EnergyAustralia

Delta electricity

Appendix I
Revised Plume Rise Assessment

MARULAN GAS TURBINE FACILITIES

SUBMISSIONS RESPONSE & PREFERRED PROJECT REPORT

VOLUME 2 | APPENDICES | May 2009

URS

REPORT

Revised Plume Rise Assessment for Marulan Gas Turbine Facilities

Prepared for

Delta Electricity & EnergyAustralia

10 October 2008

43217475

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Executive Summary

Delta Electricity and EnergyAustralia are proposing to construct and operate two separate gas turbine facilities at a site, which will be referred as *'Marulan Site'* in this report, located approximately 12 km north of Marulan, which is 25 km east of Goulburn.

Delta Electricity proposes to construct and operate a Gas Turbine Facility at the Marulan Site. Subject to final plant selection, the Delta Electricity Facility will comprise two gas turbine generators and will proceed in two stages. During Stage 1, the turbines will have a total capacity of between 250 and 350MW, where the turbines will be constructed in an open cycle configuration and operate in a peaking capacity. During Stage 2 the plant will have a total capacity of between 400 and 450MW where the turbines will operate in a combined cycle configuration for base load operation.

Operation of the Delta Electricity Facility during Stage 1 is expected to be approximately 500 hours of the year per turbine. Stage 2 operation may occur for up to 90% of the year.

EnergyAustralia also proposes to construct a similar gas turbine facility adjacent to the Delta Electricity Facility. The EnergyAustralia facility will be similar to the Stage 1 Delta Electricity Facility, and will comprise two turbines in the 175 MW range operating in an open cycle configuration, producing a total nominal facility output of 350 MW. The EnergyAustralia Facility will operate in a peaking capacity for up to 10% per year. The EnergyAustralia Facility is not currently proposed to operate in combined cycle configuration.

The assessment has been conducted as a cumulative assessment to address the potential impacts of both Facilities.

The proposed Gas Turbine Facilities have been assessed for their potential impacts 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 (height at which the plume average velocity slows to 4.3m/s) can be estimated.

The assessment has considered three scenarios:

Scenario #1: Both the Delta Electricity Facility Stage 1 and EnergyAustralia Facility plants operating in open cycle mode, with the assumption that plume merging between the two plants does occur;

Scenario #2: Both the Delta Electricity Facility Stage 1 and EnergyAustralia Facility plants operating in open cycle mode, with the assumption that merging between the two plants does not occur. This assumes independent behaviour of the plumes from each site, hence it is also representative of a single plant operating in open cycle mode;

Scenario #3: The Delta Electricity Facility Stage 2 exhaust stacks only operating in combined cycle mode.

The distances between stacks (plumes) can have a significant influence on the buoyancy of the plumes, as plumes that are located within proximity to each other will have a greater potential to merge, resulting in greater plume rise.

Further analysis of the plume radii at the critical vertical extent has indicated that for majority of hours, Scenario #2 is considered more representative of simultaneous operation. Furthermore, Scenario #2 results are considered more appropriate for consideration of the plume velocities at the OLS. Scenario #1 is considered most appropriate for the hours of greatest critical vertical extent.

Based on this assessment, for one year (2006) of modelled open cycle operation using TAPM, the OLS is exceeded during approximately 70% of the year, with an average critical vertical extent at 156m and 212m above ground level for Scenarios #1 and #2 respectively.

Furthermore, results for Scenario #3 indicate that the combined cycle Delta Electricity exhaust stacks will exceed the OLS for approximately 10% of the year, with an average critical vertical extent at 75m above ground level.

Executive Summary

Whilst this assessment is considered conservative with respect to the modelled operating times and operating 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).

Further consultation with CASA will be undertaken following detailed design. 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, CASA would need to be provided with the following information:

- “as constructed” coordinates in altitude and longitude of the Facilities;
- final height (in AHD) of the exhaust stacks; and
- ground level of the site (in AHD).

Section 1 Introduction

Delta Electricity and EnergyAustralia are proposing to construct and operate two separate gas turbine facilities at a site, which will be referred as *'Marulan Site'* in this report, located approximately 12 km north of Marulan, which is 25 km east of Goulburn.

Delta Electricity proposes to construct and operate a Gas Turbine Facility at the Marulan Site. Subject to final plant selection, the Delta Electricity Facility will comprise two gas turbine generators and will proceed in two stages. During Stage 1, the turbines will have a total capacity of between 250 and 350MW, where the turbines will be constructed in an open cycle configuration and operate in a peaking capacity. During Stage 2 the plant will have a total capacity of between 400 and 450MW where the turbines will operate in a combined cycle configuration for base load operation.

Operation of the Delta Electricity Facility during Stage 1 is expected to be approximately 500 hours of the year per turbine. Stage 2 operation may occur for up to 90% of the year.

EnergyAustralia also proposes to construct a similar gas turbine facility adjacent to the Delta Electricity Facility. The EnergyAustralia facility will be similar to the Stage 1 Delta Electricity Facility, and will comprise two turbines in the 175 MW range operating in an open cycle configuration, producing a total output of around 350 MW. The EnergyAustralia Facility will operate in a peaking capacity for up to 10% per year. The EnergyAustralia Facility is not currently proposed to operate in combined cycle configuration.

Given the quantity, velocity and temperature of the exhaust gases emitted from the exhaust stacks, 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 potentially presents 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 intent of this report is to present the information required to perform an aviation hazard analysis based on the predicted impacts of the proposed 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 (hereafter referred to as the *critical velocity*) 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.

Such plumes also potentially create risks to the structure of the aircraft, where the transient nature of the plume has the potential to overstress the frame.

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, must undergo a hazard analysis, such that suitable measures can be taken to prevent the hazards described above.

In order to ensure the potential impacts from the proposed development are adequately assessed, the assessment has investigated the cumulative impact on aviation safety from the emissions from both the Delta and EnergyAustralia Facilities. Despite the proposed operation in open cycle mode of approximately 5 % of the year for the Delta Electricity Facility and up to 10% of the year for the EnergyAustralia Facility, this assessment has modelled operation of both Facilities during every hour of the year 2006, such that probability distributions of plume rise are representative of a range of meteorological conditions.

Section 2 Background

2.1 Proposed Facilities

Nearby Airfields

The proposed Facilities are to be located north of Marulan. The nearest major airports are Goulburn (approximately 37km to the south west), and Mittagong (approximately 45km to the east north east). There are a range of small airfields in the region, the closest of which is Highland Farm, located approximately 5km to the east. **Figure 2.1** presents the location of the proposed plant relative to nearby airfields.

