gas turbine power plant for peaking operation, with a capacity of up to 1500 MW.

The proposed facility (hereafter referred to as the Facility) is to be located north of Dalton, in south western New South Wales. AGL estimate the Facility would typically operate for approximately 15% of the year, or 1300 hours, during periods of peak demand.

Given the quantity, velocity and temperature of the exhaust gases emitted from the exhaust stacks, open cycle gas turbine plumes can travel at high velocities through the atmosphere. Exhaust temperatures upwards of 500 degrees Celsius and exit velocities of around 40 metres per second enhance the dispersion characteristics of the plume and reduce the ground level impacts of pollutants. However, this factor presents potential issues for aviation safety, where the high velocity of the exhaust gases can potentially affect the handling characteristics of aircraft, with the risk of airframe damage in extreme cases.

The purpose of this report is to present the information required to perform an aviation hazard analysis based on the predicted impacts of the Facility. The statistics have been compiled in coordination with the Civil Aviation Safety Authority's (CASA) Advisory Circular "Guidelines for Conducting Plume Rise Assessments" (June, 2004). This involved use of the CSIRO's The Air Pollution Model (TAPM) model which was used to create site-specific meteorological data, including meteorology for the upper atmosphere. TAPM was also used to calculate plume rise trajectories for the gas turbine emissions.

CASA considers an exhaust plume with a vertical velocity component of greater than 4.3m/s to be a potential hazard to aircraft stability during approach, landing, take-off and for low level manoeuvring in general. At these stages of flight the stability of the aircraft is critical, especially in situations where visibility is extremely poor, such that potentially hazardous areas cannot be identified visually, and pilots are reliant on instruments for navigation.

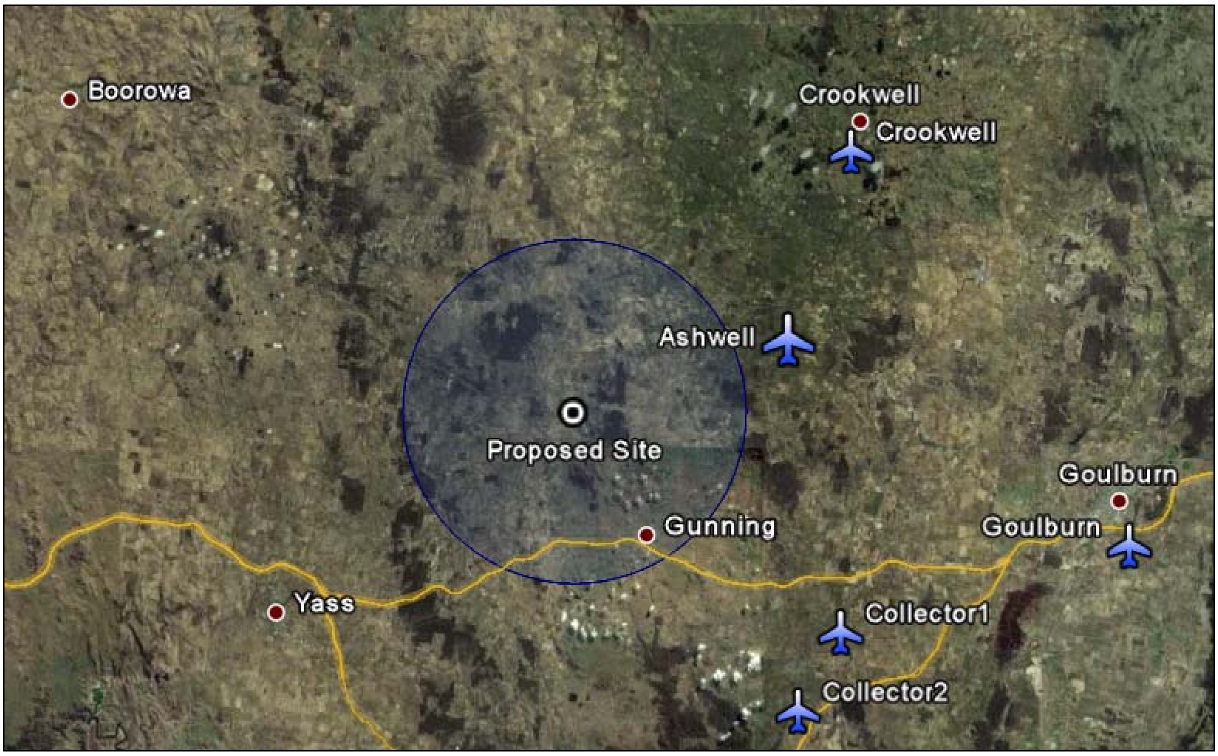
Therefore, industrial sources that may release exhaust plumes with a vertical velocity greater than 4.3m/s at the Obstacle Limitation Surface (OLS) of 110m above ground level (agl), must undergo a hazard analysis, such that suitable measures can be taken to manage the hazards described above.

Background

2.1 Proposed Location

The proposed Facility is to be located at a site approximately 13 km north-west of the central western New South Wales township of Gunning, and 50 km west-north-west of Goulburn. A review of aerial imagery of the locality indicates that aerodromes in the area are sparsely located, with no aerodromes understood to be situated within a 15 km radius[1] of the proposed site. **Figure 2-1** presents the location of the Facility relative to identified aerodromes, with a 15 km radius represented by the blue shaded region.

Figure 2-1 Proposed site and nearby aerodromes



(Image sourced from Google Earth Pro)

2.2 Proposed Operations

AGL propose the development of an open-cycle gas turbine peaking power station with a total generation capacity of up to 1500MW, and consisting of up to six gas turbines. AGL propose construction of the Facility in a staged approach, consisting of the following stages:

- **Stage 1**: Power generation of from 250 MW to 750 MW comprising:
  - two to four E Class machines ranging from 125 MW to 180 MW (total power generation of 250 MW – 720 MW); or
  - two to three F Class machines ranging from 200 MW to 250 MW (total power generation of 400 MW – 750 MW).

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[1] 15 km is typically the distance at which CASA consider a proposed facility to be remote from an aerodrome (CASA,2004)

- **Stage 2**: Power generation of up to a total of 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 of up to 1500 MW.

The Facility will consist of up to six turbine stacks, each separated by a distance of 50 m. **Table 2-1** shows each of the stack locations, as well as which stacks are present for each plant type and stage.

