Appendix C

Plume Rise Assessment

Contents

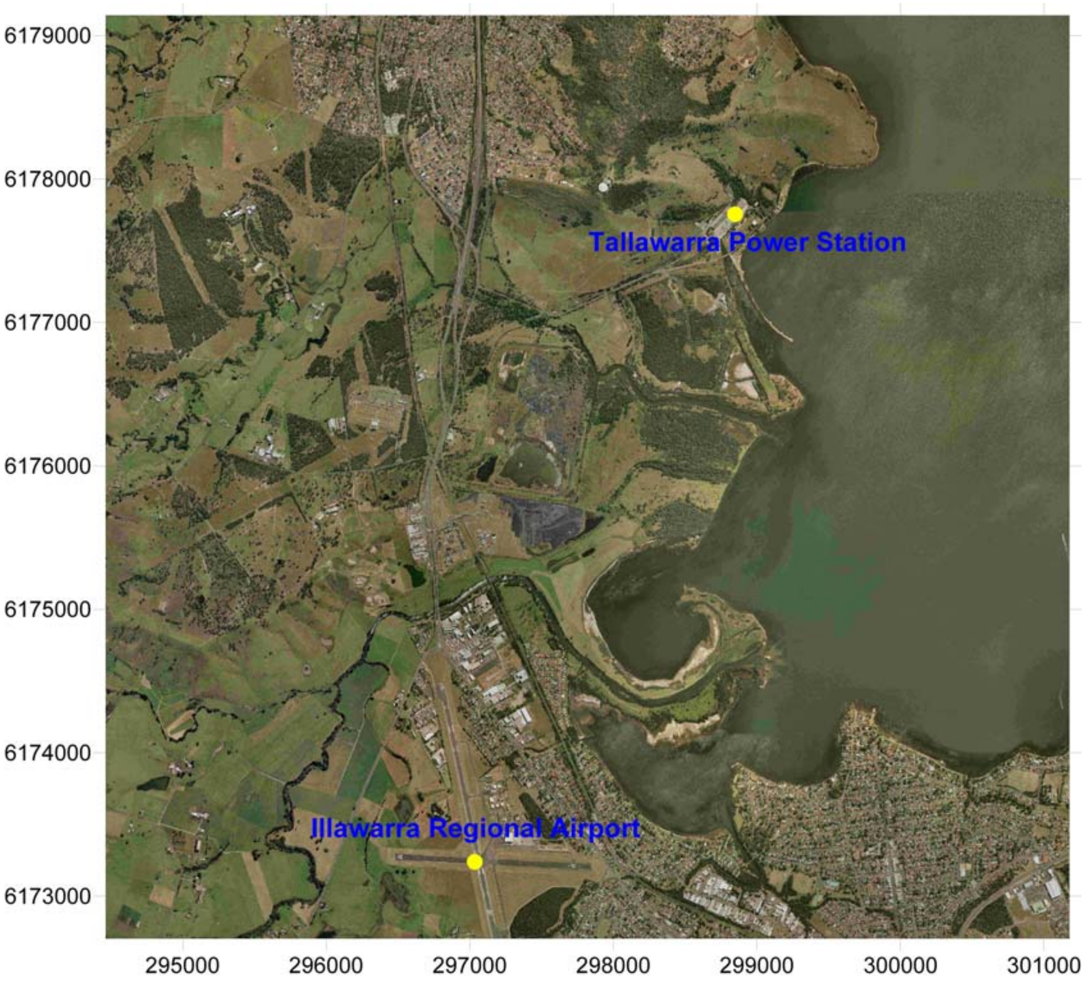
1. Introduction

1.1 General Introduction

TRUenergy has recently commissioned a combined cycle gas turbine (CCGT) power station at their Tallawarra site in the Illawarra region of NSW, known as Tallawarra Stage A. In addition, they are proposing to build an additional CCGT plant or two open cycle gas turbine (OCGT) plants, known as Stage B. The Civil Aviation Safety Authority (CASA) is concerned about plume rise impacts from the power station on aviation safety due to its proximity to Illawarra Regional Airport (refer to **Figure 1-1**).

This report provides an assessment of plume rise from both the Stage A CCGT plant and the proposed Stage B CCGT or OCGT plant using the plume rise assessment component of The Air Dispersion Model (TAPM) and CASA guidelines.

- **Figure 1-1 Tallawarra Locality**



1.2 Background to Plume Rise and Aviation Safety

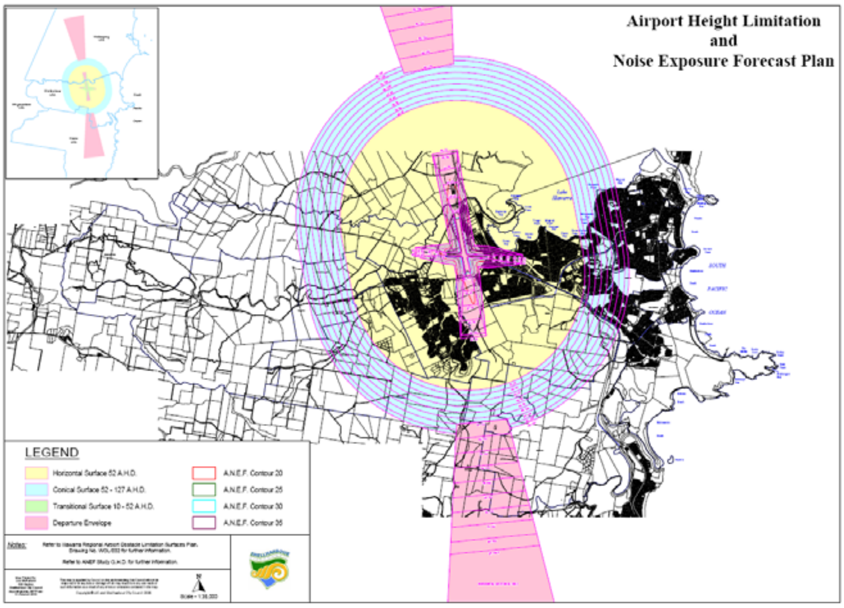
CASA has identified the need to assess the potential hazards to aviation due to the vertical velocity from gas efflux that may cause airframe damage and/or affect the handling characteristics of an aircraft in flight.

Specifically, aviation authorities have established that an exhaust plume with a vertical velocity in excess of 4.3 metres/second (m/s) may cause damage to an aircraft airframe, or upset an aircraft when flying at low levels. Typically low level flying operations are associated with the following phases of flight and flight operations:

- approach, landing and take-off;
- specialist flying activities such as, crop dusting, cattle mustering, pipeline inspection, power line inspections, fire-fighting, etc;
- search and rescue operations; and
- military low-level manoeuvres.