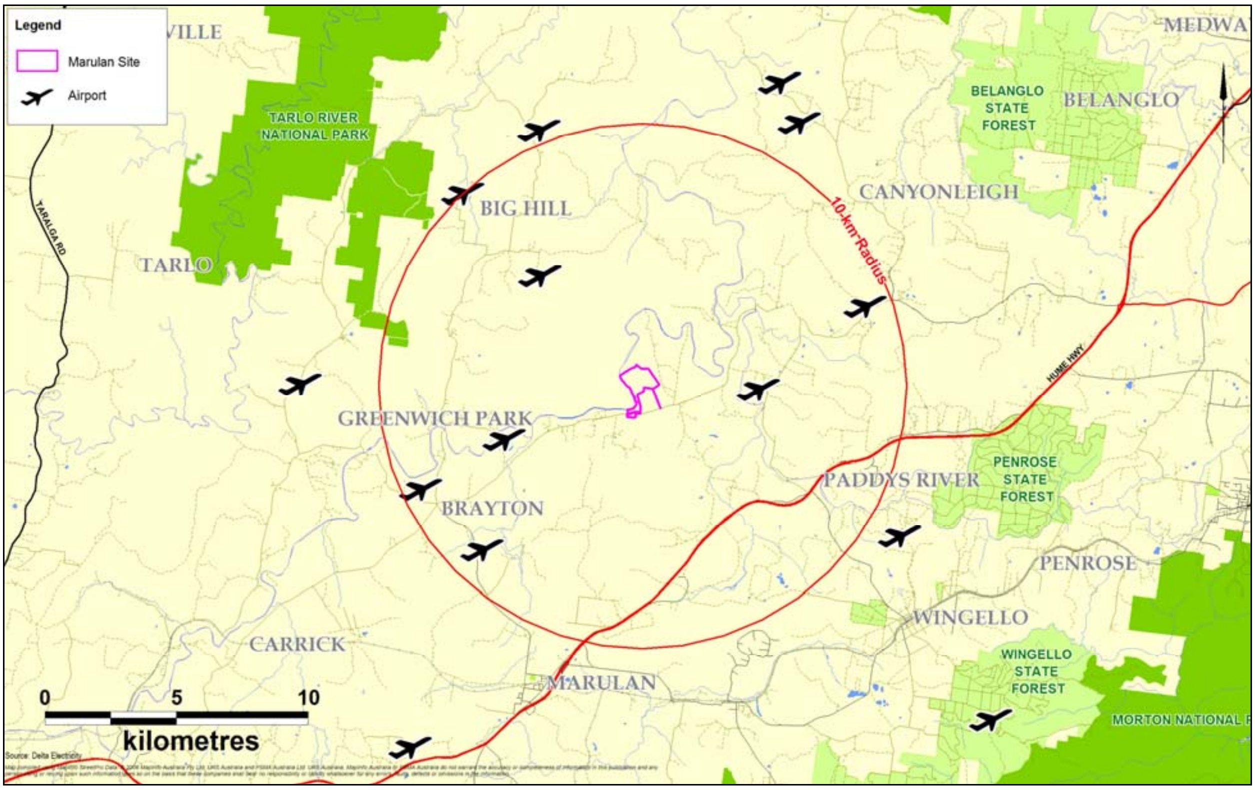


Figure 2-1 **Plant Location and Nearby Airfields**

Stack Locations

The indicative plant layout shows the exhaust stacks are oriented in a line from the north-west to south-east and at a base elevation of 605m Australian Height Datum (AHD). **Table 2-1** presents the locations of the four stacks used in this assessment. Further confirmation of the location of the final location will be provided to CASA following detailed design. **Figure 2-2** shows an indicative plant layout for the two facilities.

Section 2 Background

Table 2-1 Gas Turbine Stack locations

Proponent	Stack	Location (MGA94)		Base Elevation (mAHD)	Stack Height (m)
Delta	Stack 1	229384 mE	6166522 mN	605	40
	Stack 2	229424 mE	6166482 mN	605	40
EnergyAustralia	Stack 1	229144 mE	6166659 mN	605	30
	Stack 2	229171 mE	6166633 mN	605	30

As shown in the indicative plant layout (**Figure 2-2**) the two Delta Electricity stacks have been assumed in this assessment to be separated by a distance of approximately 60m, and the two EnergyAustralia stacks by a distance of approximately 40m. The separation of the two Facilities (taken as the distance between the centres of each pair of stacks) is approximately 285m. Furthermore, the separation between closest two neighbouring Delta and EnergyAustralia stacks is 240m.

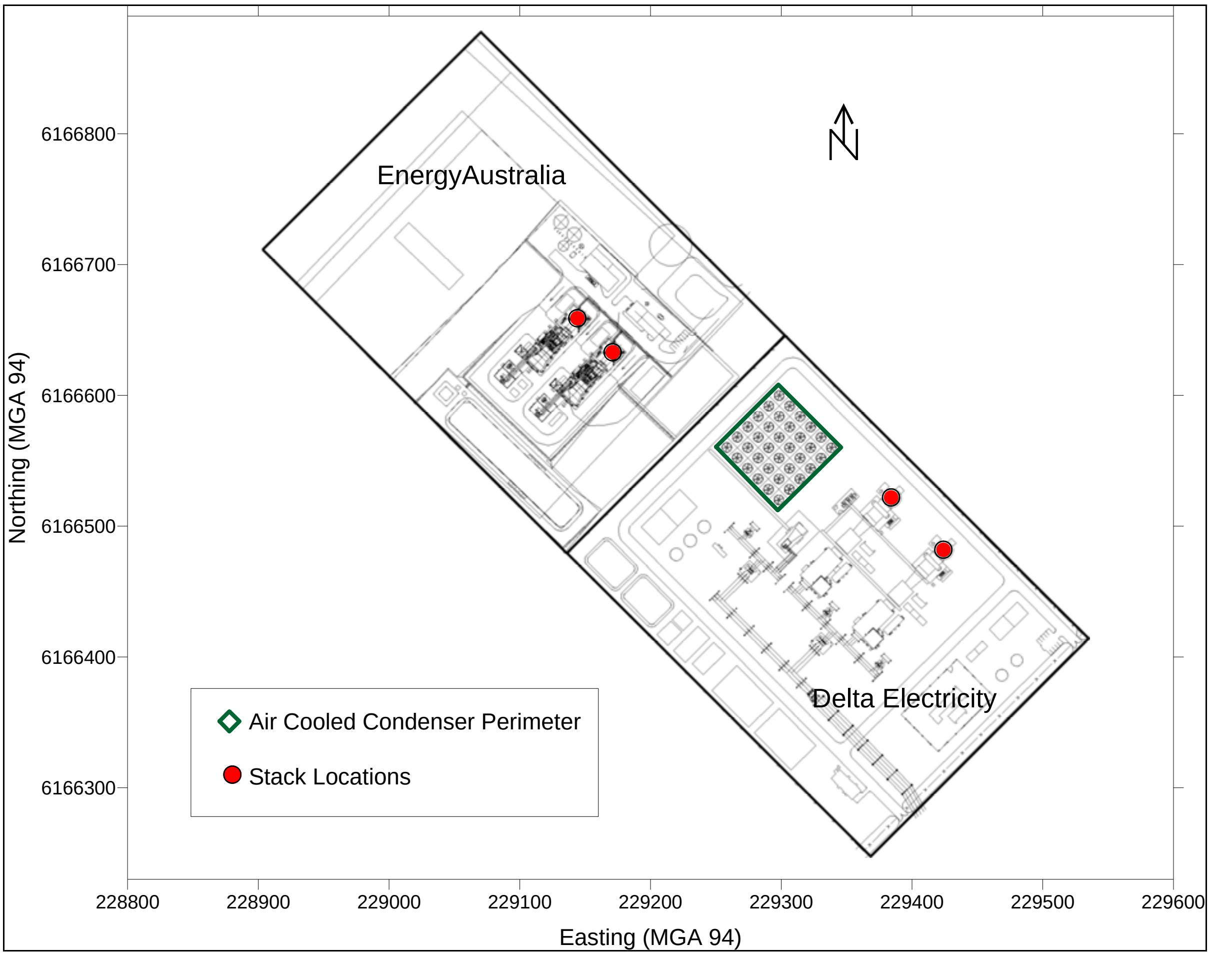


Figure 2-2 Indicative Delta Electricity and EnergyAustralia Facility Layouts

Section 2 Background

Stack Emission Parameters

Table 2-2 shows exhaust stack emission parameters for the range of operating states considered in the Air Quality Impact Assessment. Operational emission parameters are given for the turbine at full load, and are indicative of the upper limit of potential exit temperatures and exit velocities.

