Air Dispersion Modelling of Fugitive Emissions
Wagerup Refinery

Prepared for

Alcoa World Alumina Australia

By

Air Assessments

Final

October 2005

Disclaimer and Limitation

Air Assessments will act in all professional matters as a faithful adviser to the Client and exercise all reasonable skill and care in the provision of its professional services.
This report has been prepared on behalf of and for the exclusive use of the Client, and is subject to and issued in accordance with the agreement between the Client and Air Assessments. Air Assessments accepts no liability or responsibility whatsoever for it in respect of any use of or reliance upon this report by any third party.
This report is based on the scope of services defined by the Client, budgetary and time constraints requested by the Client, the information supplied by the Client (and its agents), and methods consistent with the preceding.

Air Assessments has not attempted to fully verify the accuracy or completeness of the information supplied.

Client: Alcoa World Alumina Australia

Status	**Version**	**Prepared by**	**Reviewed by**	**Submitted to Client**	
				Copies	Date
Preliminary Draft Report	A	OP	PAE	Doc	12/04/2005
Final	0	OP	-	PDF	15/04/2005
Final . Revised to include a number of corrections identified by the DoE and the independent reviewer and to clarify text where needed.	1	OP	-	PDF	31/10/2005

Table of Contents

1 Introduction

1.1 Background

Alcoa World Alumina Australia are proposing to expand the Wagerup Alumina Refinery. As part of the expansion, an assessment of the air quality impact of the existing and expanded refinery is required. Air pollutants that are being assessed include particulate and gaseous emissions from the refinery's stacks and vents, as well as fugitive particulate and gaseous emissions from the bauxite stockpile area, the residue area (RA) and cooling ponds.

Predicted concentrations from the stacks and vents at the refinery have been modelled by the Commonwealth Scientific Industrial Research Organization (CSIRO, 2005a and b) using The Air Pollution Model (TAPM). This model was used as it is a state of the air dispersion model, well suited for modelling these elevated point sources. Emission estimates for these sources were supplied to CSIRO by Alcoa based on stack testing.

Predicted concentrations from fugitive sources from surface releases, such as wind blown dust and volatile organic compounds (VOC) are addressed in this report. These substances have been modelled with a Gaussian puff model Calpuff, which is considered a more appropriate model for such sources. The derivation of the emissions for these substances are detailed in this report based on field testing and site measurements.

The cumulative results of both the refinery and fugitive modelling studies are presented in a Health Risk Assessment (HRA) of the Wagerup refinery as reported by ENVIRON et al (2005).

1.2 Sources of Fugitive Air Emissions

The major sources of fugitive particulate matter (and metals) and VOCs are the, residue area (RA), the lower dam and the bauxite stockpile area. These sites are located approximately 2 km to the west northwest and 500m and 750m to the north respectively of the main refinery area (see **Figure 1.1**).

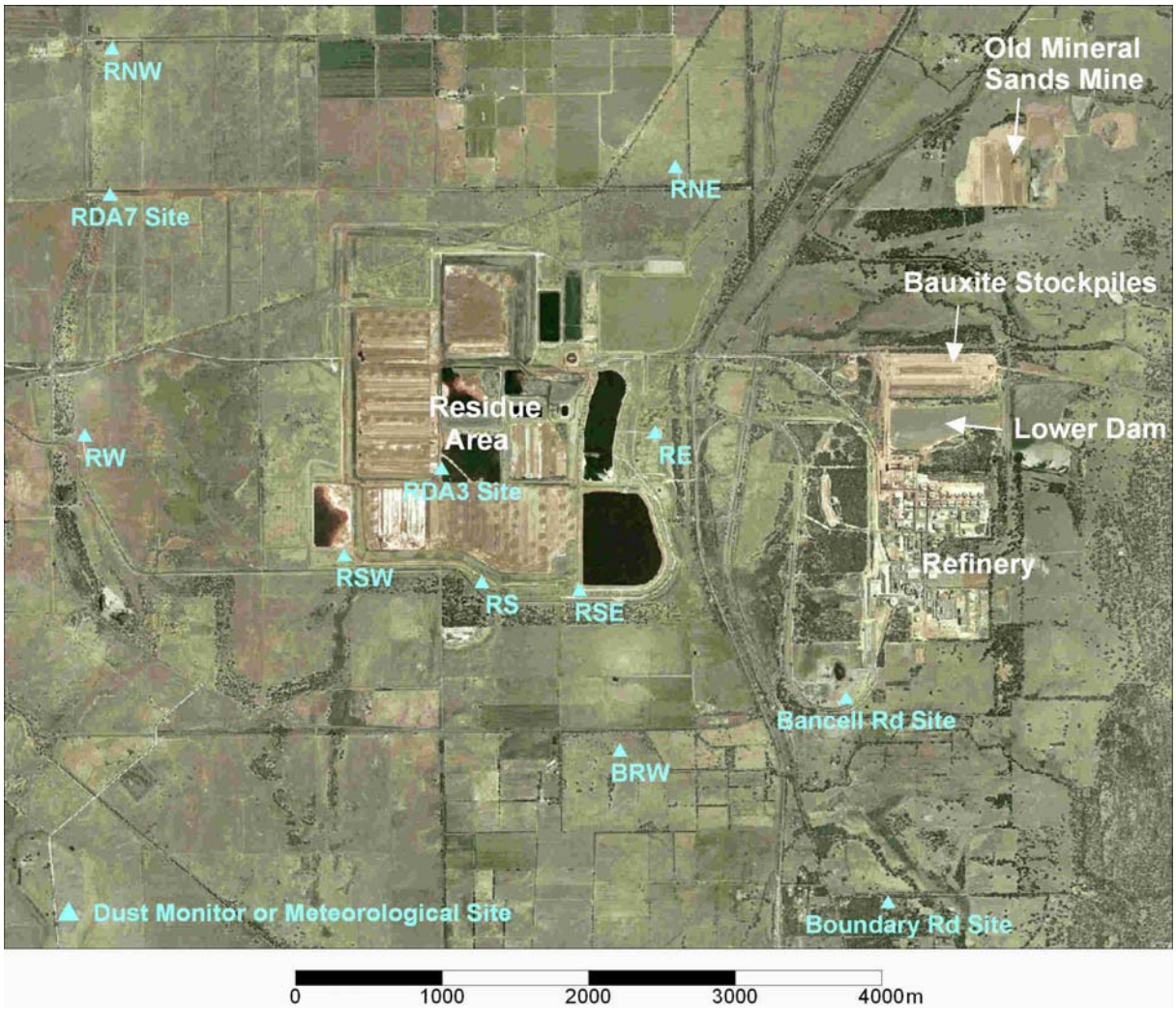


Figure 1.1 Wagerup Refinery and Residue Area including the Location of Meteorological and Dust Monitoring Sites (Aerial photo from December 2003)

1.3 Overview of Existing Bauxite Stockpiling and Residue Area Operations

1.3.1 Bauxite Stockpiles

The existing bauxite operations (see **Figure 1.2**) consist of:

- An overland conveyor and stacker that can stack ore on to either of two working stockpiles (number 1 and 2 stockpile);
- One reclaimer that is used to alternate with the stacker, with one stockpile stacked whilst the other is reclaimed, with a cycle time of approximately 12 days;
- One emergency insurance stockpile, used to store ore for the unlikely event of a major breakdown of the overland conveyor. This has been used extremely infrequently (approximately once in 10 years); and
- Emergency reclaim "turkey nest" stockpiles at the east end of the main working stockpiles. These are used when there is a reclaimer outage, with the ore loaded by front end loaders into

hoppers at the east end of the stockpile area. They are currently used around 15% of the time (Alcoa, 2004a).