The risk posed by an exhaust plume to an aircraft during low level flight can be managed or reduced if information is available to pilots so that they can avoid the area of likely air disturbance. As such, CASA requires the proponent of a facility with an exhaust plume which has an average vertical velocity exceeding the limiting value of 4.3 m/s at the aerodrome Obstacle Limitation Surface (OLS) or at 110 metres above ground level anywhere else, to be assessed for the potential hazard to aircraft operations. The OLS for Illawarra regional Airport is 52 m (AHD) (refer to **Figure 1-2**).

- **Figure 1-2 Illawarra Regional Airport OLS**



This report provides the plume rise component of hazard assessment. If the results of the investigation determine plume rise heights above the OLS – 52m AHD, which is likely as the stack heights exceed this level, then an application for Operational Assessment of Proposed Plume Rise must be made.

2. Assessment Methodology

2.1 CASA Requirements

CASA have published an Advisory Circular (AC 139-05(0)) – *Guidelines for Conducting Plume Rise Assessments*, which provides background information and guidance for the assessment of plume rise from stacks. A section of this advisory includes a methodology for the assessment of plume rise using the TAPM v2 model. Minimum requirements when modelling using TAPM have been set out by CASA, and a summary of these requirements is provided in **Table 2-1**. Modelling conducted in this assessment complies with the criteria.

▪ **Table 2-1 CASA Model Requirements**

Requirement	Assessment
The entire horizontal grid domain should be a square region with 25 by 25 (or more) grid points, with 30km outer grid and two nested grids at 10km and 3km.	✓
A further sub-3km nested grid may be added at the user's discretion provided it is not less than 800m.	✓
The horizontal domain should be less than 1000km by 1000km.	✓
The number of vertical layers should be at least 25.	✓
The grid centre coordinates should be close to the plume source (or centroid of the sources) as allowed by the resolution of the user interface.	✓
Terrain height database should be extracted from the AUSLIG 9 second DEM database for the region under consideration.	✓

The Advisory Circular recommends that the model be run in meteorological mode only. The results for hourly average upper-level meteorological data are to be used in the solution of plume rise equations that have been suitably modified by the user, to account for the effect of height- dependant plume rise merging. However, since the publication of this advisory (*in June 2004*), TAPM v3 has been released. TAPM v3 has several options not incorporated into TAPM v2, including an advanced plume rise module. This module has potential to generate hourly plume rise information as well as final plume height. The latest version of TAPM (version 3) has been used in this assessment.

The Advisory Circular also states that TAPM v2 is not suitable for the consideration of merged plumes. However, TAPM v3 now has the capacity to consider plume merging, and a buoyancy enhancement factor due to plume merging may be input by the user.

2.2 Plume Rise Model Scenario

The plume rises assessment was undertaken based on two possible operational scenarios:

1) whereby both combined cycle turbines operate with gas fuel at full load; and

2) the scenario using the OCGT stacks on distillate fuel where operations create greater flow in the stack compared to gas fuel, leading to greater plume rise.

A summary of the model scenario is provided in **Table 2-2**.

- **Table 2-2 Model Scenario**

Parameter	Existing CCGT	Scenario	
		1) CCGT	2)OCGT
Number of stacks	1	2	2
Stack height (m)	60	60	40
Stack radius(m)	2.75	2.75	3
Temperature (ºC)	78	78	526
Exit velocity (m/s)	26	26	41.7
Buoyancy enhancement factor	1.82	1.82	1.82

2.3 Plume Rise Assessment Methodology

The air dispersion model 'TAPM', developed by CSIRO Atmospheric Research, has been used to generate plume rise information for the scenario modelled. Output data pertinent to the plume rise problem are contained in a 'gradual plume rise file' (file extension 'plrg'). This file includes hourly plume rise data for all sources modelled. Final plume height, the point where the plume dissipation rate decreases to ambient levels, is also generated by the model. A full description of the plume rise equations used in the model is described by Hurley (2005).

An example of the plume rise data generated by TAPM is provided in **Table 2-3**. The data are: plume material travel time (*t*, seconds), plume vertical velocity (*w*, m/s), plume centreline height above ground (*z*, m), the lateral plume radius (*Ry*, m) and the vertical plume radius (*Rz*, m). The plume evolution data are provided for arbitrary time steps with the number of steps varying for each hour – the number of time steps reported depending on plume behaviour.

A buoyancy enhancement factor of 1.82 was applied to the TAPM generated exit velocities in order to account for the affect of merged plumes. The buoyancy enhancement factor utilised in this assessment was adopted from Manins et al (1992).

Linear interpolation was used to calculate the height at which (*w)* = 4.3 m/s (the critical vertical velocity). Calculations of the critical vertical velocity were undertaken for each hour of the 5 year modelled period (2000 – 2004). Interpolation calculations were based on the modelled (*z)* value that corresponded to the (*w*) value immediately greater than and less than (*w*) = 4.3 m/s. The interpolation gradient used to determine the height of the critical vertical velocity for each hour is denoted as follows:

Equation:

- $zC = (zB - zA) / (wB - wA)$

Where; zC is the height at the critical vertical velocity,

zB is the modelled height immediately greater than (w) = 4.3 m/s,

zA is the modelled height immediately less than (w) = 4.3 m/s,

wB is the modelled vertical velocity immediately greater than (w) = 4.3 m/s,

wA is the modelled vertical velocity immediately less than (w) = 4.3 m/s.

- **Table 2-3 Sample 'plrg' TAPM File (with buoyancy enhancement and linear interpolation applied)**

t(s)	W(m/s)	z(m)	Ry(m)	Rz(m)	Gradient	Z(4.3)
1	12.74	72	9	4		
2	8.4812	77	12	6		
3	6.6794	81	15	7		
4	5.6602	84	17	8		
5	5.005	87	19	9		
10	3.5126	96	25	13	-6.03055	91.25154
15	2.912	104	30	15		
20	2.5662	111	34	17		
25	2.3478	118	37	19		

3. Plume Rise Results

3.1 Overview

This section of the report provides result for the plume rise assessment. Included in the results are sections relating to heights above the ground where the plume decreased in velocity to the critical vertical velocity, analysis of wind speeds affecting the plume and analysis of horizontal plume displacement.

3.2 Vertical Plume Velocity

An analysis of plume velocities was undertaken to determine the maximum, minimum and average heights at which the plume vertical velocity exceeded 4.3 m/s. Results of this analysis are presented in **Table 3-1**.