Table 2-1 Gas turbine 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

2.2.1 Exit parameters

The exit parameters on which this assessment is based are shown in **Table 2-2**.

Table 2-2 Exhaust stack parameters

Exit Parameter	Units	E Class Turbine	F Class Turbine
Stack Height (above ground level)	m	35	46
Stack Diameter	m	6	6.7
Exit Velocity	m/s	40	49.5
Exit Temperature	°C	532	610

It should be noted that the exit velocity for the F Class turbine has been scaled upward by 10% (from that assessed as part of the air quality impact assessment) in order to account for F Class turbine capacities of up to 250 MW, as is proposed by AGL for this project.

Modelling Methodology

3.1 Model Setup

The analysis performed in this report was conducted using The Air Pollution Model (TAPM), Version 3.07. TAPM was used in conjunction with meteorological data for 2006 collected from Bureau of Meteorology Automatic Weather Station (AWS) at Goulburn Airport. These meteorological data were incorporated into TAPM to assist in generating site-specific meteorology at the location of the Facility. The model was set to produce an output of the plume rise from a range of exhaust stack configurations. This output consists of vertical velocity, plume centreline elevation and radius of the plume. The plume elevation and radius are calculated from the plume's point of release, until it stabilises in the atmosphere. TAPM produces this output in intervals ranging from 1 to 5 seconds, for each source (exhaust stack), for every hour of the modelling period. This allows the elevation of the plume at the point at which it reaches 4.3m/s to be interpolated.

3.1.1 TAPM Configuration

The configuration of TAPM used in this assessment was based on the guidelines included in Attachment A of the Advisory Circular "Guidelines for Conducting Plume Rise Assessments" (CASA, 2004). This is with the exception of the specified modelling period of 5 years. The year 2006 was used in this assessment. Details of the TAPM configuration are given below:

- Grid centre coordinates 149º11'30''E longitude, -34º41'00''S latitude, (MGA94: 700778 mE, 6159887 mN);
- Meteorological grid consisting of four nests of 25 x 25 grid points at 30, 10, 3 and 1 km spacing, with 25 vertical grid levels from 10 to 8000 m;
- Hourly meteorological data from the Bureau of Meteorology Goulburn Airport AWS was assimilated into the model predictions on a 60 km radius of influence, and configured to affect the two lowest vertical levels (10 and 25m);
- Eulerian dispersion was used on the outer nests, whilst Lagrangian dispersion was used on the innermost nest;
- For merged emissions scenarios, buoyancy enhancement factors equal to the number of stacks for each respective plant type were used;
- 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 Bureau of Meteorology LAPS (Limited Area Prediction System) output;

3.1.2 Plume Merging

TAPM does not explicitly account for interaction between sources with regards to plume dynamics. Every source is treated separately, with its trajectory defined by its individual exit parameters and the surrounding meteorology. This is an inadequate representation for cases where, due to the presence of multiple exhaust stacks, the plumes merge and experience enhanced buoyancy. Contact between plumes results in a reduction of the entrainment of cooler static air, thus increasing the extent and rate of plume rise.

In this assessment, the 'Buoyancy Enhancement Factor' parameter in TAPM has been used with consideration of the methodology of Manins (1992) and Hurley (2005) to account for the additional plume rise due to the merging of the plumes. This methodology takes into account the number of stacks present, their separation, as well as the exit parameters of the exhaust gas, thus arriving at parameter called the Number of Effective Stacks for use as the Buoyancy Enhancement Factor in TAPM. In TAPM, this factor is used to scale the initial condition for buoyancy flux of a single plume, thus increasing the magnitude of the plume velocity throughout its rise.

Plume rise predictions for conditions favourable to plume rise imply that the difference between the Number of Effective Stacks and the number of stacks is negligible. This implies that under conditions favourable to plume rise the emitted buoyancy from the stacks is wholly combined into the merged plume.

Hence Buoyancy Enhancement Factors equal to the number of stacks (see **Table 3-1)** were used in this assessment. This is considered conservative under the majority of meteorological conditions, and appropriate for the conditions under which the greatest plume rise is predicted to occur.

3.2 Statistical Analysis

Plume rise statistics were developed using the TAPM gradual plume rise output in accompaniment with the upper air data derived from TAPM (at heights of 9.8 to1468 m above ground level). These data were processed to give the statistical representation of the plume's vertical and horizontal plume extent required for the assessment.

The height at which the plume velocity decreases to 4.3m/s was calculated through linear interpolation of the TAPM gradual plume rise output. This gives the critical vertical extent of the plume for each hour of the modelling period (i.e. the height at which the vertical velocity reaches 4.3m/s).

The critical horizontal plume extent was calculated using the TAPM gradual plume rise output, in conjunction with the TAPM generated upper air data. The plume is assumed to adopt the ambient horizontal wind velocity immediately (Hurley, 2005).

i.e.

$$\frac{dx_p}{dt} = u$$

where x_p = horizontal plume velocity;

t = time;

u = horizontal component of wind speed.

For each time step of the gradual plume rise file that is output from TAPM, the upper air data was linearly interpolated to give the horizontal wind speed at that point. The horizontal translation of the plume during this time step was calculated as a product of the interpolated wind speed, and the length of the time step. These were summed for each time step until the critical vertical velocity of 4.3m/s was reached. The plume radius (Ry) at this height was then added to the total to give the horizontal distance from the source to the extremity of the plume boundary, at the point at which a vertical velocity of 4.3 m/s was reached (i.e. critical horizontal extent).

Statistics for wind speed at specific elevations were calculated through linear interpolation of the upper air data, which was given at 20 heights. Whilst this profile follows a power-law trend, the error of linear interpolation is considered to be negligible, considering that the intervals between lower levels are smaller where change in wind speed with elevation is greatest. These results were then manipulated to give the various statistical representations required for the hazard assessment.

3.3 Assessment Scenarios

The modelling has considered six scenarios which are detailed in **Table 3.1**.