Figure 1.2 Aerial Photograph showing the Bauxite Stockpile area, Lower Dam and Refinery with the Upper Dam at the top left of the picture

Sources of fugitive dust from the stockpile area arise from, wind erosion from the stockpiles and other bare areas and from material handling of the ore, such as stacking, reclaiming, conveyor transfers, front end loaders and from light vehicle movement.

The amount of dust generated from material handling is dependent on the moisture and silt content of the ore and the operational controls, such as the drop height used in stacking. The moisture and silt content both vary, dependent on the areas being mined in the mine pits and the season, with the moisture content being lower in the summer months. Dust from the out-loading sequence depends also on the age of the stockpiles. Old stockpiles, such as the emergency stockpiles, that may be unutilised for many months, can have the outer layer of material dry out, which can lead to the generation of greater amount of dust when reclaimed. Conversely, these may also form a crusted surface that will be less susceptible to wind erosion. Other dust sources at the stockpiles include; light vehicle movement, the use of front end loaders for loading the emergency hoppers and occasionally trucking operations used to cart away the larger rock left after reclaiming.

Dust controls at the stockpiling operations include; the covering of transfer points, the use of water sprays and a dust suppressant added to the incoming ore to minimise dust generation during handling (eg stacking) and to reduce dust lift off from wind erosion.

1.3.2 Residue Area Operations

Residue from the refinery is separated at the refinery into a coarse and fine fraction and then pumped to the residue area via pipes. The finer residue fraction, or "mud" slurry is pumped to a thickener vessel (super-thickener) located at the residue area (see **Figure 1.3**), where it is further thickened using flocculant, producing a high density, underflow slurry of around 50% weight by weight of solids.

Figure 1.3 Wagerup Residue Area

The thickened fine residue fraction from the super-thickener is pumped to the drying areas where it flows out to form a layer 0.5 to 1.0 m deep in summer and up to 2.0m deep in winter. An empty RDA before its first initial mud "pour" is shown in **Figure 1.4**.

Figure 1.4 A Residue Drying Area (Kwinana) showing pipe from which residue is poured, with operation of water cannon in background

The overflow liquid from the super thickener is released to the pond at the southern end of RDA2, where the small amount of solids remaining is allowed to settle, with the decanted water pumped into the cooling pond.

Dependent on the weather conditions, the fine residue in the RDA's will be sufficiently dry to allow the Amphi-rollers (see **Figure 1.5**) to start turning the residue within 5 to 10 days from the pour in summer and within 14 days in winter. This turning breaks the thin crust on the surface of the residue, exposing the wetter residue beneath, enabling quicker drying.

Figure 1.5 The operation of an Amphi-roller on the Residue

After a further period of drying, typically around 7 to 14 days from the "pour", the residue is sufficiently dry to allow bull dozers to plough the residue for the first time (see **Figure 1.6**).

Figure 1.6 Operation of dozer on "wet" residue

After another 7 to 10 days, the fine residue is then ploughed again by the dozers. The bay is then left for a further 7 to 10 days and then either ploughed a third time, or levelled by the dozer (see **Figure 1.7**). The process of drying the residue prior to the next pour, generally takes around 4 weeks in summer and up to 12 weeks in winter, depending on the depth of the pour and the weather conditions. As a result of the drying process, the RDAs increase in height by up to 2 m a year, though the increase in height is very variable.

Figure 1.7 Operation of dozer on "dry" residue levelling the residue in preparation for the next "pour"

The coarse residue fraction (sand) from the sand separator is generally pumped directly to the residue walls, where it is used to raise the walls/dykes of the residue area. For approximately 5% of the time, when the booster pumps that pump the sand out to the residue area walls are not available, the sand is stockpiled at the sand stockpiles. Excess dilute liquor from the stockpiles drains into the sand lake which is then pumped into the north western end of the cooling pond. The exposed area at the sand stockpile and areas on the residue area walls that are being constructed, are sealed as soon as practicable by bitumen emulsion or blue metal (see **Figure 1.8**).

The cooling lake is used to provide cooling duty for process water from the refinery. As noted previously, it also receives decant liquid from RDA2, dilute liquor from the sand lake and contaminated refinery stormwater.

Figure 1.8 Sealing of sand stockpile area with bitumen emulsion. The Sand slurry is being pumped into the stockpile in the background

Other areas at the residue area are the:

- Oxalate storage ponds, used for the emergency storage of oxalate. When required, oxalate is trucked directly from the refinery and is covered by a layer of water in the ponds;
- Run off water storage (ROWS) pond, that is used to store runoff/storm water from the refinery that has not been contaminated with caustic;
- Runoff off collection ponds (ROCP1 and ROCP2), used to store alkaline runoff from the residue area. ROCP1 is a shallow lake, which in periods of low water levels has an exposed sandy area on the east edge, which is susceptible to wind erosion. ROCP2 is a deeper lake, does not have exposed sandy areas and is not a source of dust; and
- The fresh water lake which stores fresh water from for use in the refinery process. This is not a source of dust or VOCs and is not considered further in this report.

1.3.3 Dust Control at the Residue Area

Dust from the residue area is generated primarily by wind erosion under high winds and occurs from the RDAs, sand stockpiles, ROCP1 and along the roads. The RDAs are considered to be the primary source of dust at the RA and are most susceptible to wind erosion towards the end of the drying cycle, when the moisture content of the residue is low and also when the area is flatter. The drying residue is also susceptible to wind erosion if a sodium carbonate "powder" surface develops on the surface. These surfaces develop as sodium is a mobile ion and tends to migrate to the surface during the drying process. Other sources of dust at the residue area are activities such as, dozing when operating on the

drier residue, light vehicle movement and during construction activities when raising the dykes. The raising of dykes/levies by trucks, front end loaders (FELs) and graders is conducted on a periodic basis for the areas furthest from the current pumps, where the existing pumps cannot send the coarse residue. Lastly a significant source of dust may occur through the construction of new RDA areas. This can occur through the building process where sand and clay are carted to construct the wall and floor of the new RDA.

To control dust at the residue area, Alcoa:

- Operate a water cannon system on all the drying areas. This is operated semi automatically by the residue area operations personnel. This system and its effectiveness is described in more detail in the report by ENVIRON (2005);
- Areas in the drying beds where sodium carbonate surfaces develop and areas not reached by water cannon are also targeted by using dozers to turn the material to bring the moister material to the surface and also by spraying from water carts;
- Non-drying areas at the residue area, such as the dykes/embankment are revegetated where possible, or covered by bitumen emulsion or blue metal (see **Figure 1.9**);
- Sand stockpile areas are sprayed with bitumen emulsion or blue metals as soon as practicable to cover the sand; and
- Road dust is suppressed by covering by blue metal or waste oil and watered with water carts when needed. Generally, there is little traffic at the residue area with vehicle access restricted and vehicle speeds kept low.