- **Table 3-1 Critical Vertical Velocity Exceedance Summary**

Turbine	Maximum Height (m)	Minimum Height (m)	Average Height (m)
CCGT	506	60 (stack height)	98
OCGT	1179	40 (stack height)	198

Additional analysis concerning plume vertical velocity was undertaken to determine the height at which the plume vertical velocity exceeded 4.3 m/s for a defined proportion of the modelled period. CASA (2004) defines the percentile bands to be examined. Results are presented in **Table 3-2**.

Table 3-2 Proportional Exceedance of Critical Vertical Velocity

Percentile Exceedance of 4.3 m/s	Height (m)	
	CCGT	OCGT
100%	72	82
90%	82	124
80%	86	134
70%	88	146
60%	91	157
50%	94	170
40%	97	185
30%	100	205
20%	105	239
10%	117	308
9%	118	320
8%	121	332
7%	123	347
6%	127	364
5%	132	383
4%	139	406
3%	147	440
2%	162	489
1%	193	586
0.5%	224	673
0.3%	244	747
0.2%	262	800
0.1%	305	877
0.05%	352	955

3.3 Wind Speed Analysis

CASA requires analysis of TAPM generated upper air meteorology data to determine the percentage of time wind speeds are less than 0.1, 0.2, 0.3, 0.4 and 0.5m/s for eight well spaced heights. Heights analysed should range between the point source and the maximum height at which the plume vertical velocity decreases to 4.3m/s. Results are presented in **Table 3-3**.

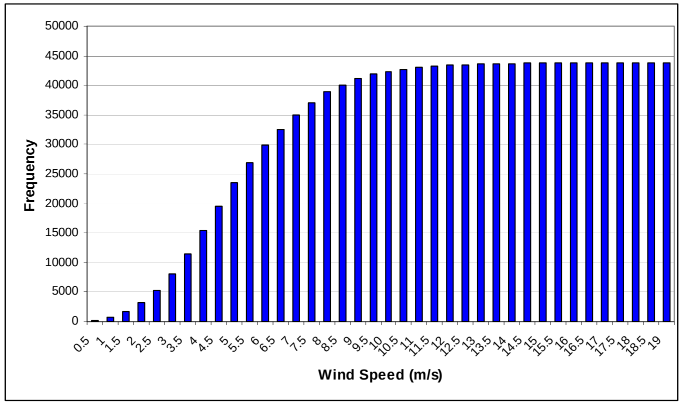
- **Table 3-3 Percentage of Time Wind Speed less than CASA Value**

Height (m)	< 0.1 (m/s)	< 0.2 (m/s)	< 0.3 (m/s)	< 0.4 (m/s)	< 0.5 (m/s)
CCGT					
100	0.01 %	0.07 %	0.12 %	0.20 %	0.31 %
150	0.01%	0.08 %	0.11 %	0.21 %	0.33 %
200	0.01 %	0.05 %	0.11 %	0.21%	0.33 %
250	0.01 %	0.08 %	0.13 %	0.25 %	0.38 %
300	0.01 %	0.06 %	0.10 %	0.21 %	0.35 %
400	0.01 %	0.05 %	0.11 %	0.20 %	0.31 %
500	0.01 %	0.06%	0.11 %	0.19 %	0.30 %
600	0.02 %	0.06 %	0.13 %	0.25 %	0.37 %
OCGT					
50	0.02 %	0.05 %	0.13 %	0.23 %	0.41 %
100	0.01 %	0.07 %	0.12 %	0.20 %	0.31 %
200	0.01 %	0.05 %	0.11 %	0.21%	0.33 %
400	0.01 %	0.05 %	0.11 %	0.20 %	0.31 %
600	0.02 %	0.06 %	0.13 %	0.25 %	0.37 %
750	0.01 %	0.07 %	0.12 %	0.23 %	0.38 %
1000	0.01 %	0.05 %	0.13 %	0.24 %	0.39 %
1250	0.01 %	0.05 %	0.12 %	0.24 %	0.39 %

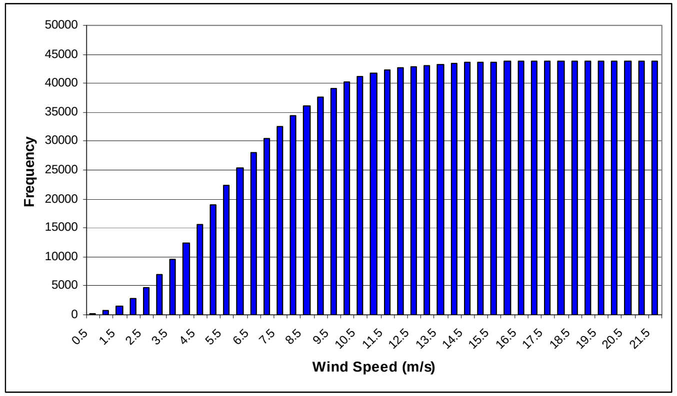
Cumulative frequencies of wind speeds at 8 well spaced heights for both the CCGT and OCGT plants were calculated. The heights range between the height of the point source and the maximum height that the plume reaches before decreasing the critical vertical velocity. Cumulative frequency wind speed plots for the CCGT are presented for 100 m, 150m 200m, 250m, 300m, 400m, 500m and 600 m in **Figure 3-1**. Cumulative frequency wind speed plots for heights of 100 m, 150m 200m, 250m, 300m, 400m, 500m and 600 m for OCGT are presented in **Figure 3-2**.

- **Figure 3-1 CCGT - Cumulative Frequency of Wind Speed with Height**

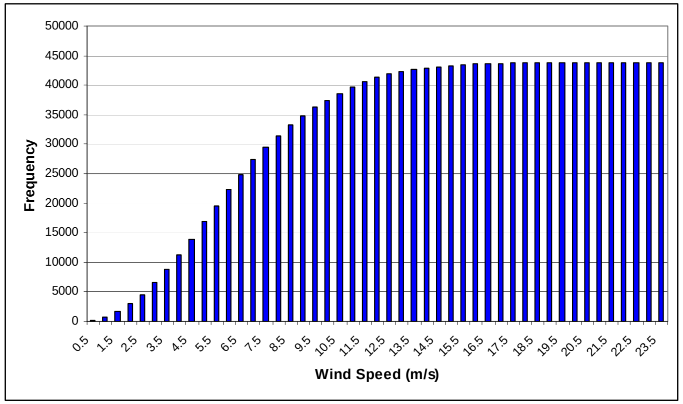
100 Metres



150 Metres



200 Metres



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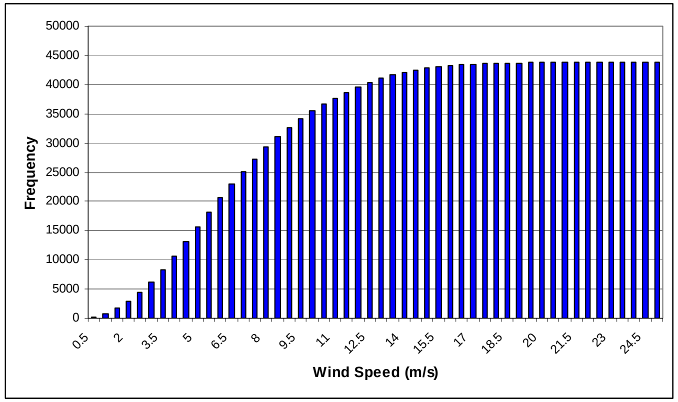