Table 2-2 Indicative Stack Emission Parameters

Stack Parameter	Units	Delta Electricity			EnergyAustralia	
Stack Height*	m	40			30	
Stack Diameter	m	6			6.5	
Scenario		Stage 1 - OCGT		Stage 2 - CCGT	Open Cycle	
		Start Up	Operational	Operational	Start Up	Operation
Exit Temperature	°C	398	532	125	398	532
Exit Velocity	m/s	27	40	20	23	34

*The platform height (from which the base of the stack is referenced) for the facility is 605m AHD.

Air Cooled Condenser

During Stage 2, the Delta Electricity Facility will operate in combined cycle configuration, where heat is recovered from the gas turbine exhaust to drive a steam turbine. This process necessitates a condenser, where the steam is cooled after exiting the steam turbine.

Delta Electricity proposes to use an Air Cooled Condenser (ACC) for this purpose, where ambient air is ducted through a heat exchanger medium. In order to improve the performance of the cycle, the ACC is configured to operate at a low temperature differential, hence it is large in size, and emits the air at around 20 degrees above ambient temperature. The physical perimeter of the ACC is outlined in the indicative layout contained in **Figure 2-2**.

The physical structure of the unit is elevated 30m from the ground, and uses base mounted axial blowers to drive air through heat exchanger elements mounted in a series of A-frame structures, which form the top of the ACC. Preliminary designs indicate the velocity of the air as it passes through the face to be 1.8m/s. Accounting for the additional surface area associated with the A-frame configuration, the effective vertical velocity of air passing through a plane directly above the ACC is 2.8m/s.

Under low wind speed conditions, there exists the potential for the ACC plume to accelerate to beyond 4.3m/s (as a result of buoyancy effects) and exceed the OLS. There also exists the potential for the ACC plume to merge with plumes from other sources on the Marulan Site. However, given the low exit velocity, and the relatively small quantity of thermal energy (as compared to open cycle operation) emitted from the ACC, this scenario is not considered to constitute the worst case scenario beyond that detailed in this assessment. This assessment has focused on the worst case scenario of open cycle operation, and has not quantified plume rise from the ACC.

Section 3 Modelling Methodology

3.1 Model Setup

The analysis performed in this report was conducted using CSIRO's "The Air Pollution Model" (TAPM). TAPM was used in conjunction with meteorological data collected from Automatic Weather Stations (AWS's) at Goulburn Airport, Lynwood and Berrima. The meteorological data methodology is further discussed in **Appendix A** of the Air Quality Assessment reports for both Delta Electricity and EnergyAustralia.

The model was also set to produce an output of the plume rise from the exhaust stacks. This output consists of plume averaged vertical velocity, plume centreline elevation and radius of the plume. The plume elevation and radius are measured 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 interpolation of the plume elevation, at the point at which it depreciates to the critical velocity of 4.3m/s.

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 –AC139-05(0) – June 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 –34°36'30'' latitude, 150°02'30'' longitude (MGA94: 228724mE, 6166410mN);
- 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;
- 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; and
- Goulburn Airport, Lynwood and Berrima meteorological data for the year 2006 were assimilated into the model predictions on a radius of influence of 15km, 15km and 13km respectively.
- Eulerian dispersion was used on the outer nests, whilst Lagrangian dispersion was used on the innermost nest;
- Buoyancy enhancement from multiple stacks was calculated according to the method described in Manins et al. 1992;

3.2 Meteorological Data Assimilation

The TAPM generated wind fields were influenced by local surface wind data for 2006, from Goulburn Lynwood and Berrima. They were configured to affect the lowest two levels of TAPM generated wind fields (9.8 and 24.8m). This was performed to improve the representation local meteorological conditions. TAPM typically has difficulty representing conditions in the surface layer when it is stratified, and/or turbulence is weak or intermittent. This forms a limitation of the assessment, where synthetic meteorology has been used in the absence of on site measurements of both surface and upper air meteorology. In similar assessments, where stack heights of less than 20m have been assessed, the incorporation of local Automatic Weather Station (AWS) data at the surface has resulted in a slightly more conservative assessment, with an increase in predicted maximum and average plume extents of around 10%. Given the greater stack heights being considered at Marulan (30 – 40m), meteorological predictions at the surface are considered to be of lesser importance.

3.3 Assessment Scenarios

Given the adjacent location of the two plants, the presence of two configurations for the Delta plant (OCGT and subsequent conversion to CCGT), and both operating and start up scenarios for each plant, there exist a number of permutations of operational states available for assessment.

The plume trajectory is calculated by TAPM through a numerical solution of a system of coupled first order differential equations, each of which quantify the finite changes in buoyancy, momentum and volume flux, as the plume moves through the atmosphere. The plume is treated using a "top hat" methodology, where the plume exists within a finite boundary, and physical quantities are averaged across the plume. For this reason, all quantities reported in this assessment are plume averaged, and do not represent peak velocities within the plume. Further detail of this methodology is provided in *The Air Pollution Model (TAPM) Version 3. Part 1:Technical Description* CSIRO (2005).

Table 3-1 provides the initial conditions for Buoyancy, Momentum and Volume Flux, as derived from the stack exit parameters. For a given atmospheric profile, the value of these initial conditions are indicative of the potential of a plume to progress upwards, where higher values indicate greater plume rise potential.

Table 3-1 Initial Conditions for Source Dependent Plume Rise Parameters

Initial Condition*		Delta Electricity			EnergyAustralia	
		Stage 1 - OCGT		Stage 2 - CCGT	Open Cycle	
	Units	Start Up	Operational	Operational	Start Up	Operation
Buoyancy Flux	$m^3.s^{-3}$	1325	**2224**	444	1325	**2219**
Momentum Flux	$m^4.s^{-2}$	2914	**5331**	2695	2482	**4520**
Volume Flux	$m^3.s^{-1}$	108	**133**	135	108	**133**

*Based on an ambient temperature of 298K (25°C).
Bold values indicate worst case plume emission values for each facility.

As can be seen in the table, for each plant, the open cycle operational scenario represents the worst case scenario for potential risks to aviation safety. The marginally higher volumetric flow (volume flux) for the Delta Electricity Facility Stage 2 is most likely due to a rounding simplification in the exit parameters, and is not considered to be indicative of greater plume rise potential.

Hence, the open cycle operational scenario is of key importance with respect to high plume rise velocities.

Plume Merging / Buoyancy Enhancement Factors

TAPM does not directly 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 plume rise. Contact between plumes results in a reduction of the entrainment of cooler static air, thus increasing the extent and rate of plume rise (relative to a single plume in isolation).

In this assessment, the 'Buoyancy Enhancement Factor' parameter in TAPM has been used in accordance with the methodology specified in Manins (1992). This factor is included to account for the additional plume rise due to the merging of the plumes. This methodology takes into account the number of exhaust stacks present, their separation, as well as the exit parameters of the exhaust gas, thus arriving at a Number of Effective Stacks (N_E) for use as the Buoyancy Enhancement Factor in TAPM.

Section 3 Modelling Methodology

In TAPM this enhancement factor is used to scale the initial condition for buoyancy flux (for a given individual source), thus increasing the magnitude of the plume velocity throughout its rise. As the plume progresses through the atmosphere, buoyancy flux is transferred to momentum flux, as the buoyancy forces act upon the plume. The modification of this initial condition is a method of incorporating the contribution to the buoyancy flux associated with entrainment of warmer gas from a neighbouring plume.

The use of the buoyancy enhancement factor to affect the initial conditions of the plume means that plume merging is incorporated into the calculation of plume velocity from the point of release, despite the fact that neighbouring plumes may not have yet made contact. Given that momentum effects are dominant (over buoyancy effects) in the early stages of plume development, for stacks with smaller separation this effect is considered to be minor and moderately conservative.