Figure 1.9 Blue metal covering on a road and bitumen coverage on embankment to minimise wind erosion

1.3.4 VOC Emissions at the Residue Area

VOCs and odour are emitted from the drying area through evaporation of the liquor contained in the deposited residue and from the various liquid surfaces at the residue area. The source of these emissions is described in detail in **Section 6**.

1.4 Lower Dam

The lower dam is located immediately to the north of the refinery and is used for storage of water and cooling duty for some refinery processes where it receives water containing VOCs. As such, it is a source of fugitive VOCs and odour. Emissions of particulate matter from the exposed "beach" areas around the dam are negligible and have been neglected in this study.

1.5 Expanded Operations - Wagerup 3

With the expansion of Wagerup refinery, the amount of bauxite used by the refinery is estimated to increase from 8.76 to 17.04 Mtpa (on a wet as received basis) (Alcoa, 2004a), with the production of alumina increasing from 2.4 Mtpa to 4.7 Mtpa. The increase in bauxite usage, increase in stockpiling and handling and the greater amount of residue formed, all have the potential to generate additional dust, VOCs and odour. These changes to the bauxite area and residue area and the dust controls proposed are described in **Section 5,** with the changes to the residue area and lower dam in terms of VOC and odour emissions described in **Section 6**.

2 Meteorology

2.1.1 Available Meteorological Data

Meteorological data available in the Wagerup region include that collected by:

- Alcoa at the Bancell road and residue area (RDA3 and RDA7) meteorological monitoring sites (see **Figure 1.1**). Details of the Alcoa monitoring and the parameters measured are provided in **Table 2.1**;
- Iluka Ltd , which maintains a meteorological station at a site just north of Waroona; and
- The Department of Environment which has collected wind data at two sites for several months each in late 2003. These sites however are considered not suitable for investigations, due to their short monitoring periods, low height of the anemometers (3 to 4 m above ground level) and close proximity to trees and buildings.

Table 2.1 Alcoa Wagerup Meteorological and Dust Monitoring Network as at 2005

Site	Wind	Other Meteorological Measurements	Dust Monitoring	Sampling Frequency	Period
Bancell Rd	10 m	AT(10), RH(10) SR, RAIN	-	6 minute	Pre 2000 to 15/7/03
	10 and 30m	AT (2, 10, 30), RH (2), NR, SR, RAIN	-	6 minute	18/7/03 to present
Residue South	-		TSP - TEOM	6 minute	Pre 2000 to present
Residue South West	-		TSP - TEOM	6 minute	23/9/00 to present
Residue South East	-		TSP - HVAS	24 hour	Pre 2000 to 11/12/03
Residue East	-		TSP - HVAS	24 hour	Pre 2000 to present
Residue West	-		TSP - HVAS	24 hour	3/2/2000 to present
RDA7	~5m		TSP - TEOM	6 minute	1/12/03 to present
RDA3	7.2m		-	6 minute	Pre 2000 to present
Residue North West			TSP - HVAS	24 -hour	6/5/2000 to present
Residue North East			TSP - HVAS	24-hour	17/12/03 to present
			PM_{10} - HVAS	24-hour	17/12/03 to present
Boundary Road			TSP - HVAS	6-minute	1/5/02 to present
			PM_{10} - TEOM	6-minute	1/5/02 to present
			$PM_{2.5}$ - TEOM	6-minute	1/5/02 to 30/12/03
Bancell Road West			TSP - HVAS	24-hour	17/12/03 to present
			PM_{10} - HVAS	24-hour	17/12/03 to present

Note: Meteorological measurements, AT is air temperature, RH relative humidity, NR net radiation, SR global radiation with the numbers in brackets referring to the measurement height.

2.1.2 Siting and Quality of Data

2.1.2.1 Bancell Road - 2000 to 15 July 20003- 10m Tower

The Bancell road site (up to the 15 July 2003) consisted of a 10m mast with wind measurements undertaken at 10m. This mast was situated approximately 60m to the SW of the existing 30m mast. Its location was to some degree influenced by the proximity of trees 80m distant, particularly to the south along Bancell road, which tend to result in lower wind speeds for "southerly" winds.

SKM (2001a) found that in comparison to the RDA3 winds, that the Bancell road 10m wind speeds were only 62% of those measured at 7.2m at RDA3. The generally higher wind speeds at RDA3 for all wind directions were interpreted to indicate that RDA3 was more exposed, as sited on a ridge or embankment and with no obstacles surrounding it.

Figure 2.1 presents the wind speed ratio between the Bancell road and RDA3 sites for 2000/2001 plotted as a function of the wind direction, indicating the much lower wind speeds recorded for the south and west directions and the generally lower wind speeds overall. Therefore, the 10m data at the old Bancell road site tended to record lower wind speeds for the south and west directions, where nearby trees where present, though for winds from the northwest through to the north to east, as there were no nearby trees, the recorded winds will be representative.