Table 3-1 Modelling scenarios and parameters

Scenario Name	Stack Height	Temperature (°C)	Velocity (m/s)	Diameter (m)	Buoyancy Enhancement
E Class - Single Turbine	35	532	40	6	1
E Class - Stage 1	35	532	40	6	4
E Class - Stage 2	35	532	40	6	6
F Class - Single Turbine	46	610	49.5	6.7	1
F Class - Stage 1	46	610	49.5	6.7	3
F Class - Stage 2	46	610	49.5	6.7	6

Single Turbine Scenarios

In the single turbine scenarios, the impact of a single turbine unit is assessed independently of neighbouring plumes. This is considered representative of a single turbine in operation. This scenario is also representative of the impact of multiple turbines operating in the absence of plume merging, and hence represents the lower bound of plume impact from multiple stacks. Given the exhaust parameters, and the close proximity of the stacks, it is unlikely that adjacent plumes will not merge, however this scenario is still useful for the purposes of defining a lower bound of potential plume impact.

Plant (Merged Emissions) Scenarios

For the plant type scenarios (Stages 1 and 2), a buoyancy enhancement factor has been applied in order to account for interactions between neighbouring plumes. The selected buoyancy enhancement factors assume that buoyancy is completely conserved as adjacent plumes are merged (see **Section 3.1.2** for further detail). Whilst some degree of buoyancy enhancement is inevitable, for the majority of conditions (especially moderate and high wind speeds) this represents a conservative assumption. Under conditions conducive to plume rise (when the greatest plume rise impact is generated), it is expected that buoyancy would be completely conserved until the complete merging of adjacent plumes. Hence the plant type scenarios are considered to represent the upper bound of the plume impact from multiple stacks, where the merging assumptions are conservative for the majority of meteorological conditions, and appropriate for conditions conducive to plume rise, when worst case impacts are predicted to occur.

Results

4.1 Local meteorology

The TAPM generated meteorology indicates that the region experiences moderate to high wind speeds, primarily from the north to north west, with an average wind speed of 4.38 m/s, and 1.4% calms (wind speeds less than 0.5m/s) recorded for the year 2006. This is largely consistent with meteorology of the region as presented in the air quality impact assessment for the project.

The TAPM predicted wind rose is provided in **Figure 4-1**.

Figure 4-1 TAPM generated wind rose for the Dalton site 2006, all hours, 10 m elevation

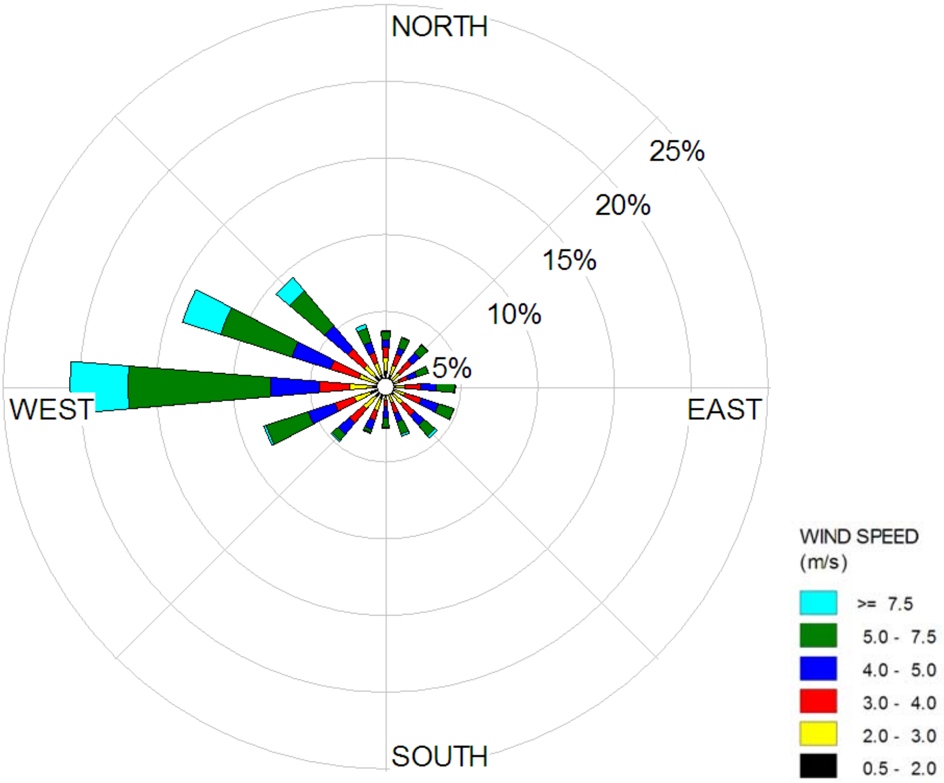
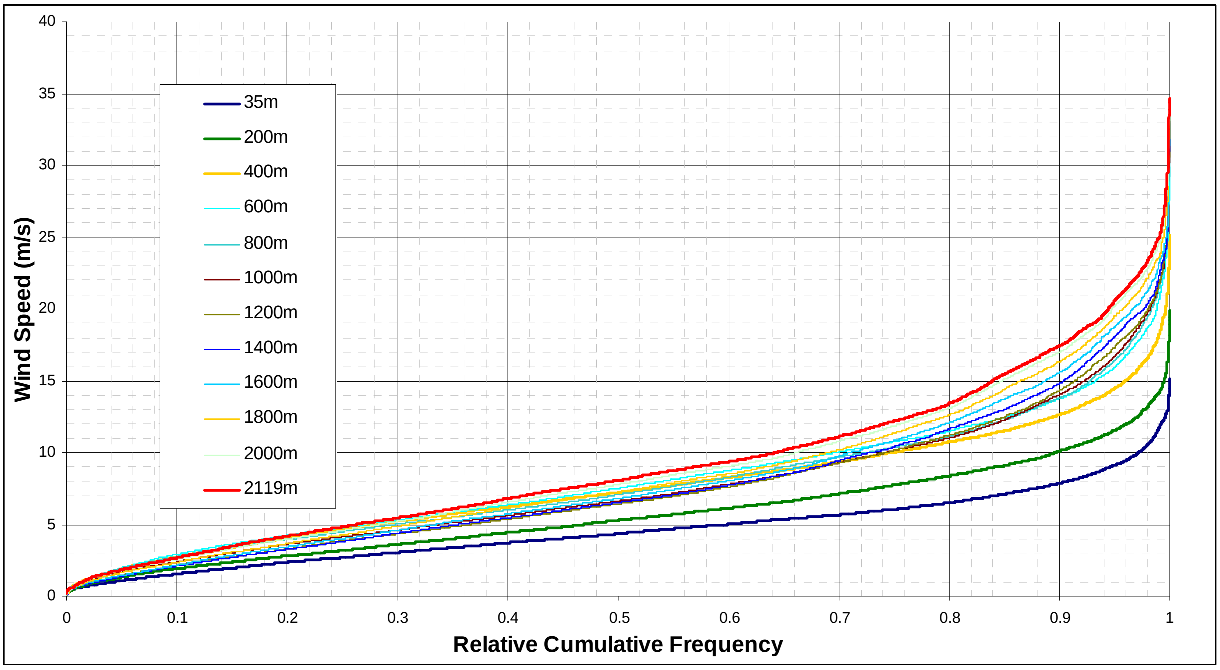