The calculation methodology for the Number of Effective Stacks is unable to treat sources with dissimilar separations, diameters, velocities, and exit temperatures. Given the uneven spacing, and the differences in height and diameter between the Delta and EnergyAustralia stacks, it was necessary to consider a combination of emission parameters that represent the worst case for potential impacts upon aviation safety.

- In open cycle configuration, for the purposes of this assessment, both the Delta Electricity and EnergyAustralia plants have identical volumetric flow, and exhaust temperature. Hence stack diameter, (and the resulting impact on exit velocity) represents the only difference in stack emission parameters between the two open cycle plants. The marginally worse case of the two proposed plants is the 6.0m stack, due to the slightly higher exit velocity of 40m/s.

- The proposed stack heights vary between 30 and 40m, with the 40m stack representing the marginally worse case.

Hence in the scenarios considered in this assessment, it has been assumed that each stack has an exit velocity of 40m/s and is 40m high.

Amongst other parameters, the Number of Effective Stacks (N_E) is dependent upon the final plume rise of a single plume in isolation. For two of the open cycle stacks, as considered in this assessment at a separation of 40m and under meteorological conditions favourable to plume rise, the rise of a single plume is such that the difference between Number of Effective Stacks (N_E) and the number of stacks is considered negligible. This implies that under conditions favourable to plume rise the emitted buoyancy from the two stacks is wholly combined into the merged plume.

On this basis, each pair of open cycle stacks has been amalgamated into a virtual stack, which has a cross sectional area equivalent to that of two individual stacks. The initial buoyancy, volume and momentum fluxes for the virtual stack are equivalent to the sum of the respective initial fluxes for two individual stacks, but with the assumption that the plumes are merged at the source. Trials in TAPM have indicated that under meteorological conditions favourable to plume rise, the difference in critical vertical extent of a virtual stack (representing two stacks) and a single stack with a TAPM Buoyancy Enhancement Factor of 2, is negligible. Hence for all but worst case meteorological conditions, this assumption is considered conservative, and for worst case conditions this is considered slightly conservative.

Through the use of a 'virtual stack' to represent each of the proposed open cycle Delta Electricity and EnergyAustralia Facilities, the larger separation (of approximately 290m) can be accounted for. Unlike for two stacks within a given plant (at 40m separation), for larger separation distance, the difference between the Number of Effective Stacks (N_E), and the Number of Stacks is significant, even under conditions favourable to plume rise.

Section 3 Modelling Methodology

Table 3-2 shows the parameters considered in this assessment.

Table 3-2 Stack Parameters by Scenario

Scenario Number	Temperature (°C)	Velocity (m/s)	Diameter (m)	N_E
#1	**532**	**40**	**8.48**	**1.7**
#2	**532**	**40**	**6**	**2**
#3	**125**	**20**	**6**	**2**

The three scenarios designated by the parameters in **Table 3-2** are considered to be representative of the following situations:

Scenario #1: Both the Delta Facility Stage 1 and EnergyAustralia Facility (plants operating in open cycle mode), with the assumption that merging between the two plants does occur;

Scenario #2: Both the Delta Facility Stage 1 and EnergyAustralia Facility (plants operating in open cycle mode), with the assumption that merging between the two plants does not occur. This assumes isolation of each Facility's plumes, hence it is also representative of a single plant operating in open cycle mode;

Scenario #3: The Delta Facility Stage 2 (exhaust stacks operating in combined cycle mode).

In order to provide an indication of whether a **Scenario #1 or Scenario #2** is appropriate for a given altitude, an investigation into the plume radius against the height of the critical velocity has also been made and is discussed in **Section 4.2.1**.

3.4 Plume Rise Statistics

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 10 to 1400 m above ground level). This data was 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 (between 9.3, 23.3 , 46.7, 93.4, 140, 187, 233, 280, 373, 467, 560, 700, 934, 1167, 1401, 1634, 1867, 2334, 2801 and 3268m). 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 processed to give the various statistical representations required for the hazard assessment.

Section 4 Results

4.1 Local meteorology

Bureau of meteorology data from the Goulburn Airport Automatic Weather Station indicates that the region experiences light to moderate wind speeds, primarily from the west and east, with an average wind speed of 4.09 m/s, and 11.8% calms (wind speeds less than 0.5m/s) recorded for the year 2006 inclusive. Further discussion of the meteorology of the region is provided in **Appendix A** to the main Air Quality Assessment Report.

Meteorology for the proposed development site was predicted using TAPM. The TAPM predicted wind rose is provided in **Figure 4-1**. TAPM has predicted a lower percent of calms (1.15%) than those observed in the region (e.g. Berrima 11%, Goulburn 11%, Moss Vale 7%). As discussed in **Section 3.2** the stack heights at Marulan imply that wind predictions at 10m (which TAPM has most difficulty representing) are not influential in plume rise outputs.

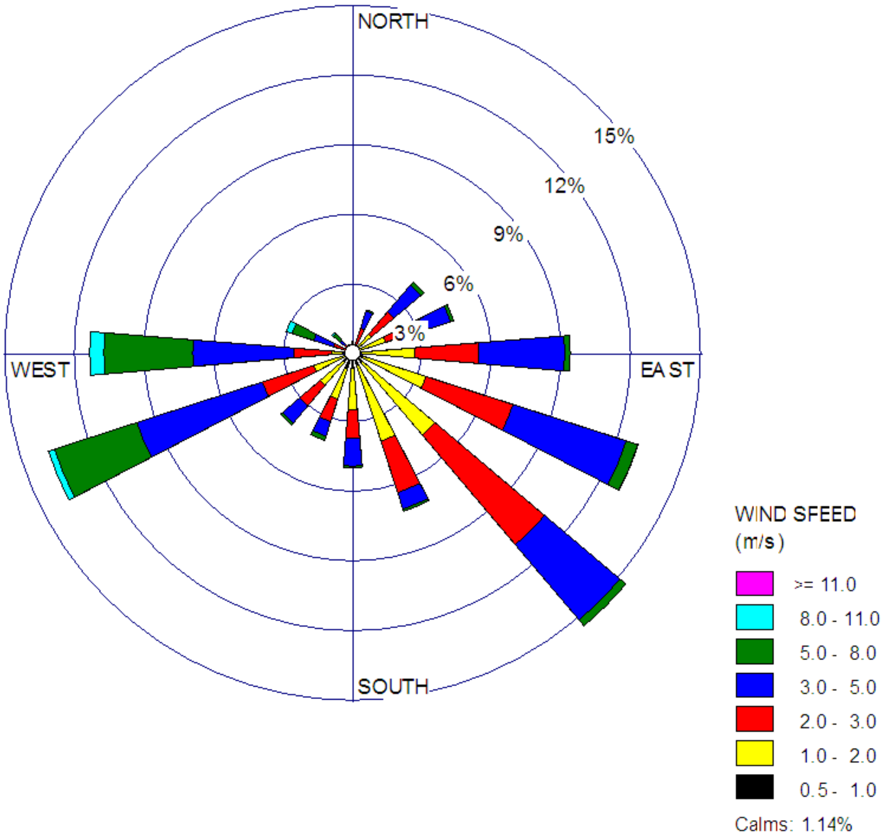


Figure 4-1 TAPM generated wind rose for Marulan 2006, all hours, 10m elevation

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 40m elevation, there is approximately 80% probability that the wind speed for a given hour is less than or equal to 5m/s. The decreasing probability of low wind speeds with increasing elevation is indicated by rightward trend as elevation increases.