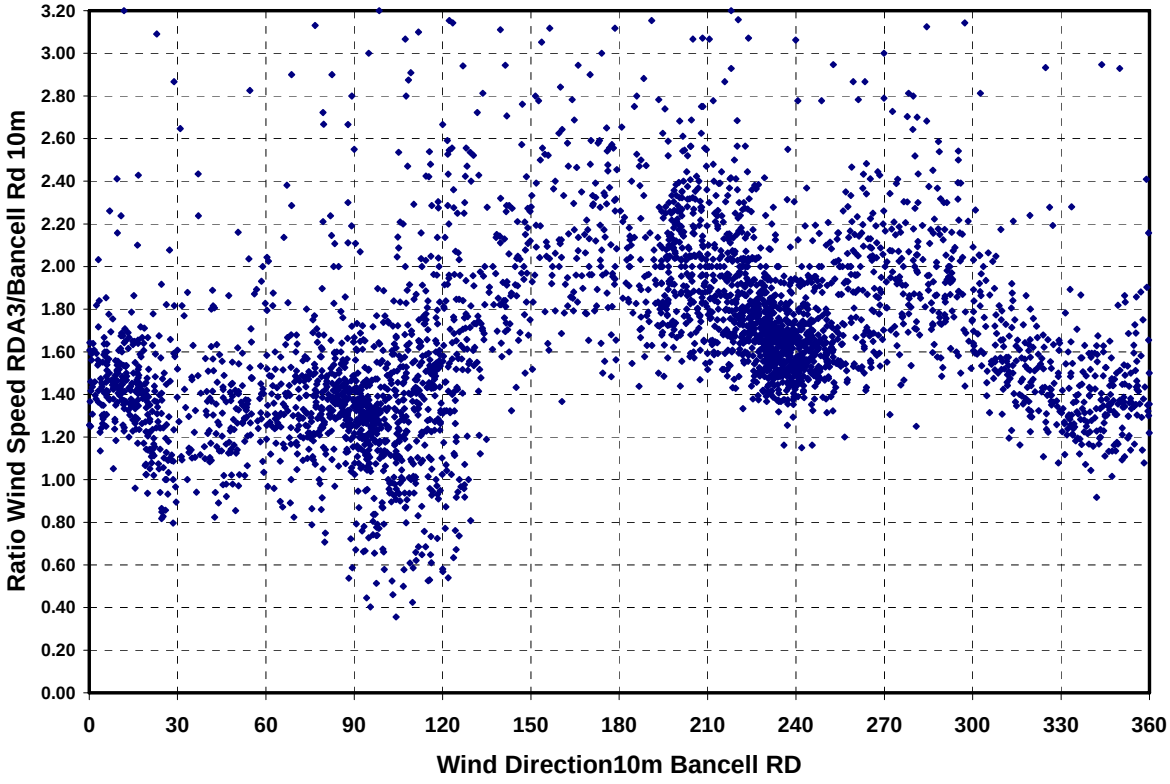


Figure 2.1 Ratio of RDA3 wind speed to Bancell Road 10 m wind speeds for 1/7/2000 to 30/6/2001 for wind speeds greater than 5 m/s at both sites

2.1.2.2 Bancell Road - 18 July 20003 Onwards - 30m Tower

The present 30m tower was installed at a position approximately 60m to the NE of the previous site with data collection commencing from 18 July 2003. At the time of the installation, the general area was also cleared to remove the smaller trees and shrubs (Alcoa, 2004b). Therefore, the winds at this site were better sited away from trees, though the 10m sensor was sheltered for easterly winds by the proximity of the 30m tower itself, resulting in lower and more turbulent winds being recorded from the east. Both sets of wind data (10m and 30m) suffer from data loss and averaging problems in some of the data originally supplied and used by CSIRO for 2003/2004. This was due to intermittent data spikes which affected the wind speeds. For this study, this data has been reprocessed using the raw 6

minute scalar wind speed and wind vector data for the period 31 October 2003 until May 2004 to reduce this problem and allow for a greater data return.

2.1.2.3 RDA3

The RDA3 site is used and maintained primarily for real time dust control purposes. It is situated approximately 7.2m above ground level on a N/S embankment between RDA2 and RDA4. To the east of the site, there is a drop of around 3 m (into RDA2), such that the height is around 10m above the lake surface level. The RDA4 height to the west however has been increasing with time. In 2000/2001, RDA4 was several metres lower than the road, whilst in 2003/2004 it was around the same height or slightly higher than the road and in early 2005 it was 1 to 2 metres higher than the road. During 2002 to 2003 a large splitter dam was constructed to divide RDA2. Consequently, there is now a 10 to 15m high embankment 300m to the north to north east of the site (see **Figure 1.3**).

Figure 2.2 presents the ratio of the 30m Bancell road winds to the RDA3 winds for 2003/2004 (the period used in the modelling in this report).

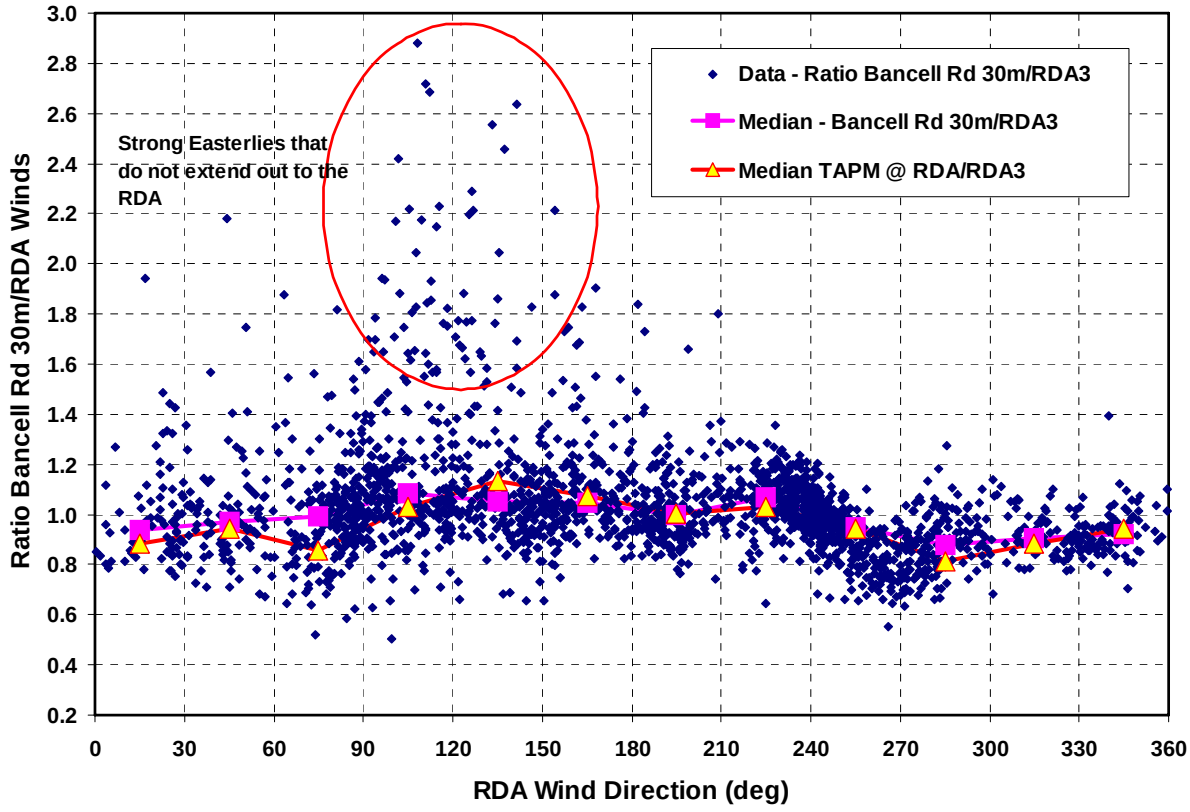


Figure 2.2Ratio of RDA3 wind speed to Bancell Road 30 m wind speeds for 18/7/2003 to 31/3/2004 for wind speeds greater than 5 m/s at the RDA3 site

Figure 2.2 indicates that the RDA3 winds in 2003/2004 are:

- Roughly equivalent to the 30m Bancell road winds for winds from 70 degrees to 240 degrees,

- Higher than the Bancell road 30m winds for winds from 240 degrees to 70 degrees, with
- A number of easterly winds where the Bancell road 30m winds are much higher than at the RDA3 site. The reason for these higher easterlies will be discussed later in **Section 2.1.3.1.**

This relationship between the Bancell road 30m and RDA3 winds is also very similar to that found between the predicted TAPM winds (at the residue area) and the observed RDA3 winds, indicating that this relationship is not due to the siting of the Bancell road site, but is a wind flow effect at the RDA3 site.