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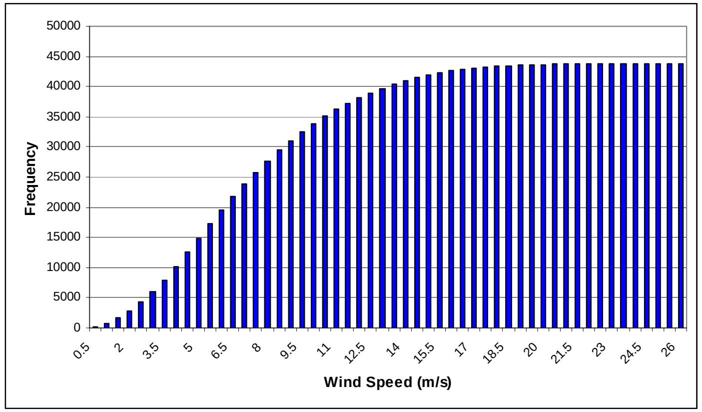
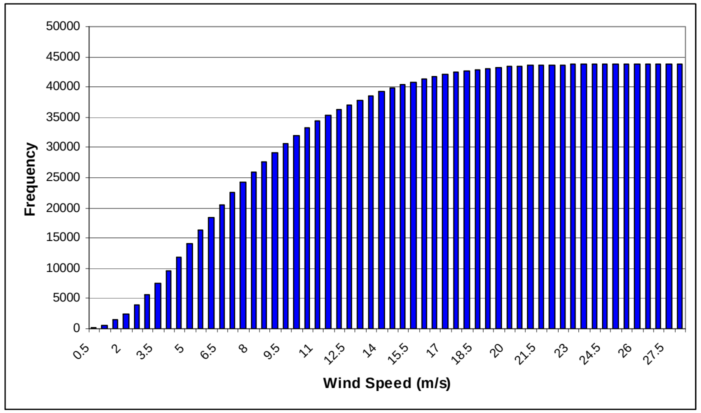
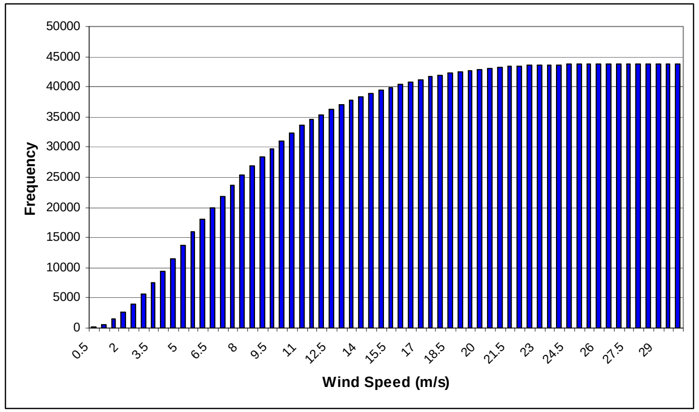


400 Metres



500 Metres



600 Metres

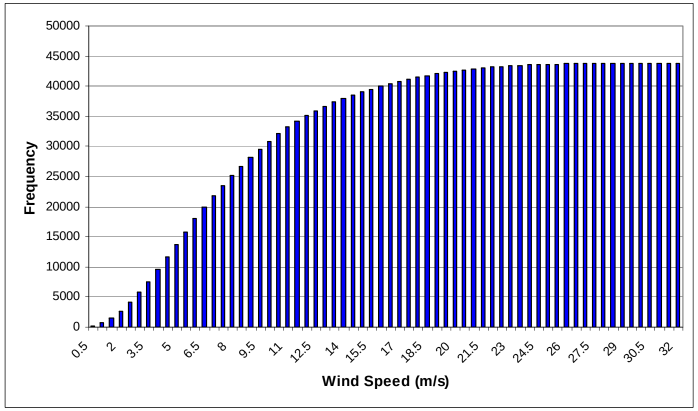
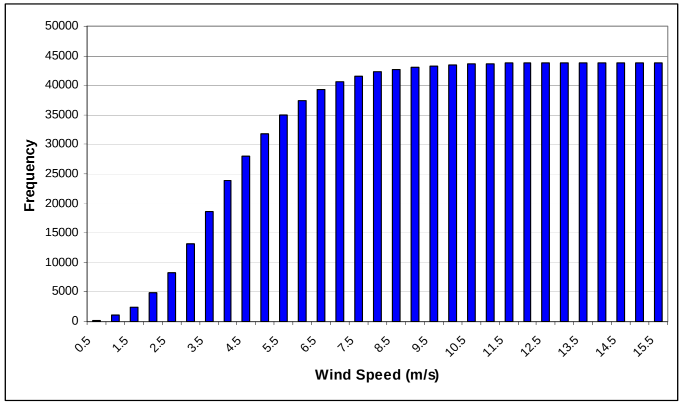
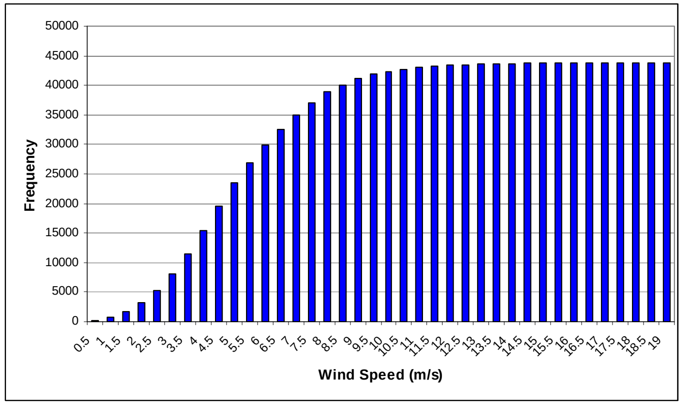