Figure 4.2 shows the relative cumulative frequency for wind speeds at various elevations. This figure represents the probability (at various elevations) of experiencing a wind speed less than or equal to a given value, based on the TAPM results for 2006. For example, at 35 m elevation, there is approximately 90% probability that the wind speed for a given hour is less than or equal to 8 m/s. The decreasing probability of low wind speeds with increasing elevation is indicated by rightward trend as elevation increases.

Figure 4-2 TAPM upper air wind speed relative cumulative frequency



Each row of **Table 4.1** displays the percentage of the year for which winds are less than the wind speed noted at the left of the row. The heights included range from the lowest point of release, to the highest point during the modelling period (across all scenarios) at which the plume velocity was predicted to depreciate below 4.3m/s.

Table 4-1 TAPM upper air wind speeds frequencies by percentage occurrence

Wind Speed	Elevation (m agl)										
	30	200	400	600	800	1000	1200	1400	1600	1800	2000	2119
<=0.1m/s	0.01%	0.01%	0.03%	0.01%	0.00%	0.03%	0.02%	0.05%	0.02%	0.02%	0.00%	0.00%
<=0.2m/s	0.05%	0.11%	0.09%	0.05%	0.05%	0.06%	0.06%	0.13%	0.07%	0.10%	0.05%	0.01%
<=0.3m/s	0.14%	0.23%	0.14%	0.14%	0.13%	0.17%	0.17%	0.23%	0.13%	0.21%	0.10%	0.05%
<=0.4m/s	0.42%	0.45%	0.24%	0.19%	0.21%	0.27%	0.29%	0.35%	0.29%	0.30%	0.27%	0.14%
<=0.5m/s	0.71%	0.62%	0.34%	0.26%	0.35%	0.45%	0.49%	0.50%	0.45%	0.45%	0.41%	0.25%
<=1.0m/s	4.11%	2.76%	1.29%	1.44%	1.48%	1.67%	2.28%	2.61%	2.31%	1.88%	1.59%	1.45%
<=1.5m/s	9.41%	6.16%	3.28%	2.98%	3.32%	3.95%	5.33%	5.70%	5.30%	4.20%	3.42%	3.00%
<=3.0m/s	29.1%	22.7%	11.9%	10.6%	11.7%	14.7%	17.4%	17.6%	16.2%	14.4%	12.7%	11.9%
<=5.0m/s	59.8%	46.8%	28.0%	26.9%	29.7%	33.7%	36.7%	35.6%	33.4%	31.0%	28.3%	26.3%

4.2 Plume Rise Statistics

The modelling results show that, as expected for an open cycle gas turbine facility, the plant will produce exhaust plumes with vertical velocities that exceed 4.3m/s above the OLS. **Table 4.2** displays the maximum, minimum and average critical plume extents. The critical vertical plume extent is the height (for a given hour modelled) at and below which, the vertical velocity (w) of the plume exceeds 4.3m/s. The critical horizontal plume extent is the total downwind translation of the plume boundary at the point at which the vertical velocity decreases to 4.3m/s. The maximum critical horizontal plume extent of 959 m was predicted to occur at a height of approximately 1860 m (see outermost contour of **Figure 4.11** for detail of variation of maximum critical horizontal plume extent with altitude).

Table 4-2 Maximum, minimum and average critical plume extents

	Critical Plume Extent (m agl)					
	Maximum		Minimum		Average	
Scenario	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
E Class Single Turbine	688	203	50	22	105	63
E Class Stage 1	1695	530	77	77	252	220
E Class Stage 2	1821	668	99	113	326	308
F Class Single Turbine	1120	280	67	33	153	98
F Class Stage 1	1740	601	98	91	294	257
F Class Stage 2	2119	959	148	172	451	455

It should be noted that that for the Stage 2 – F Class scenario, an internal limit within TAPM was reached for the two hours of the year where the first and third highest impact was predicted. This is due to a restriction within the model where plume rise is terminated after 5 minutes. For these two hours the plume rise profile was extrapolated to 4.3 m/s. Whilst the plume velocity is not linear with time, given the small amount of extrapolation (both profiles had decreased below 5 m/s at the file limit) any error is considered minor.

4 Results

Table 4.3 shows the critical vertical plume extent by percentage of time, for the year 2006. For example, the result of 839 m for 0.05% for the F Class single turbine scenario indicates that for 1 in every 2000 hours, the plume velocity exceeds 4.3m/s at a height greater than or equal to 839 m.

Table 4-3 Heights below which the vertical velocity exceeds 4.3m/s by percentage of 2006

	Height below which vertical plume averaged velocity >4.3 m/s (m agl)					
	E Class			F Class		
Percentage of time	Single Turbine	Stage 1	Stage 2	Single Turbine	Stage 1	Stage 2
100%	50	77	99	67	98	148
90%	59	121	161	83	148	237
80%	63	142	189	93	172	273
70%	68	162	216	101	195	309
60%	75	185	245	111	220	342
50%	84	212	276	126	249	378
40%	95	244	312	145	281	416
30%	113	281	352	171	319	467
20%	140	324	404	204	366	561
10%	185	409	532	254	473	757
9%	190	427	550	260	493	791
8%	197	444	578	268	511	826
7%	203	462	605	276	532	877
6%	210	488	645	288	567	930
5%	218	529	703	305	612	993
4%	227	569	773	324	676	1071
3%	242	642	857	345	762	1184
2%	269	746	1008	385	883	1316
1%	319	928	1194	454	1074	1484
0.5%	377	1067	1327	537	1216	1673
0.3%	421	1156	1404	626	1282	1760
0.2%	463	1213	1486	674	1345	1796
0.1%	539	1437	1675	747	1592	1863
0.05%	606	1547	1720	839	1647	1976

4 Results

Figure 4.3 is another representation of the data contained in **Table 4.3** and provides the critical vertical plume extent by percentile. For example, this figure indicates that for approximately 40% of the modelled hours, the vertical velocity of the F Class - Single Turbine plume decreases below 4.3m/s at or below 110 m elevation.