That the wind speeds at 7.2m at the RDA3 site are approximately equivalent to the 30m winds at Bancell road for winds from 70 to 240 degrees and exceed the 30m Bancell road winds from winds from 240 to 0 degrees is considered due to:

- The open nature of the residue area. Based on surface layer theory, a 10m anemometer at a site with roughness of 0.02 to 0.05m would record similar wind speeds to that recorded at 30m in an area with surface roughness of 0.4m. A roughness length of 0.4m was selected in the modelling by SKM, (2003a) as appropriate for the Bancell road area, though a lower value of around 0.25m is used in this study for consistency with the CSIRO modelling. A 7.2m anemometer at the residue area would be equivalent to a 30m height if the respective roughness lengths where 0.01m and 0.4m for the two areas; and
- The raised elevation of the residue area. That is, the residue area is effectively a small plateau of up to 20 to 40m higher than the surrounding coastal plain, which will result in higher wind speeds than the surrounding areas as predicted by the Wind Analysis and Siting Program (WAsP) in SKM (2001b); and
- The effect of the siting on the embankment. For the 2000/2001 RA shape, SKM (2001b) using WAsP, found for easterly and westerly winds that the wind speeds at 8m on the embankment would 18% higher than that measured on a flat area on the RA, whilst for northerly and southerly winds along the embankment may have little if no wind speed-up effect. For the profile in 2003/2004, this speed up will be different and may account for the variation of the wind speed with direction that is now observed.

2.1.2.4 Degradation of the RDA3 wind sensor with time

Apart from the siting issues, the RDA3 wind sensor has not been maintained as often as required (the wind sensor prior to 2005, was last fully overhauled in early 1998), and over the years the wind speed bearings have degraded, which has increased its stalling speed. This effect is illustrated in **Figure 2.3** which shows the annual percentage of winds less than 1 m/s, which increases consistently from 1998. For comparison the Nth Waroona winds are also presented. This site is the only other site with long term records in the area. Note that statistics for the other years at Nth Waroona are not available due to the large data losses for these years. The data from Nth Waroona also shows an increase in the percentage of winds less than 1 m/s for the period 1999/2000 to 2001/2002, though not as great as the RDA3 data. This may be due to the anemometer also degrading with time there (it now has a slight stalling problem), but may also be due to 1999/2000 having above average wind speeds and corresponding number of low wind speed days.

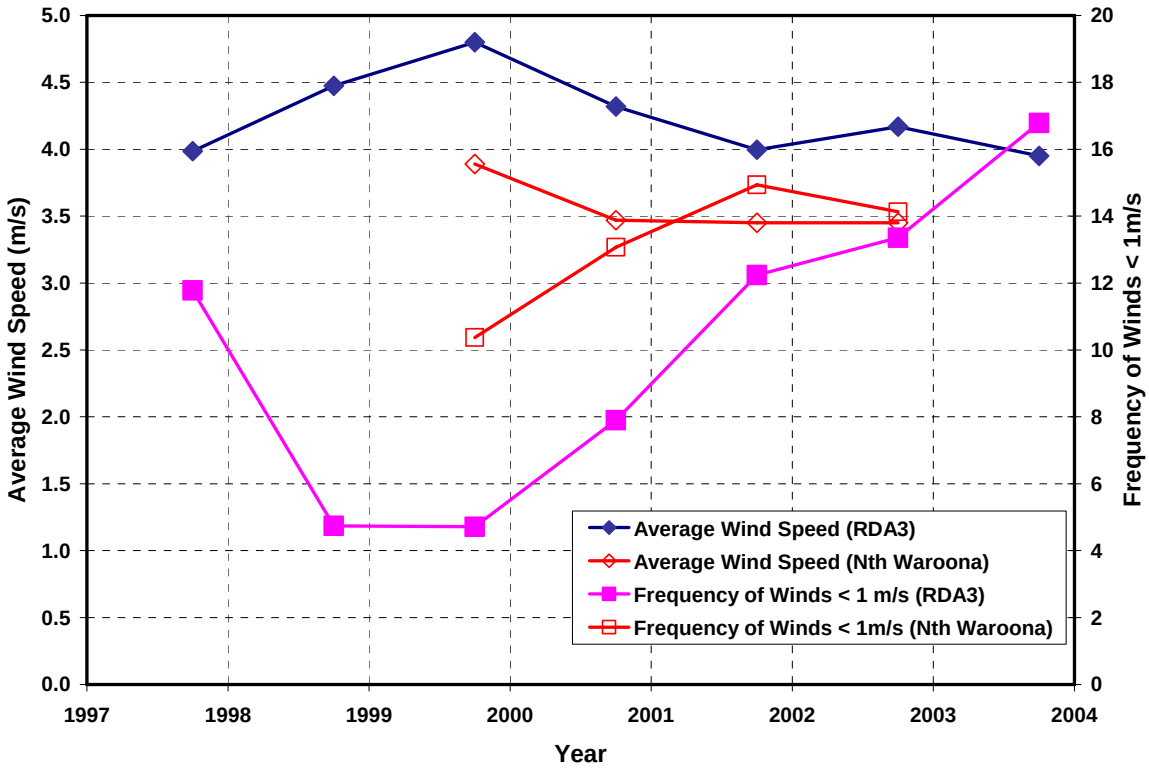


Figure 2.3 Average Wind Speed and Frequency less than 1 m/s for the RDA3 sensor for the 12 month periods from 1/4/97 to 30/3/98 to 1/4/03 to 30/3/04

Figure 2.3 also presents the annual average wind speeds from the two sites, which show very similar trends, with a less obvious change with time for the RDA3 winds. **Figure 2.3** does indicate however, that 1999/2000 had above average wind speeds, which is also supported by the analysis undertaken by CSIRO as presented in **Section 2.1.6**.

That the effect of the degraded bearings is predominant at the lower wind speeds is due to the force of the wind at higher wind speeds overcoming the increased frictional force of the bearings. For example, Dear et al (1990) showed that for a Dines anemometer with a stalling speed of 1.5 m/s, that the under-reading in the wind speeds decreased with increasing wind speed and that above 10 m/s was non existent. Note, the Dines anemometer was the standard anemometer used by the Bureau of Meteorology.

The stalling issue of the anemometer and the correction applied in this study is discussed later in **Appendix A** with the "corrected" data presented in **Figure 2.15**. Wind directions from this wind sensor are not considered to be affected by this issue, based on comparison of the directions with Bancell road data and discussions with the technicians servicing the equipment. This occurs as the wind direction sensor has separate, less exposed bearings.

2.1.2.5 RDA7

The RDA7 dust monitoring site was installed in December 2003, with a wind sensor installed at 5m to assist in determining the source of dust at the TEOM dust monitor there. The site has open paddocks to the east of it with no obstructions and will measure representative winds from this direction. To the west however, there are small trees that will tend to lower the measured wind speeds. For the period, December 2003 to October 2004, the data logger did not correctly average the wind directions, such that northerly winds were not recorded. As such, for the modelling period used in this report 2003/2004, the site has been discounted as a source of wind data.