Figure 3-2 OCGT - Cumulative Frequency of Wind Speed with Height

50 Metres

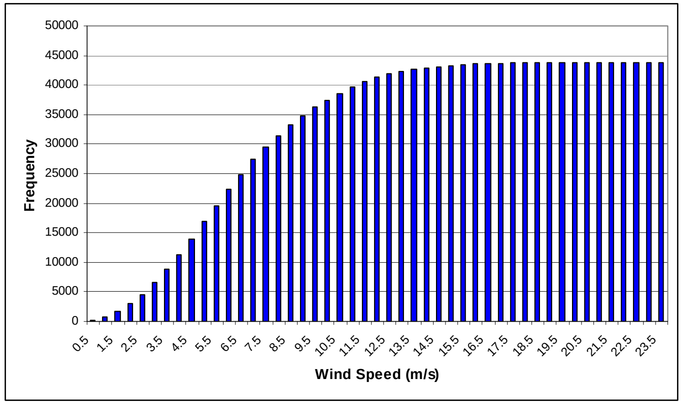


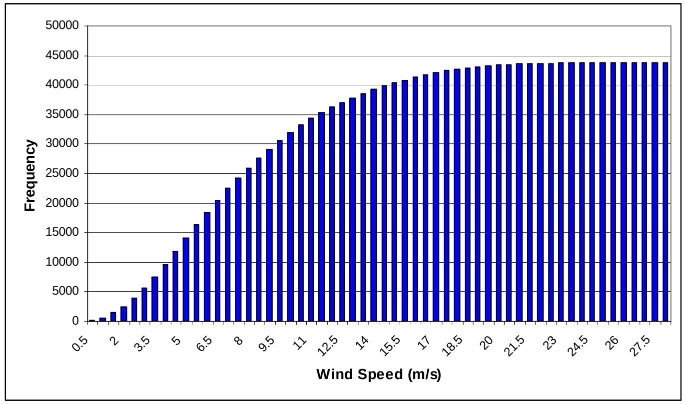
100 Metres



200 Metres

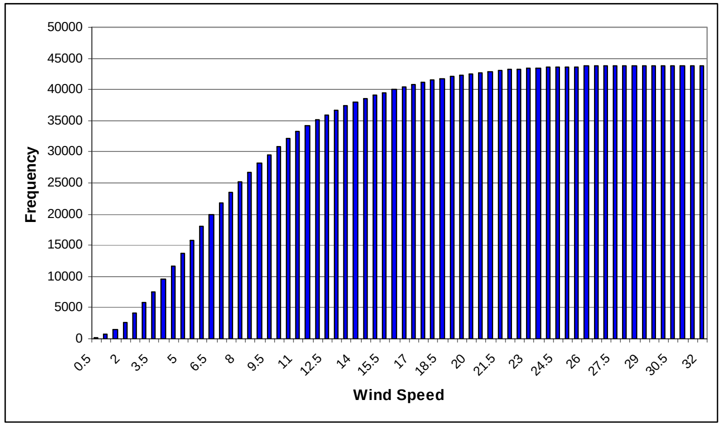
400 Metres

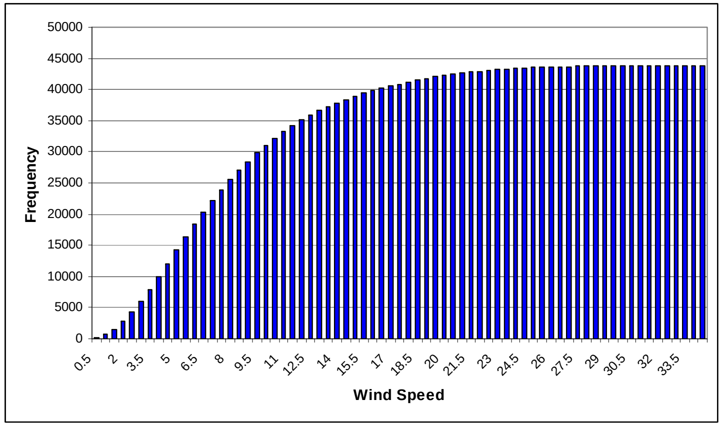




600 Metres

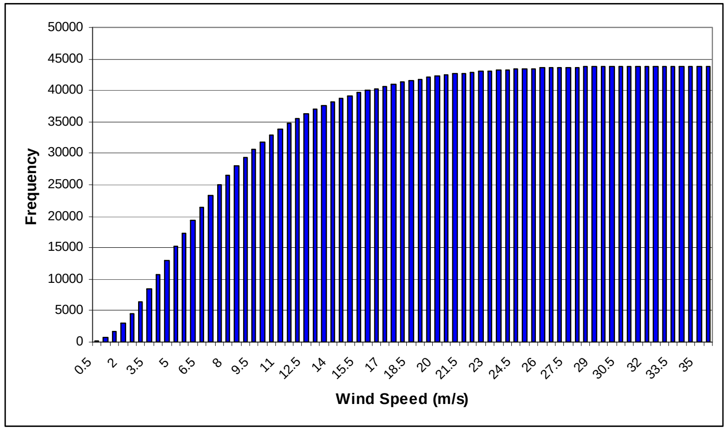
750 Metres





1000 Metres

1250 Metres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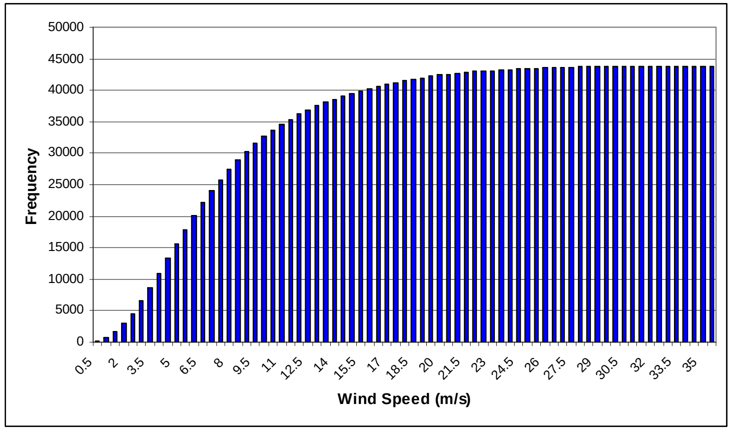
Frequency
0.5 2 3.5 5 6.5 8 9.5 11 12.5 14 15.5 17 18.5 20 21.5 23 24.5 26 27.5 29 30.5 32 33.5 35
Wind Speed (m/s)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Frequency
0.5 2 3.5 5 6.5 8 9.5 11 12.5 14 15.5 17 18.5 20 21.5 23 24.5 26 27.5 29 30.5 32 33.5 35
Wind Speed (m/s)

3.4 Horizontal Plume Displacement

Horizontal plume displacement was analysed for the period 2000 – 2004. TAPM output (*.plrg files) for each year in the modelled period were used to evaluate lateral plume expanse at 8 levels between the height of the point source and the maximum height where the plume vertical velocity is reduced to 4.3m/s.