Figure 4-3 Critical vertical plume extent by percentile

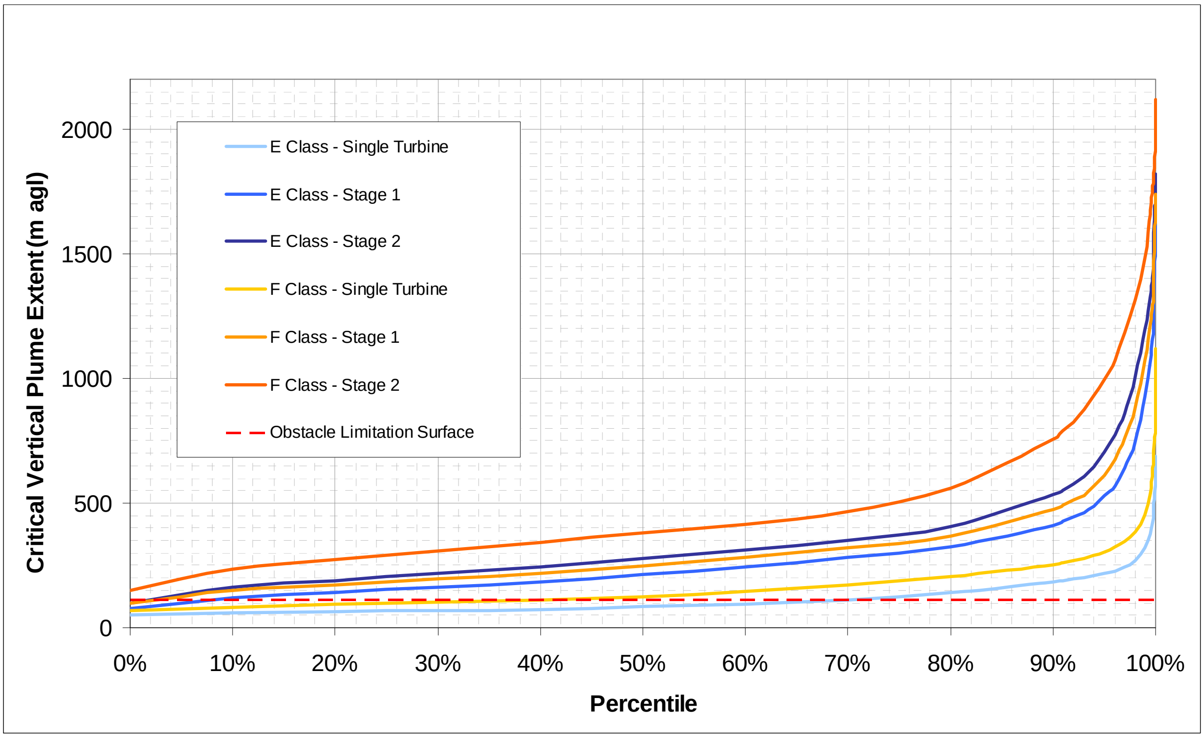


Figure 4.4 though to **Figure 4.9** illustrates the vertical and horizontal extent of the critical plume, giving the fraction of hourly meteorological cases that the plume vertical velocity exceeds 4.3 m/s. For example, in **Figure 4.4** for contour level 0.01 (1% of the time, or 87 hours per year), the critical vertical extent is greater than approximately 320 m and the critical horizontal extent approximately 120 m. It should be noted that the contour of 0.000114 is representative of the worst hour (1/8760 = 0.000114) and thus indicates entire region of space at which the vertical velocity was predicted to be greater than 4.3m/s for any instance during the year of 2006.

4 Results

Figure 4-4 Probability density plot representing the region of space for which the plume velocity exceeds the critical velocity of 4.3m/s – E Class Single Turbine

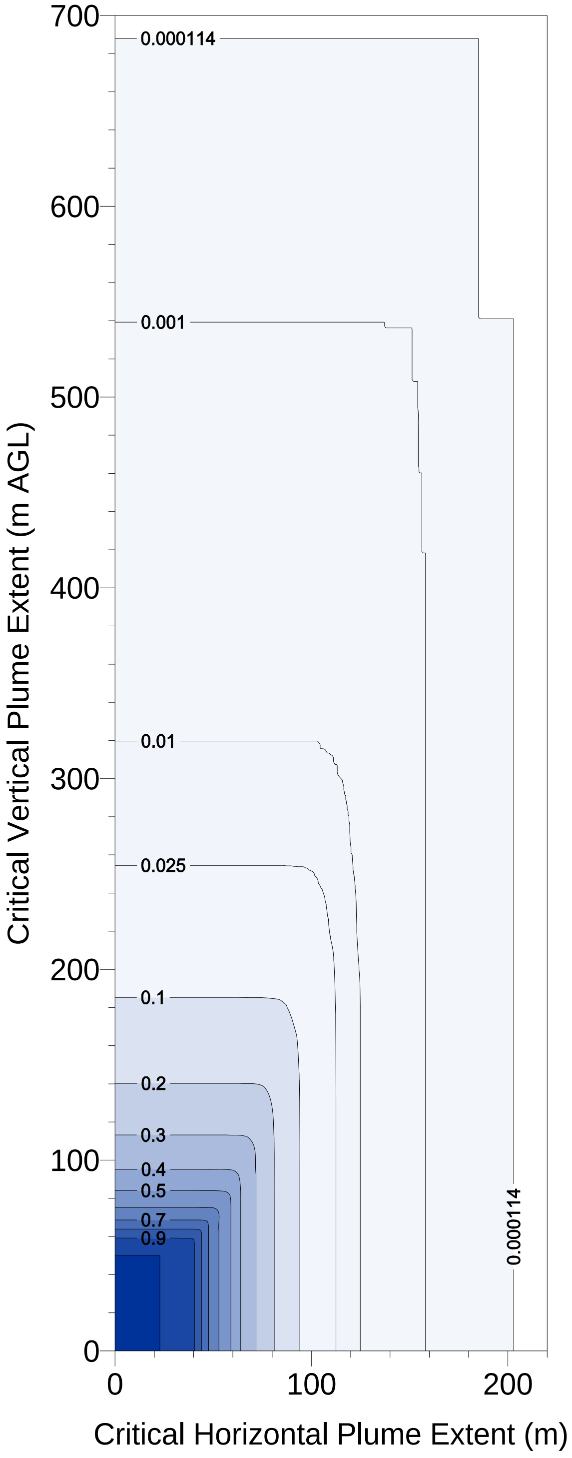


Figure 4-5 Probability density plot representing the region of space for which the plume velocity exceeds the critical velocity of 4.3m/s – E Class, Stage 1