2.1.2.6 Iluka - North Waroona

The Iluka site, north of Waroona consists of wind speed and direction sensors at 10m along with air temperature, relative humidity, solar radiation and rainfall. This site has been maintained since 1992 to assist in determining the meteorology and air dispersion for a planned mine there. The site is situated in a large clearing (greater than 100m to any trees) at the foot of the escarpment, and is the closest of any of the meteorological sites in the area to the scarp. Data quality is considered good, though with a slight tendency to stall at low wind speeds in the later years, though not to the extent of the RDA3 wind speed sensor.

2.1.2.7 TAPM predicted winds

Besides observational data, the model TAPM can be used to generate winds across the region. The advantages of TAPM are that it can be used to predict winds at all locations, at any height above the surface and with no missing data gaps. The disadvantages are that it may not reproduce exactly the winds at a site, due to limitations in the modelling approach and the solutions of the equations driving the model. A comparison of the predictive ability of TAPM against the Bancell road site and RDA3 site is presented in CSIRO (2004a). CSIRO concluded that without "nudging", the wind direction and wind speed were not as well predicted as the other meteorological parameters, such as temperature and relative humidity. CSIRO concluded that:

"The model wind predictions are better in the daytime than in the night time, and they are better in winter than in summer. The overall wind speed comparison at Bancell Road is dominated by the strong night time easterlies/southeasterlies. The model performance for wind predictions at RDA is better than that at Bancell Road. The performance of TAPM in predicting the local meteorology at Wagerup is comparable to its performance in predicting the near surface meteorology elsewhere in the world. TAPM generally predicts stronger wind speeds at Wagerup, and its performance for wind speeds is not as good as for other locations" CSIRO (2004a).

Additional to this conclusion, examination of the wind data indicates that TAPM (un-nudged) also:

- Tended to over-predict the wind speeds, especially for low winds speeds (A comparison of the predicted to observed wind speeds is presented in **Appendix A**);
- Tended to over-predict the frequency and strength of the east and south easterly winds in summer; and

- Under-predicted the frequency of northerly winds, particularly closer to the scarp at the Bancell road site.

2.1.3 Meteorology

The meteorology of the Wagerup area has been described previously in (SKM 2001c and SKM, 2003b) with the description following based on that presented in those reports.

The Wagerup Refinery is located on the Swan coastal plain 25 km from the Indian Ocean and to the immediate west of the Darling escarpment, approximately 130 km due south of Perth. The climate of the area is Mediterranean, with hot dry summers and cool wet winters.

The winds at Wagerup are controlled by the synoptic weather patterns and local features such as the topography and sea and land breezes. In the summer the passage of high pressure systems to the south generate synoptic easterlies over the region, whilst in the winter months the passage of cold fronts and low pressure systems result in more frequent westerly synoptic flows, between periods of lighter winds. For the Wagerup refinery, at the base of the Darling escarpment, topographical features are critically important in modifying these larger scale winds. These topographic features tend to:

- Generate local, very strong winds during summer, principally at night and in the early morning, which are known as "gully winds" or "foothill winds";
- Create rotors or wind reversals near the foothills under easterly winds;
- Channel or deflect winds with a westerly component along the escarpment; and
- Create light drainage (katabatic flows) down the escarpment.

2.1.3.1 Foothill Winds

The most pronounced effect of the Darling Escarpment is the generation of very strong easterly winds that can occur from early evening to mid morning, which are most frequent in the summer months. These winds, when they develop, extend from the top of the escarpment to a distance up to several to around ten kilometres from its face, with the winds being up to a factor of two or more higher than occurs elsewhere on the coastal plain. Hourly averaged wind speeds of 15 m/s (30 knots) are commonly recorded in the foothills during the summer months.

Pitts and Lyons (1988, 1989 and 1990) and Blockley and Lyons (1994) found that the development of the very strong easterly winds requires both the presence of a temperature inversion in the lowest 800 m of the atmosphere and moderate to strong synoptic easterly winds. With such conditions, a hydraulic jump or internal standing waves in the airflow can develop, accelerating the winds down the escarpment and to a finite distance across the coastal plain. Pitts and Lyons (1998 and 1989) presented aircraft observations of the potential temperature in the atmosphere for a number of strong easterly days, as illustrated in **Figure 2.4** for the morning of the 3 February 1987.

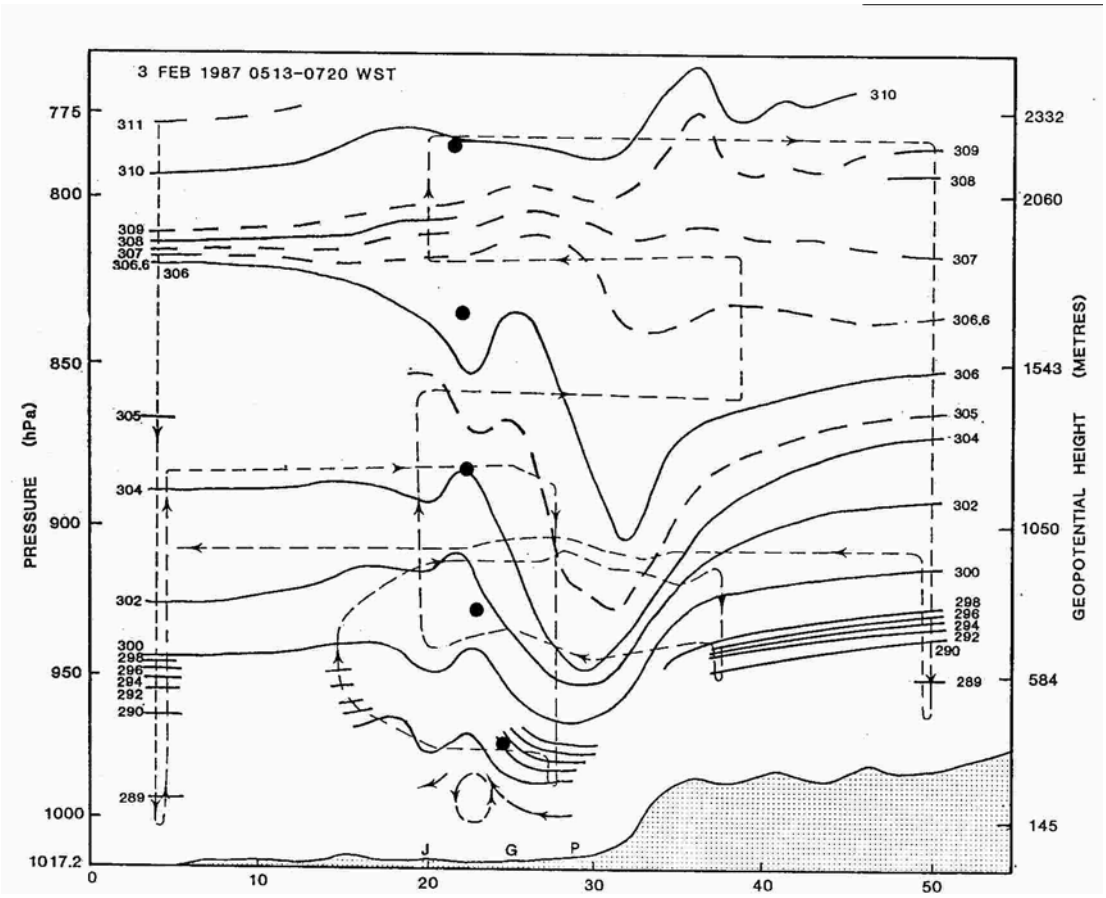


Figure 2.4 Observed Potential Temperatures above the Swan Coastal plain (Port Kennedy to Jarrahdale) on 3 February 1987 from Pitts and Lyons (1988)