3.4.1 Average Plume Horizontal Displacement

Plume development, based on average plume characteristics, were analysed for the period 2000 – 2004. **Table 3-4** shows the development of the average plume through 8 vertical levels for the CGGT scenario. The vertical heights of the plume analysed are between the height of the point source and the average height where the plume vertical velocity decreases to 4.3 m/s. **Figure 3-3** shows a schematic plot of the average plume horizontal dispersion for the proposed CCGT stacks.

- **Table 3-4 CCGT - Average Plume Development (2000 – 2004)**

Vertical Velocity (m/s)	Height (m)	Horizontal Plume Radius (m)
10.5	75	10.3
8.9	78	11.9
7.5	81	13.9
6.5	84	15.7
5.8	87	17.5
5.3	90	19.2
4.8	93	20.9
4.3	98	23.7

- **Figure 3-3 CCGT - Average Plume Horizontal Dispersion (Small Extent)**

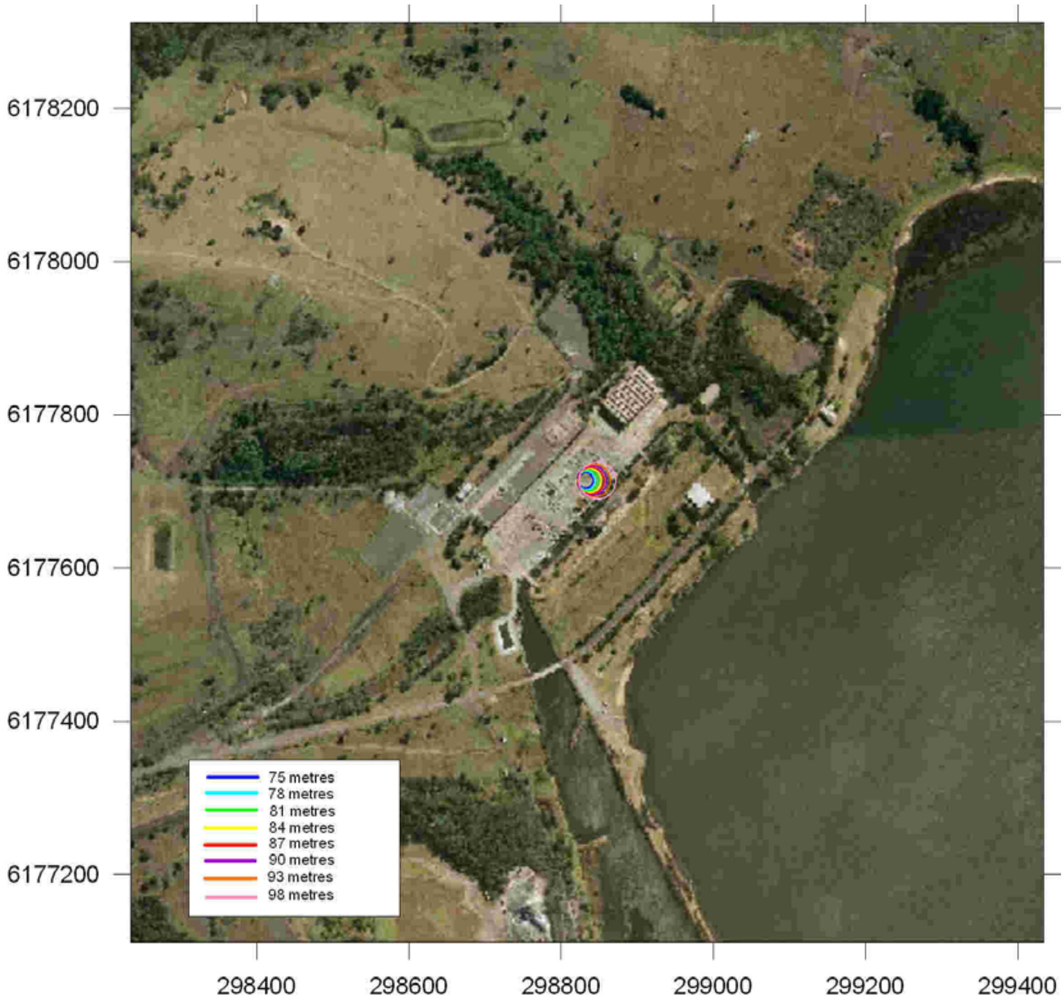


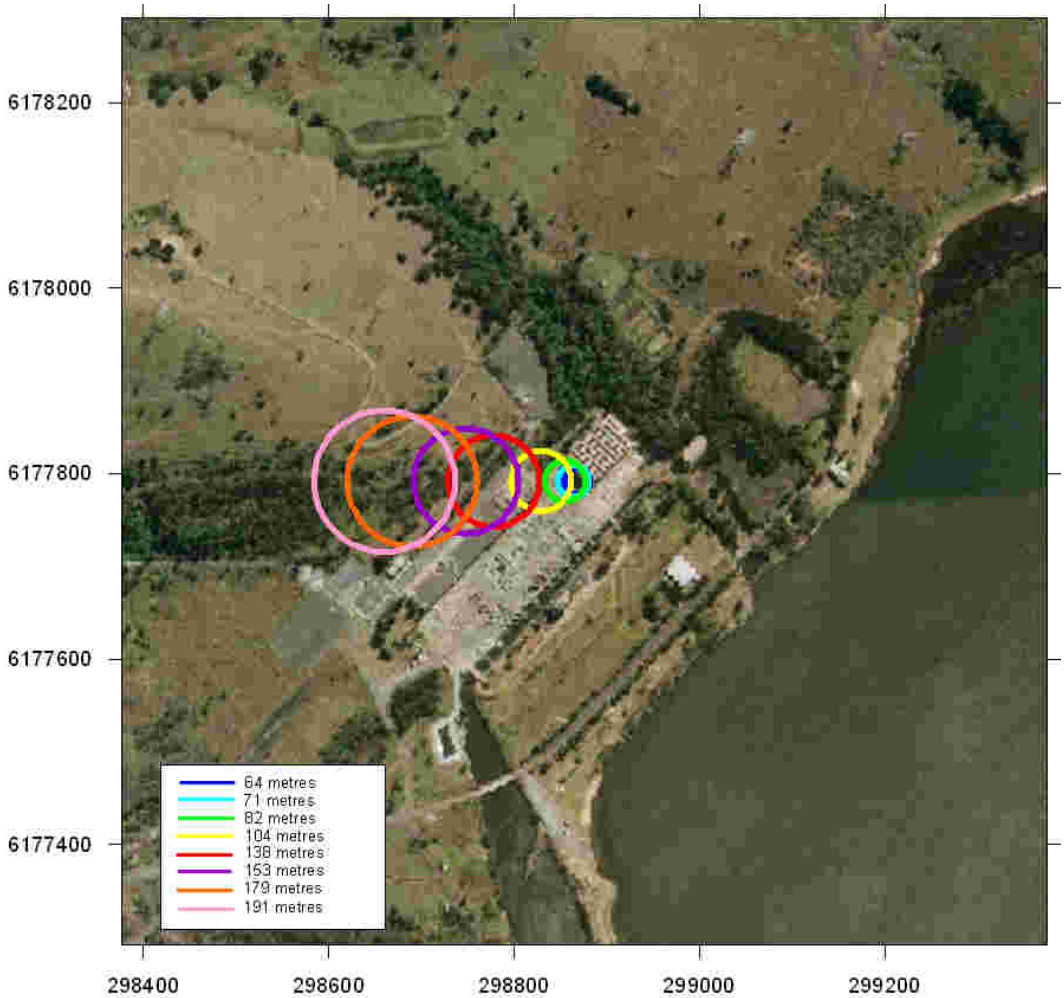
Table 3-5 shows the development of the average plume through 8 vertical levels for the OGGT scenario. The vertical heights of the plume analysed are between the height of the point source and the average height where the plume vertical velocity decreases to 4.3 m/s.