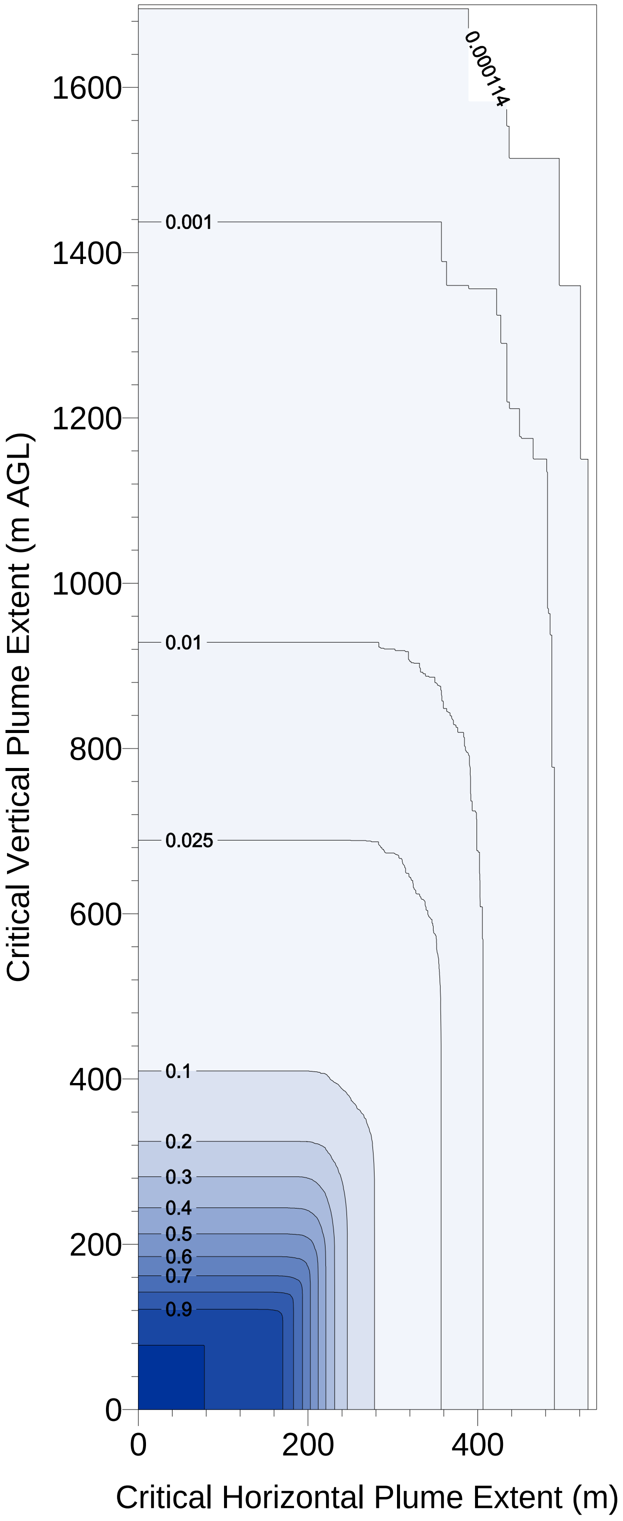


Figure 4-6 Probability density plot representing the region of space for which the plume velocity exceeds the critical velocity of 4.3m/s – E Class, Stage 2

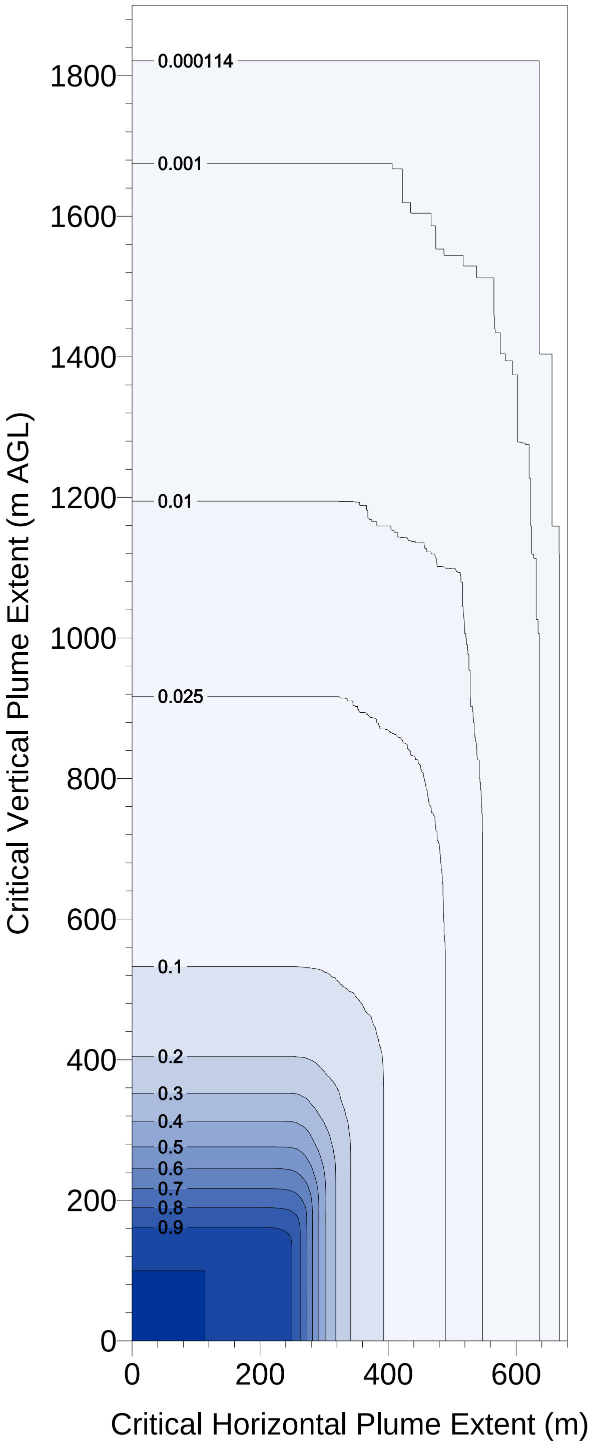


Figure 4-7 **Probability density plot representing the region of space for which the plume velocity exceeds the critical velocity of 4.3m/s – F Class, Single Turbine**