Areas where the potential temperature lines converge to the ground indicate regions with higher surface wind speeds than on average, such as in the first 5 kilometres to the west of the escarpment. Also, indicated on the figure is a rotor where the winds rotate in the vertical resulting in a westerly wind near the surface. These observations were modelled by Pitts and Lyons (1989) and Blockley and Lyons (1994) who both reproduced the observed features, with the predicted wind speeds higher by a factor of two in the lee of the escarpment and often the presence of a rotor, as indicated by the westerly winds (see **Figure 2.5**). Pitts and Lyons (1988) used an early version of the Colorado State University model in hydrostatic mode, whilst Blockley and Lyons (1994) used the Regional Atmospheric modelling System (RAMS) in non-hydrostatic mode. Blockley and Lyons (1994) found that for the events simulated, that the use of the hydrostatic approximation reproduced the main features of the flow, though the use of a non-hydrostatic model was required to adequately resolve the location of trapped lee waves downwind of the main wave, such as result in the formation of rotors.

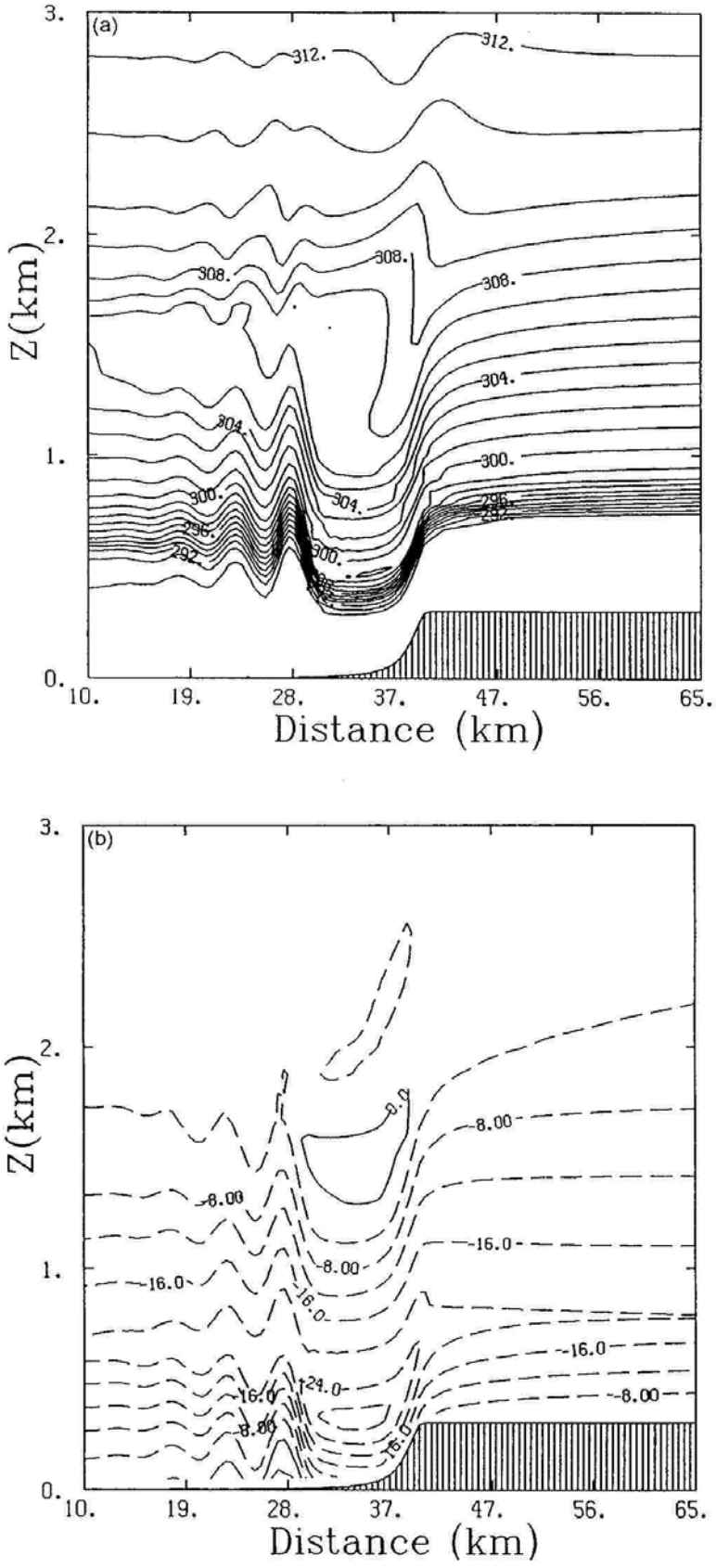


Figure 2.5 Predicted Potential Temperatures and east west Wind Speeds in m/s (dashed lines easterly, solid westerlies) for 3 February 1987 from Blockley and Lyons (1994)

As requiring the presence of an inversion in the temperature profile for an existing easterly synoptic wind, these foothill winds typically occur in summer from early evening to several hours after sunrise. These winds as produced by the north/south escarpment, generally produce an essentially two dimensional wind field. That is, the winds are primarily determined from the distance from the scarp with the N/S variation relatively minor. This is supported by the agreement between the wind conditions for sites along the escarpment, such as at North Waroona (see later) and at the Pinjarra Refinery (not shown in this report).

Examples of some of these foothill winds are presented in **Figure 2.6** and **Figure 2.9** indicating that the:

- Night of 22/23 January 2004 had strong easterly foothill wind at Bancell road which were not recorded further from the scarp at the RDA3 or RDA7 sites. RDA7 in the middle of the three sites actually records generally light 2 m/s south westerly winds. Note, data from North Waroona is not presented for this period as no data was recorded there from 3 December 2003 to 18 February 2004;
- Night of 23/24 January 2004 again had strong winds at Bancell road for less than 5 hours, with the other sites having much lighter easterlies. At 0330 the 30m Bancell road winds shift from a strong easterly wind to a light north westerly wind, with winds at RDA7 site remaining light easterly, whilst at the RDA3 site the winds occasionally swing to the north west;