Section 4 Results

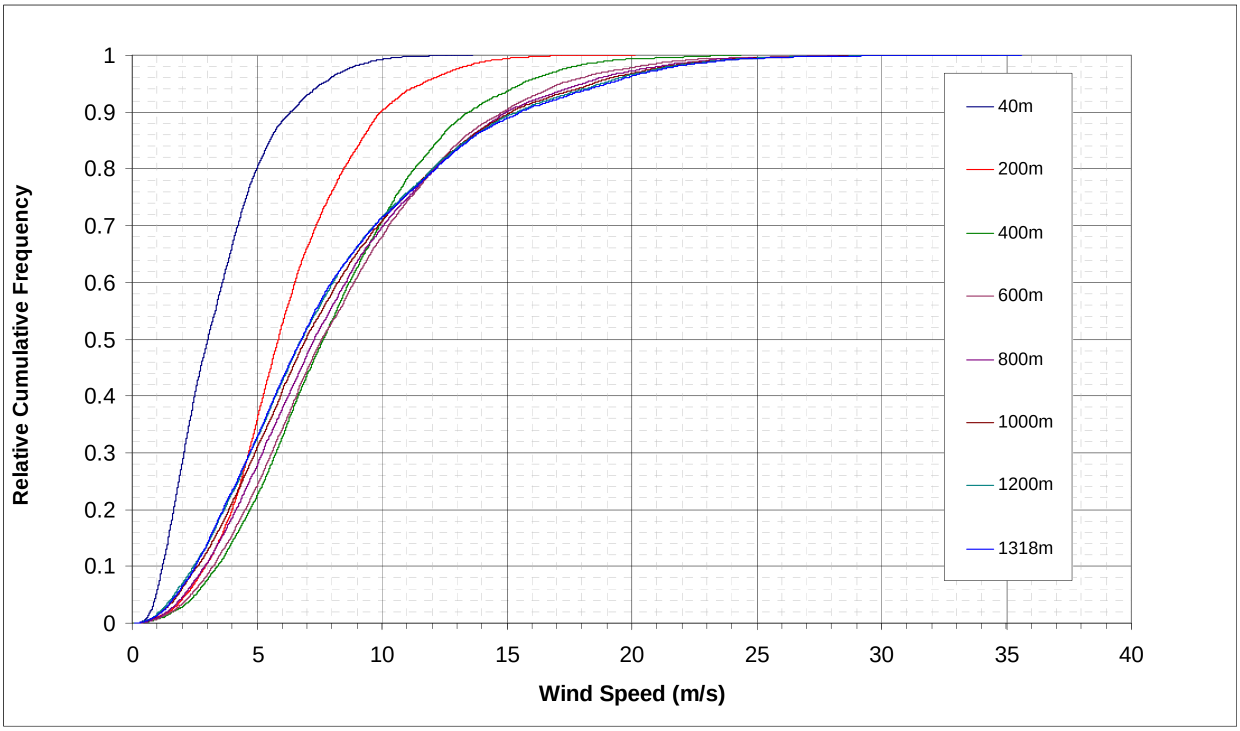


Figure 4-2 TAPM upper air wind speed relative cumulative frequency

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 point of release (top of exhaust stack), to the highest point during the modelling period at which the plume vertical velocity decays to below 4.3m/s.

Table 4-1 Wind Speed Frequency for Various Heights

Elevation Wind Speed	40m	200m	400m	600m	800m	1000m	1200m	1318m
<=0.1m/s	0.00%	0.01%	0.02%	0.00%	0.00%	0.00%	0.01%	0.00%
<=0.2m/s	0.01%	0.03%	0.03%	0.01%	0.00%	0.02%	0.05%	0.01%
<=0.3m/s	0.08%	0.05%	0.06%	0.03%	0.02%	0.07%	0.08%	0.08%
<=0.4m/s	0.23%	0.07%	0.10%	0.08%	0.10%	0.14%	0.23%	0.17%
<=0.5m/s	0.50%	0.18%	0.16%	0.11%	0.17%	0.31%	0.32%	0.31%
<=1.0m/s	5.72%	1.00%	0.70%	0.74%	0.92%	1.28%	1.62%	1.35%
<=1.5m/s	15.99%	2.07%	1.60%	1.71%	2.35%	3.26%	3.88%	3.40%
<=3.0m/s	49.53%	10.46%	7.60%	8.44%	10.55%	12.56%	13.72%	13.93%
<=5.0m/s	80.14%	35.70%	22.43%	24.10%	27.63%	30.87%	32.59%	32.74%

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.

Table 4-2 Maximum, Minimum and Average Critical Plume Extents

	Critical Plume Extent (m)					
	Scenario #1		Scenario #2		Scenario #3	
Statistic	Vertical	Horizontal	Vertical	Horizontal	Vertical	Horizontal
Maximum	1318	435	931	347	379	78
Minimum	76	79	61	51	47	17
Average	212	183	156	116	75	32

The critical vertical plume extent is the height (for a given hour modelled) at and below which, the plume averaged vertical velocity (w) exceeds 4.3m/s. The critical horizontal plume extent is the sum of the total downwind translation of the plume centreline, and the plume radius at the point at which the plume averaged vertical velocity decreases to 4.3m/s. For Scenario #1 the maximum critical horizontal plume extent of 435m occurs in the hour of the peak vertical extent of 1318m (see outermost contour of **Figure 4-6** for detail of variation of maximum critical horizontal plume extent with altitude).

For Scenario #1 the maximum predicted critical vertical plume extent was 1318m, which was predicted to occur on the 25/09/2006 during the 15th hour of the day. During this hour, calm conditions were present in conjunction with a mostly neutral atmospheric temperature profile. Low wind speeds resulted in minimal entrainment of cooler ambient air into the plume. These factors allowed the plume to conserve its buoyancy to a greater degree, causing it to rise at a greater velocity, and to a greater extent. **Figure 4-3** shows ambient wind speed, ambient potential temperature and vertical plume velocity for the hour in which the maximum of 852m was predicted. The dashed red line on the right hand plot indicates the critical vertical velocity of 4.3m/s.

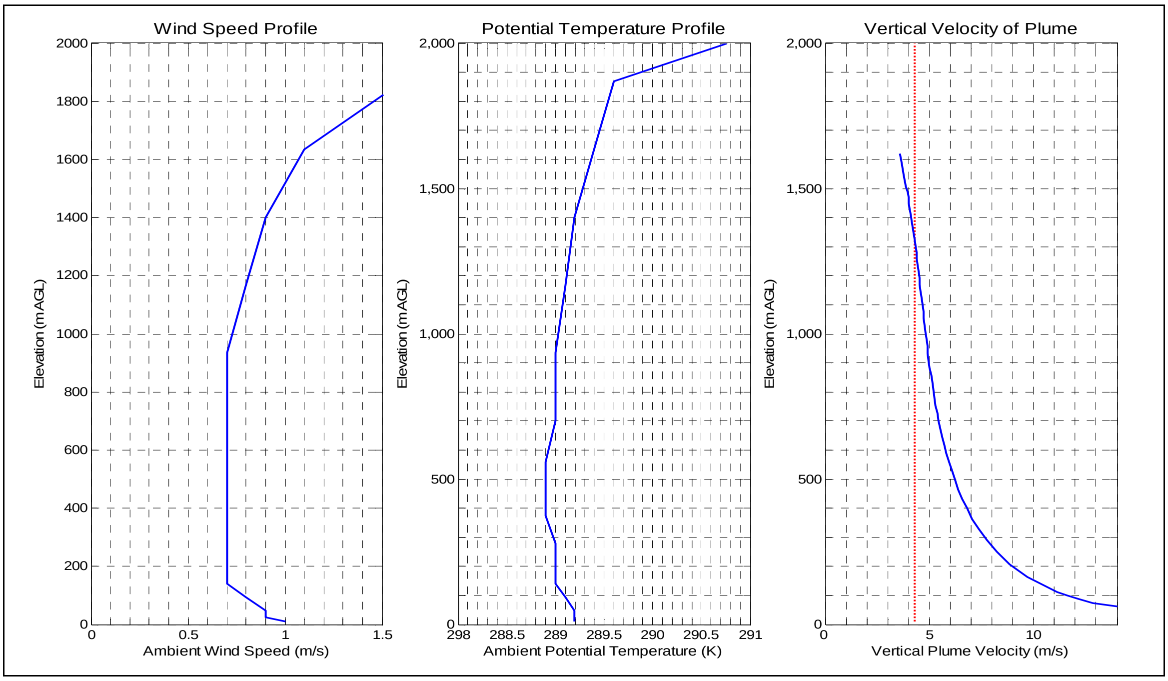


Figure 4-3 Model Predictions for Maximum Critical Vertical Extent: 25/09/2006, Hour 15