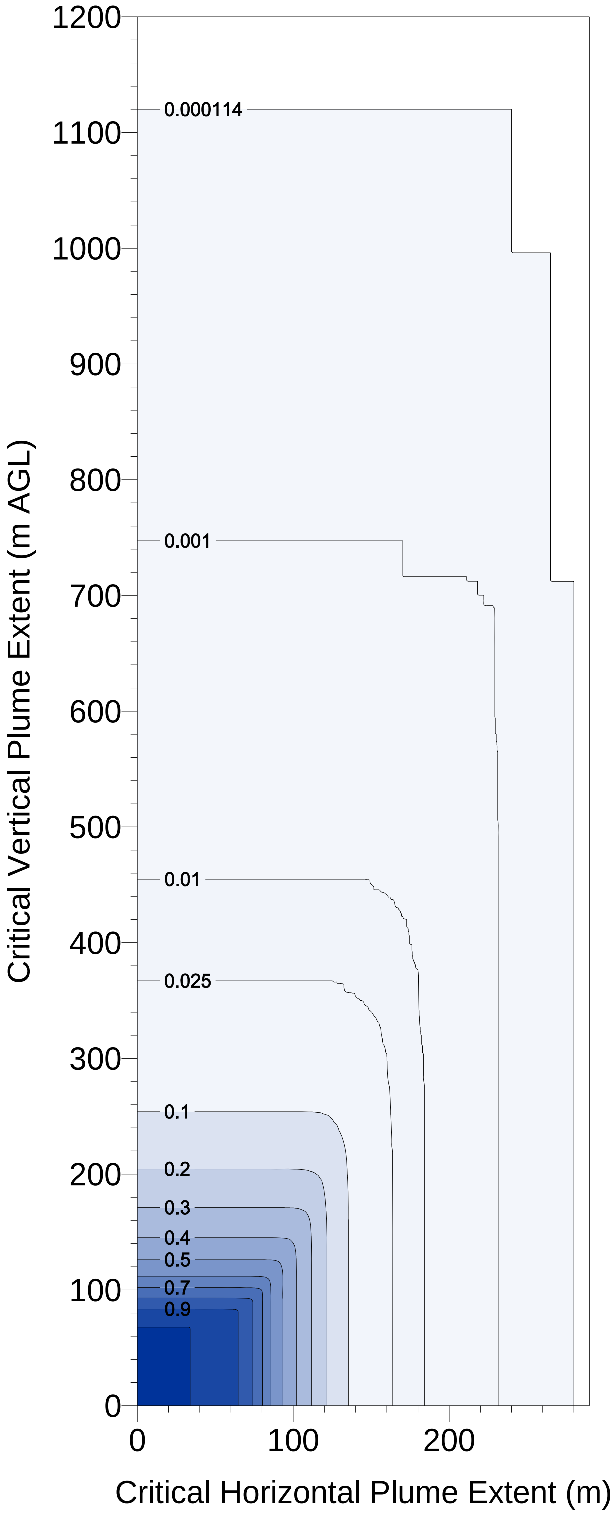


Figure 4-8 Probability density plot representing the region of space for which the plume velocity exceeds the critical velocity of 4.3m/s – F Class, Stage 1