Figure 3-4 shows a schematic plot of the average plume horizontal dispersion for the proposed OCGT stacks.

- **Table 3-5 OCGT - Average Plume Development (2000 – 2004)**

Vertical Velocity (m/s)	Height (m)	Horizontal Plume Radius (m)
12.40	64	14
10.81	71	17
9.11	82	22
7.19	104	32
5.58	138	49
5.12	153	57
4.48	179	70
4.23	191	76

- **Figure 3-4 OCGT - Average Plume Horizontal Dispersion (Small Extent)**



3.4.2 Peak Plume Horizontal Displacement

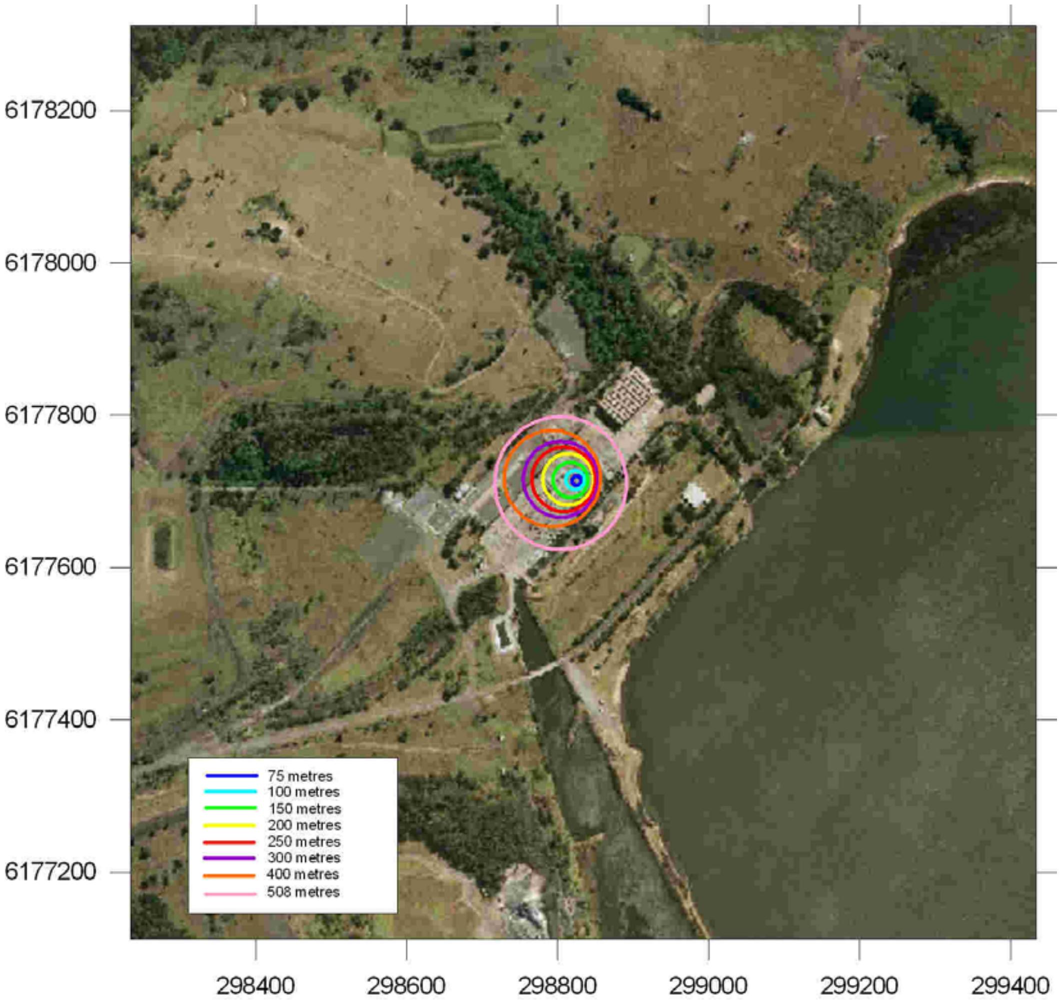
The peak plume development was selected as the hour in the modelled period that had the maximum height (above ground level) where the plume velocity decreased to 4.3 m/s.

The hour identified as the having peak plume development for the CCGT stacks was the 13th hour of the 3rd June 2002. **Table 3-6** shows plume characteristics for the peak plume development at 8 well-spaced levels between the point source height and the height at which the plume vertical velocity has fallen to 4.3 m/s. **Figure 3-5** shows the spatial extent of the peak plume with respect to height for large and small extents respectively.