4.2.1 Plume Radii at Critical Vertical Extent

Figure 4-4 shows the horizontal plume radius at the point at which both the Delta Electricity and EnergyAustralia plumes (when each plant is assessed in absence of the other) reach the critical vertical velocity, for each hour of 2006. This has been included to provide an indication of whether the assumption of plume merging between the Facilities is appropriate for a given altitude. Given that there is approximately 240m between the closest two neighbouring Delta Electricity and EnergyAustralia stacks, the neighbouring plumes will first touch when the plume radius has grown to approximately half that of the distance between the stacks (i.e. 120m).

On this basis, **Figure 4-4** presents the plume radius against the critical vertical extent, for the source considered in Scenario #2 of this assessment. The figure indicates that except where critical extents are reached above 400m (as indicated by the points to the right of the dashed green line), the plumes from the neighbouring Delta and EnergyAustralia Facilities will not merge prior to the velocity decaying below the critical vertical velocity.

Hence, for elevations below 400m, it is considered that plume rise statistics for Scenario #2 are more appropriate than those for Scenario #1.

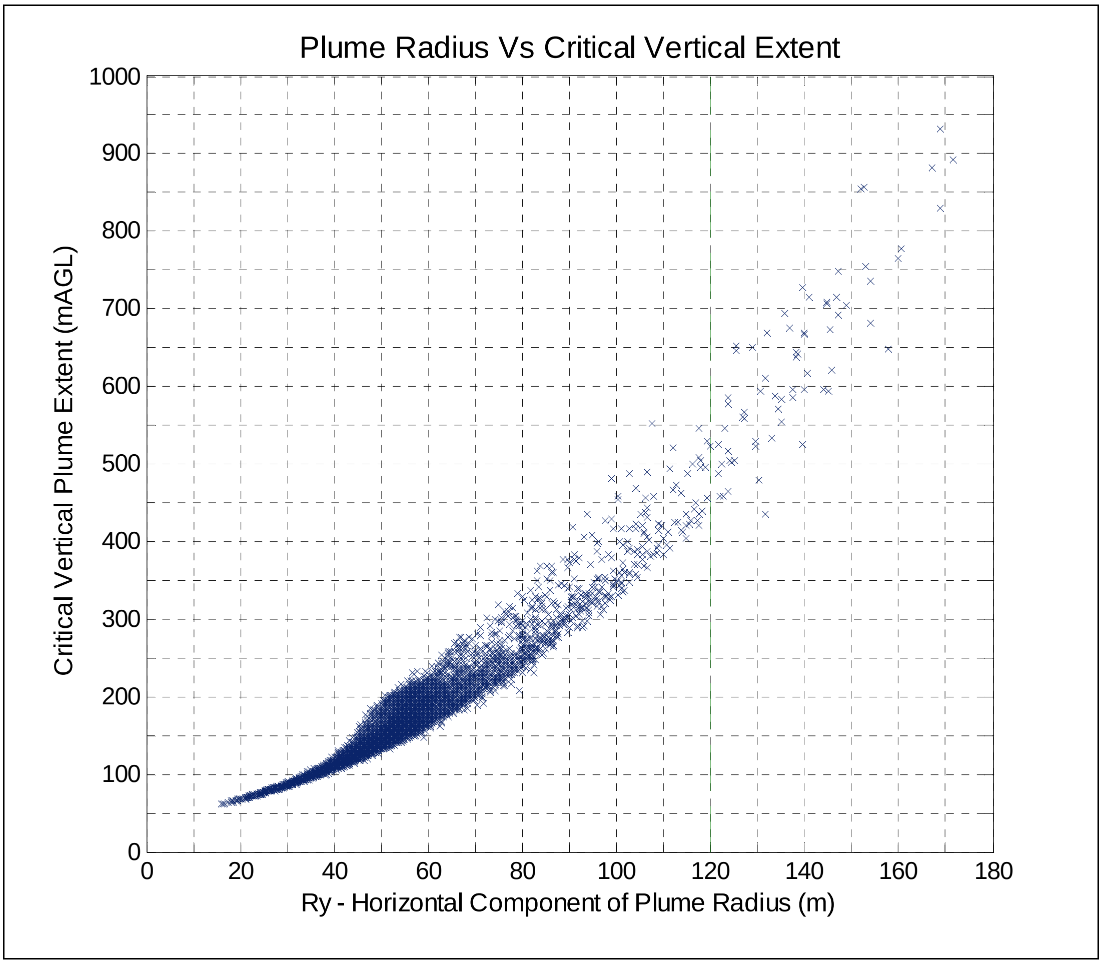


Figure 4-4 Plume Radius Vs Critical Vertical Extent - OCGT Operation

Section 4 Results

Table 4-3 shows the critical vertical plume extent by percentage of time, for the year 2006. The Scenario #1 result of 1080m for 0.05% indicates that based on the TAPM predictions for 2006, for 1 in every 2000 hours, the plume velocity exceeds 4.3m/s at a height greater than or equal to 1080m.

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

Percentage of time, 2006	Height below which *w* >4.3m/s (mAGL)		
	Scenario		
	#1	#2	#3
100%	76	61	47
90%	122	90	53
80%	141	103	56
70%	158	115	59
60%	174	127	62
50%	191	140	66
40%	208	155	71
30%	227	172	80
20%	249	193	92
10%	309	225	112
9%	321	231	115
8%	333	240	118
7%	353	249	121
6%	374	261	125
5%	397	275	129
4%	428	297	133
3%	468	324	140
2%	540	366	150
1%	670	457	172
0.5%	837	584	191
0.3%	892	652	215
0.2%	941	695	229
0.1%	1012	755	253
0.05%	1080	857	279

Figure 4-5 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 Scenario #3, approximately 90% of the time, the vertical velocity of the plume decreases to 4.3m/s at or below 110m elevation.