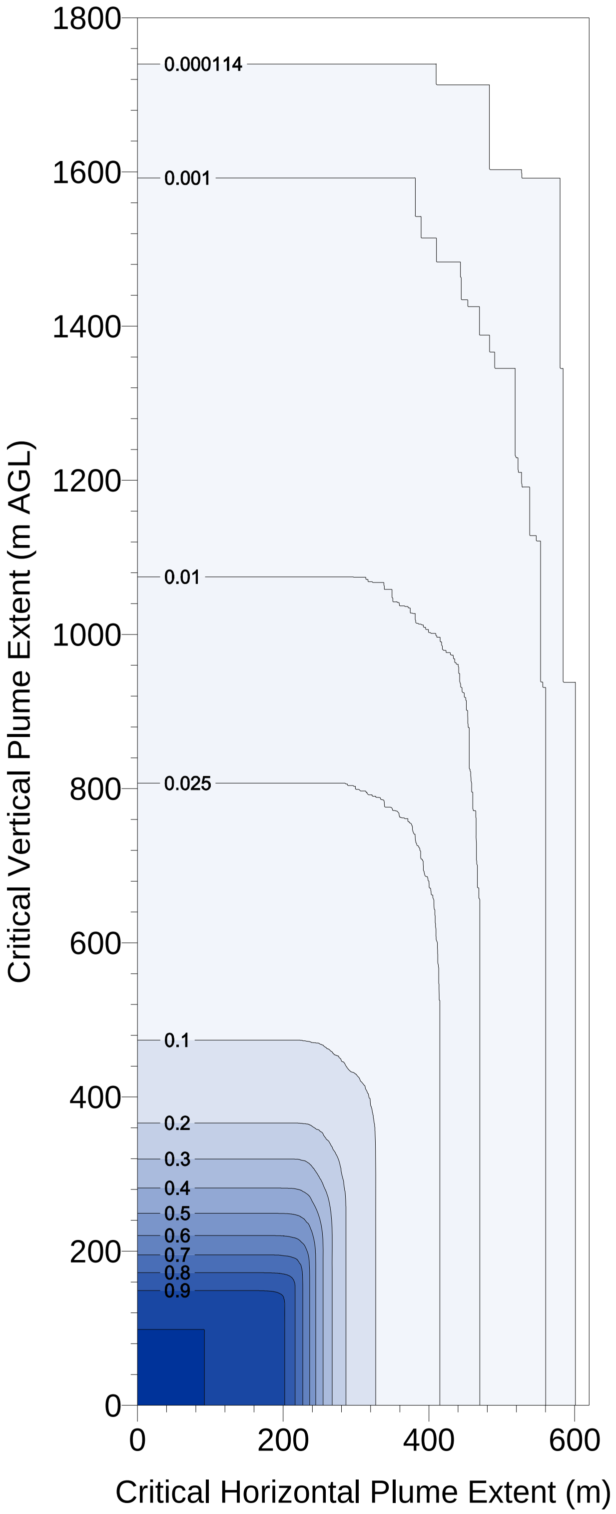
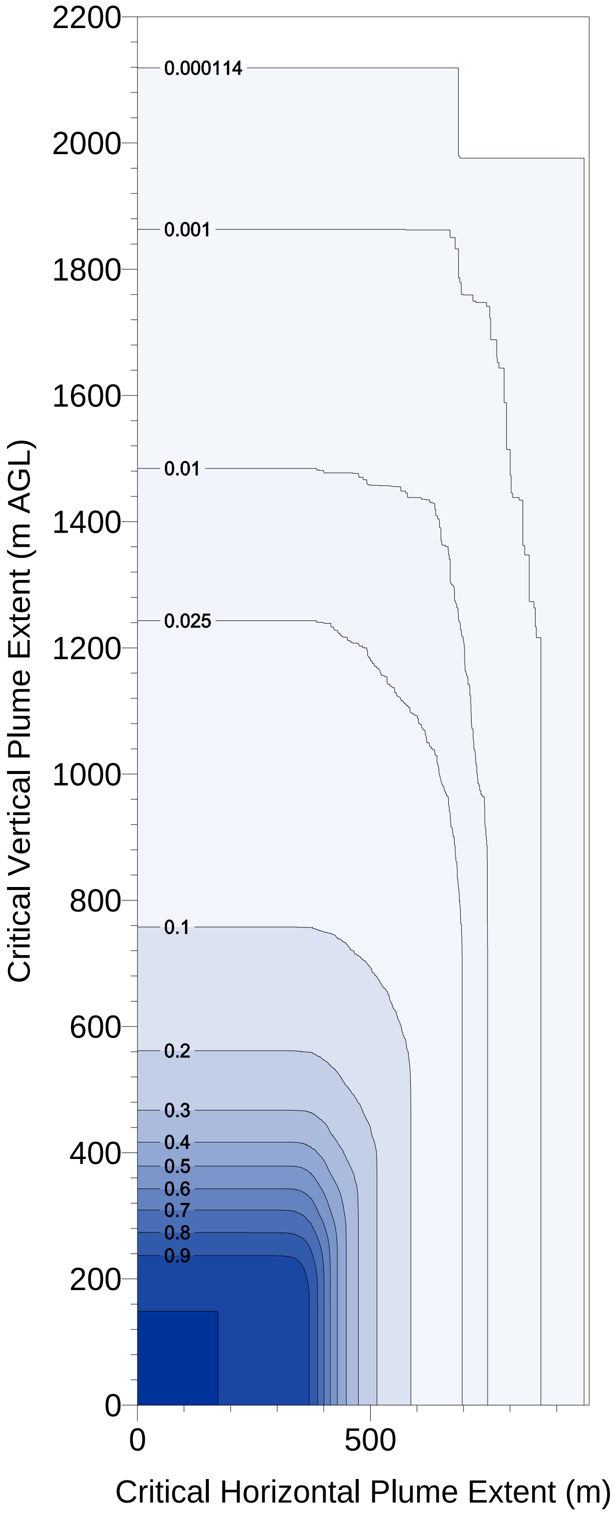


Figure 4-9 Probability density plot representing the region of space for which the plume velocity exceeds the critical velocity of 4.3m/s – E Class, Stage 2



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Conclusions

The Dalton Power Project has been assessed for its potential impact on aviation safety. This has been performed using the CSIRO's TAPM model to predict upper air meteorology, and plume rise profiles for each hour of the year 2006, such that the critical vertical extent of the plume (greatest height at which the plume averaged velocity slows to 4.3 m/s) could be estimated.

The assessment has considered six scenarios, which have indicated that thermal plumes from the Facility will penetrate the Obstacle Limitation Surface (OLS) of 110 m above ground level (agl) at velocities greater than the CASA-specified critical velocity of 4.3 m/s.

Assessment scenarios were based upon two approaches:

- **Single Turbine Scenarios -** In the single turbine scenarios, the impact of a single turbine unit was assessed independently of neighbouring plumes. This is considered representative of a single turbine in operation. This scenario is also representative of the lower bound of plume impact multiple turbines.

- **Plant (Merged Emissions) Scenarios -** For the plant type scenarios, a buoyancy enhancement factor was applied in order to account for interactions between neighbouring plumes. The selected buoyancy enhancement factors assumed that buoyancy was completely conserved until the complete merging of adjacent plumes under all meteorological conditions. Hence the plant type scenarios are considered to represent the upper bound of the plume impact from multiple stacks.

Given the greater degree of buoyancy enhancement that occurs under meteorological conditions conducive to plume rise, the merged emissions scenarios are considered most appropriate for maximum vertical extents, and conservative for the remainder of meteorological conditions.

Consideration should be given for the plant to be designated a potential hazard to aircraft operators in the area. The implementation of such designation is at the discretion of the Civil Aviation Safety Authority (CASA). It is proposed that further consultation with CASA will be undertaken following the detailed design stage. It is understood that CASA will require confirmation of any changes to the design that may affect the plume rise assessment. Prior to operation of the facilities, AGL would provide CASA with the following information:

- "As constructed" coordinates in latitude and longitude of the Facility;
- Final height (in AHD) of the buoyant sources; and
- Ground elevation of the site (in AHD).

References

- CASA (2004), *Advisory Circular AC 139-05(0) Guidelines for conducting Plume Rise Assessments*.
- Hurley, P J, CSIRO (2005) *The Air Pollution Model (TAPM) Version 3: Technical Description*;
- Manins, P C, (1992) *Plume Rise from Multiple stacks*, Clean Air (Australia) May 1992 Vol 26 Part2 pp 65-68;

6

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 Energy Limited 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.

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