- **Table 3-6 CCGT - Peak Plume Development (13th hour – 03/06/02)**

Vertical Velocity (m/s)	Height (m)	Horizontal Plume Radius (m)
19.3	75	6
10.8	100	12.3
7	150	23.2
6	200	33.6
5.6	250	42.2
5.4	300	49.7
5.1	400	63.4
4.3	506	87.3

- **Figure 3-5 CCGT - Peak Plume Horizontal Dispersion (Small Extent)**

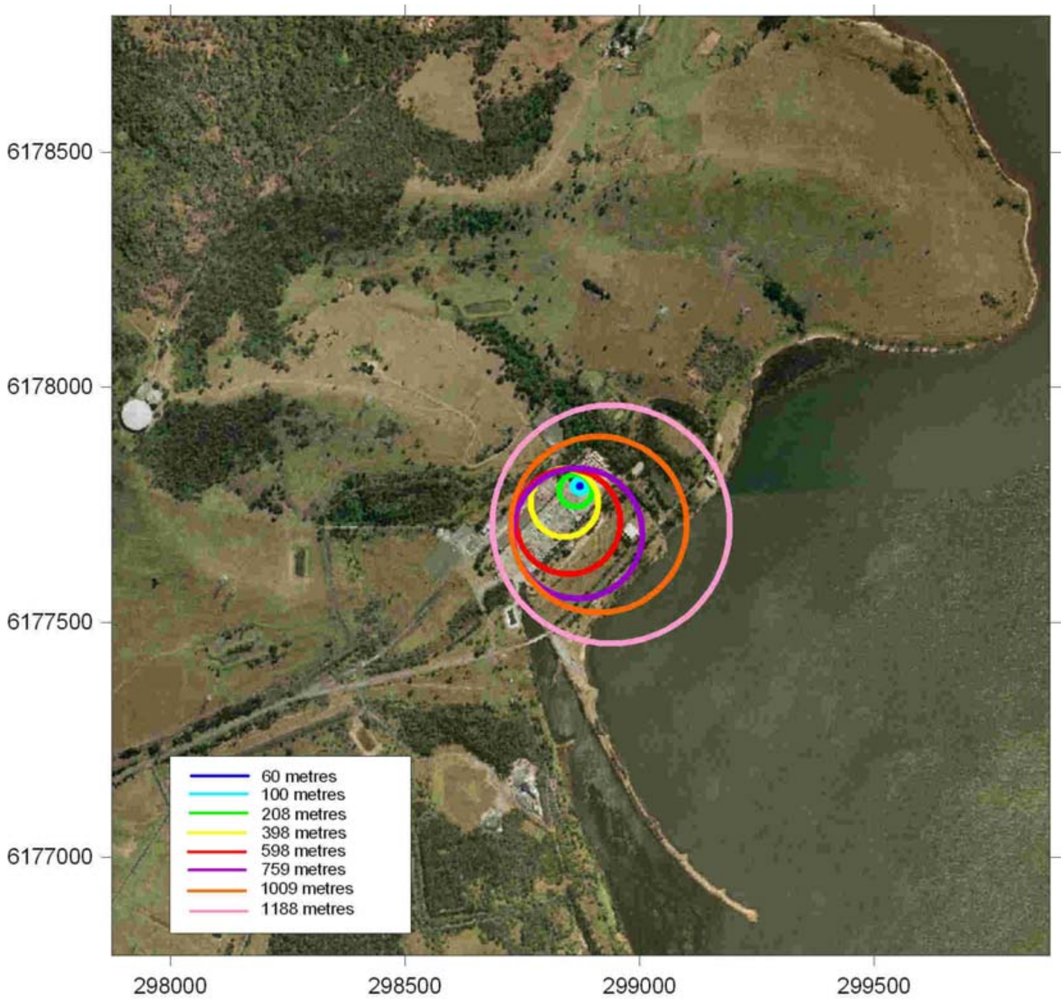


The hour identified as the having peak plume development for the OCGT stacks was found to be the 11 hour of the 14th July 2000. **Table 3-7** shows plume characteristics for the peak plume development at 8 well-spaced levels between the point source height and the height at which the plume vertical velocity has fallen to 4.3 m/s. **Figure 3-6** shows the spatial extent of the peak plume with respect to height for large and small extents respectively.

- **Table 3-7 OCGT - Peak Plume Development (11th hour – 14/07/00)**

Time (s)	Vertical Velocity (m/s)	Height (m)	Horizontal Plume Radius (m)
1	21.51	61	8
5	15.82	100	15
20	11.54	208	35
55	8.77	398	72
100	7.57	598	111
140	7.04	759	138
210	5.82	1009	187
275	4.19	1188	253

- **Figure 3-6 OCGT - Peak Plume Horizontal Dispersion (Small Extent)**



4. Conclusions

This report provides an assessment of plume rise from scenarios using either one CCGT or 2 OCGT plants at Tallawarra Stage B power station. The methods used in this assessment were consistent with the methods outlined by the CASA (2004) Advisory Circular. The TAPM v3 model was used to predict upper level meteorology and plume rise characteristics for the Tallawarra site.

The scenario adopted for this assessment involving the proposed CCGT stack assumed that proposed turbines would be operating at full load and fuelled by gas. The OCGT scenario assumed that proposed turbines would be operating at full load and fuelled by distillate. This operation scenario provides a conservative assessment of plume rise from the OCGT stacks due to the exhaust characteristics of the distillate fuel.

A buoyancy enhancement factor of 1.82 was applied to TAPM predicted plume vertical velocities. The buoyancy enhancement factor was used to conservatively account for the possibility of two plumes merging. Results for this assessment are considered in the context that the OLS for Illawarra Regional Airport is 52 metres AHD.

The maximum height reached by the plume before decreasing in vertical velocity to 4.3 m/s was 506 metres for the CCGT plant and 1179 metres for the OCGT plant. These plumes are considered to be the peak plume for each scenario and were analysed for horizontal displacement at 8 vertical levels. Result showed the horizontal displacement of the peak plumes as minimal, with the plumes lateral extent being confined above the Tallawarra site.

Examination of average plume vertical velocity and extent found that the average plume (for the modelled period), would decrease in vertical velocity to below the critical vertical velocity (4.3 m/s) by 98 metres for the CCGT plant by 200 metres for the OCGT plant above ground level. Evaluation of average plume horizontal displacement and spread showed that the average plume would be confined above the Tallawarra site until its vertical velocity decreased to < 4.3 m/s.

On the basis that plume rise does exceed 4.3m/s and the Illawarra Regional Airport has an OLS of 52 AHD, an application will need to be made to CASA for an Aircraft Operational Assessment.

5. References

CASA (2004), *AC 139-05(0): Guidelines for Conducting Plume Rise Assessments*, Civil Aviation Safety Authority, Australia.

Hurley, P. (2005) The Air Pollution Model (TAPM) Version 3 User Manual, CSIRO, Australia.

Manins, P. et al (1992), *Plume Rise from Multiple Stacks*, Clean Air Vol. 26/2, Australia.