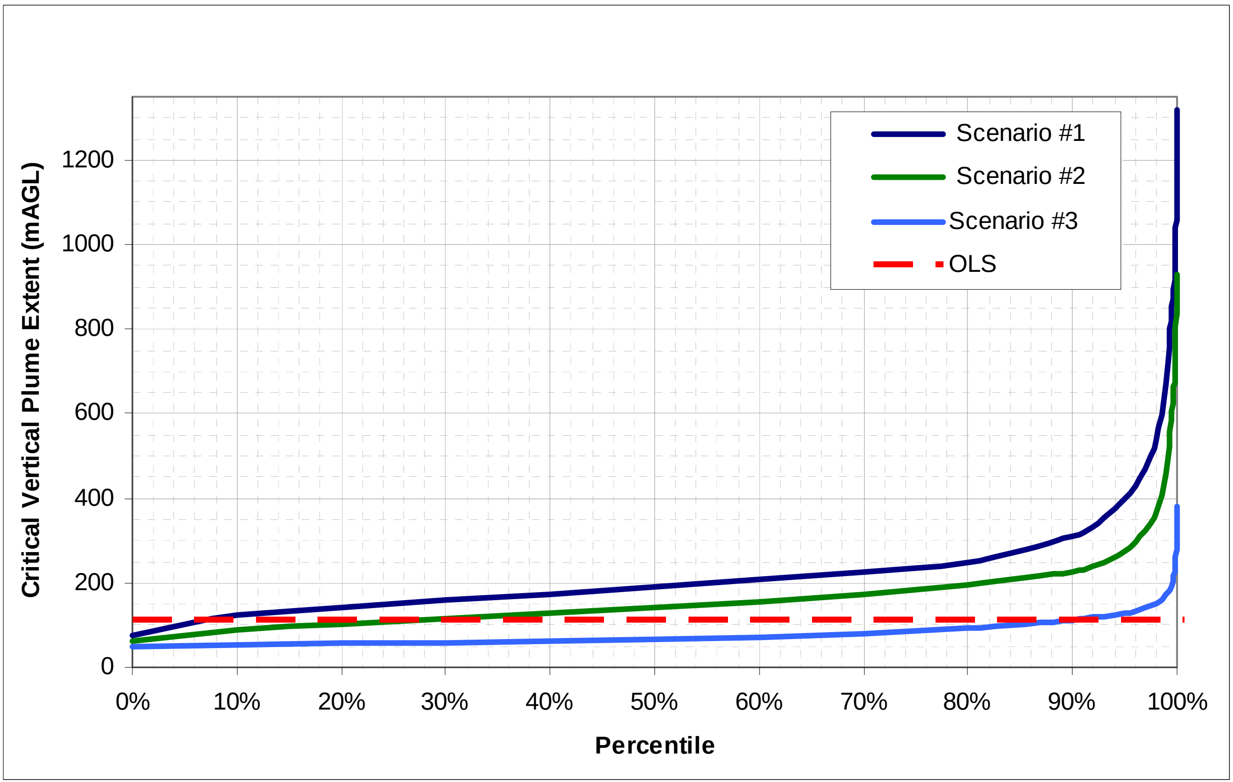


Figure 4-5 Critical vertical plume extent by percentile

Figures 4-6 to 4-8 illustrate the vertical and horizontal extent of the critical plume as probability density contours. These figures indicate the fraction of time that the plume vertical velocity exceeds 4.3 m/s. For example, for Scenario #1, the contour level 0.01 indicates that 1% of the time (or 87 hours per year), the plume height is approximately 670m and the corresponding total horizontal extent is around 300m. 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 hour during the year of 2006.

Figure 4-6 Scenario #1 - Probability density plot representing the region of space for which the plume averaged velocity exceeds the critical velocity of 4.3m/s.

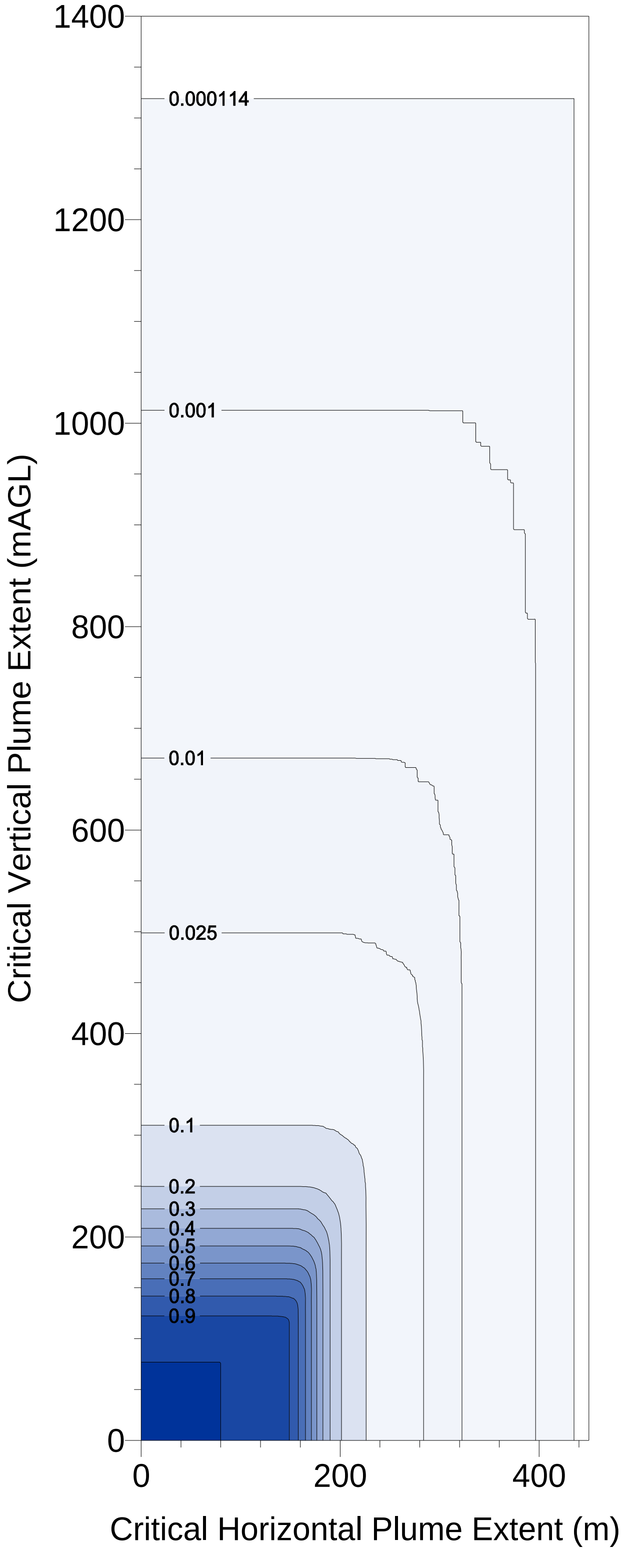


Figure 4-7 Scenario #2 - Probability density plot representing the region of space for which the plume averaged velocity exceeds the critical velocity of 4.3m/s.

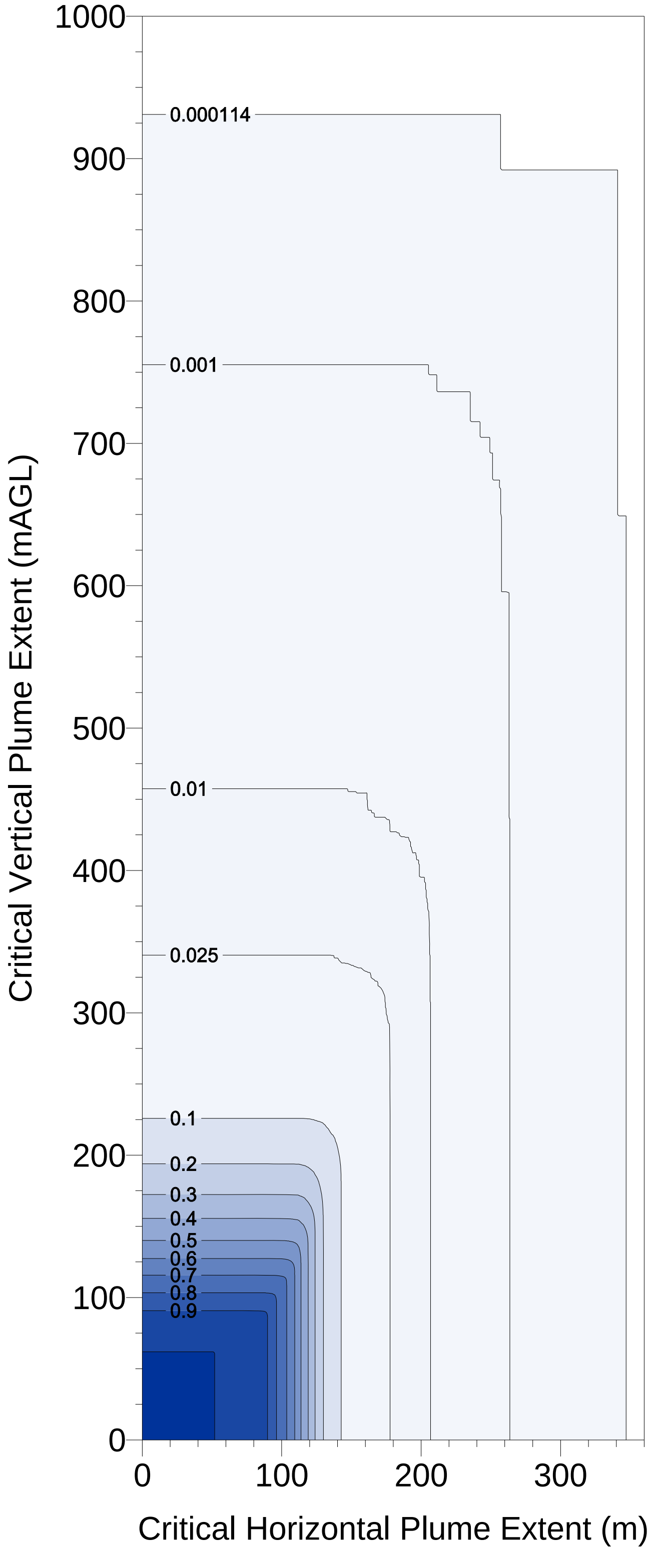
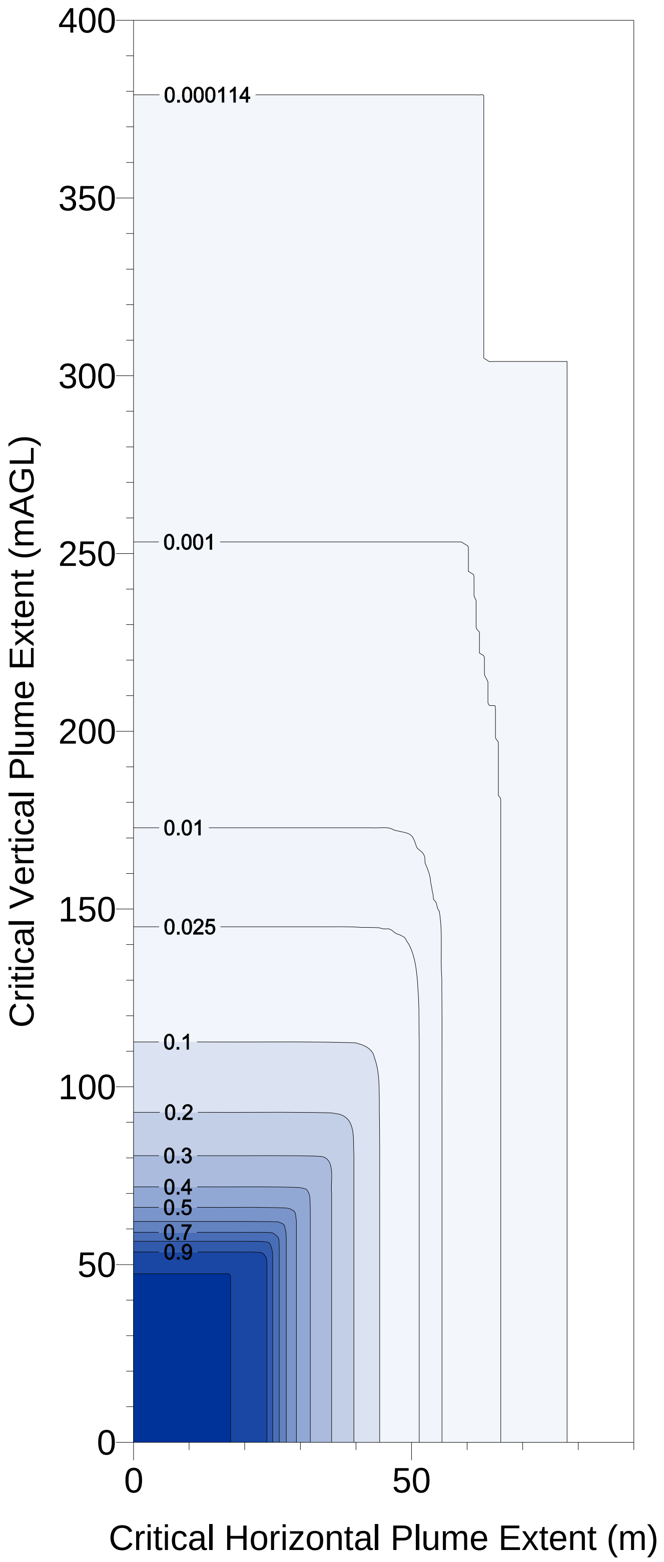


Figure 4-8 Scenario #3 - Probability density plot representing the region of space for which the plume averaged velocity exceeds the critical velocity of 4.3m/s.



Section 5 Conclusion

The proposed Gas Turbine Facilities have been assessed for their potential impacts 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 (height at which the plume averaged velocity slows to 4.3m/s) can be estimated.

The assessment has considered three scenarios:

Scenario #1: Both the Delta Electricity Facility Stage 1 and EnergyAustralia Facility plants operating in open cycle mode, with the assumption that plume merging between the two plants does occur;

Scenario #2: Both the Delta Electricity Facility Stage 1 and EnergyAustralia Facility (plants operating in open cycle mode), with the assumption that merging between the two plants does not occur. This assumes isolation of the two plumes, hence it is also representative of a single plant operating in open cycle mode;

Scenario #3: The Delta Electricity Facility Stage 2 exhaust stacks only operating in combined cycle mode.

The distances between stacks (plumes) can have a significant influence on the buoyancy of the plumes, as plumes that are located within proximity to each other will have a greater potential to merge, resulting in greater buoyancy.

Further analysis of the plume radii at the critical vertical extent indicated that for the majority of hours, Scenario #2 is considered more representative of simultaneous operation. Furthermore, Scenario #2 results are considered more appropriate for consideration of the plume velocities at the OLS. Scenario #1 is considered most appropriate for the hours of greatest critical vertical extent.

Based on this assessment, for one year (2006) of modelled open cycle operation using TAPM, the OLS is exceeded during approximately 70% of the year, with an average critical vertical extent at 156m and 212m above ground level for Scenarios #1 and #2 respectively.

Furthermore, results for Scenario #3 indicate that the combined cycle Delta Electricity exhaust stacks will exceed the OLS for approximately 10% of the year, with an average critical vertical extent at 75m above ground level.

Whilst this assessment is considered conservative with respect to the modelled operating times and operating 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).

Further consultation with CASA will be undertaken following detailed design. 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, CASA would need to be provided with the following information:

- "as constructed" coordinates in altitude and longitude of the Facilities;
- final height (in AHD) of the exhaust stacks; and
- ground level of the site (in AHD).

Section 6 References

Hurley, Peter 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;

CASA (2004) *Advisory Circular AC 139-05(0) Guidelines for conducting Plume Rise Assessments.*

Section 7 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 Delta Electricity 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 14 February 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 September and October 2008 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.

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