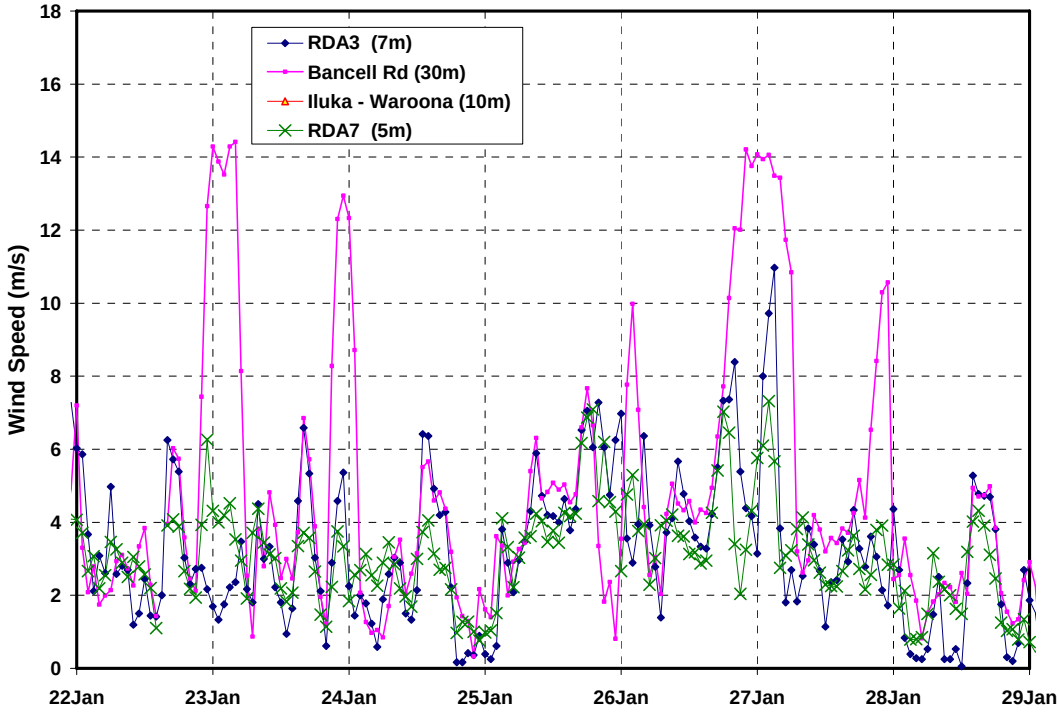


Figure 2.6 Wind Speeds for the Period 22 to 29 January 2004

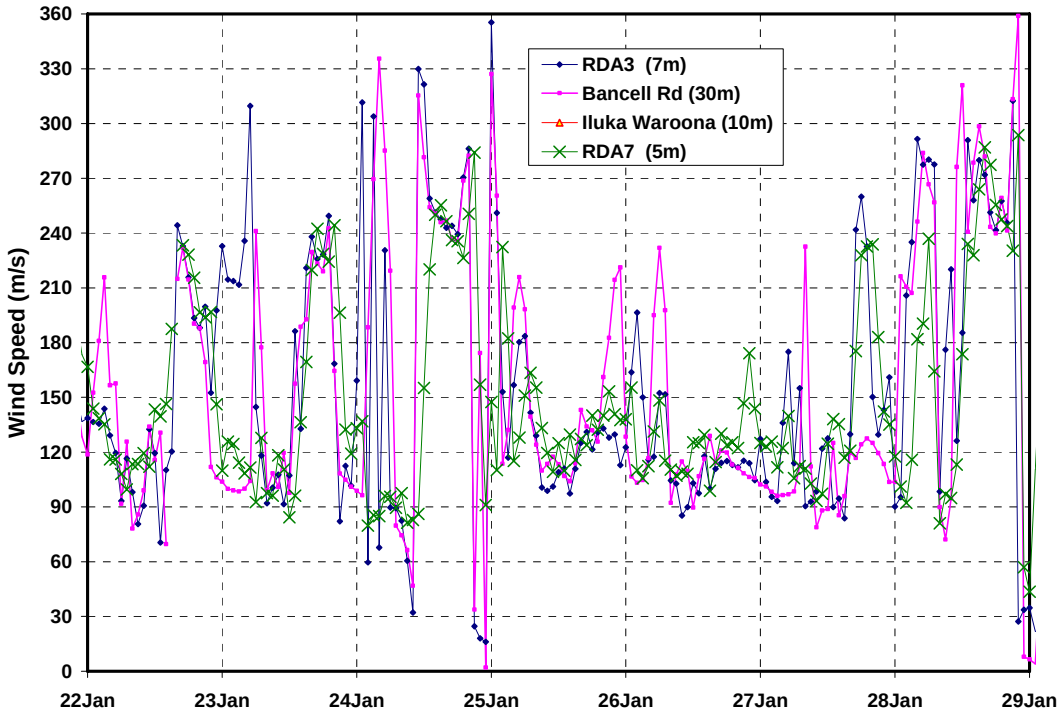


Figure 2.7 Wind Directions for the Period 22 to 29 January 2004

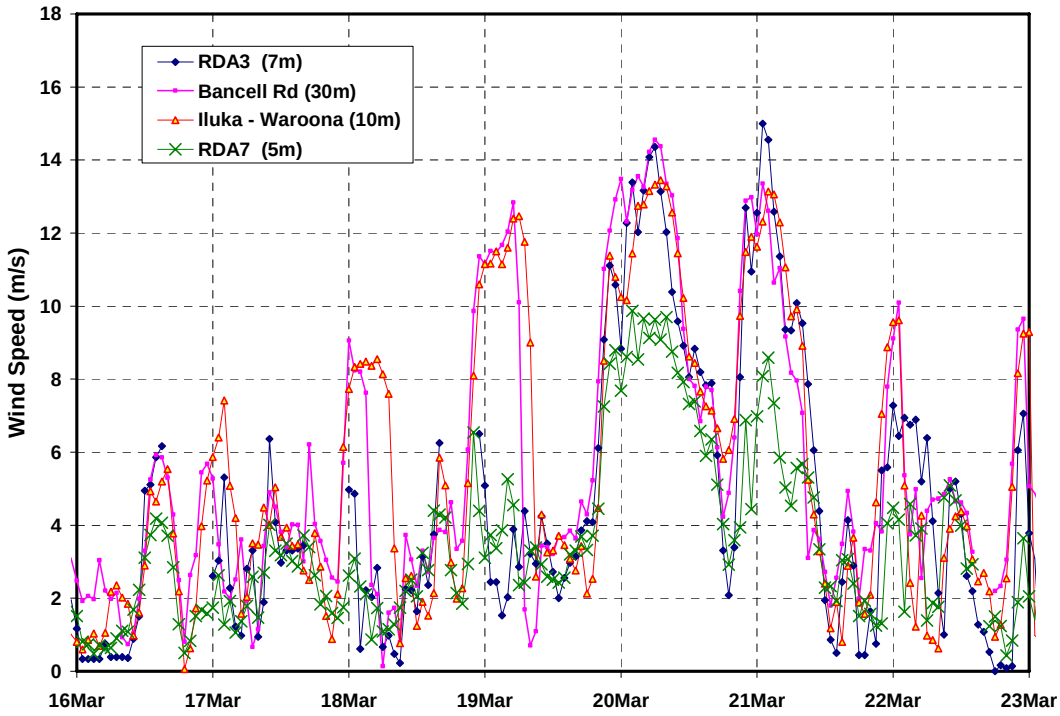


Figure 2.8 Wind Speeds for the Period 16 to 23 March 2004

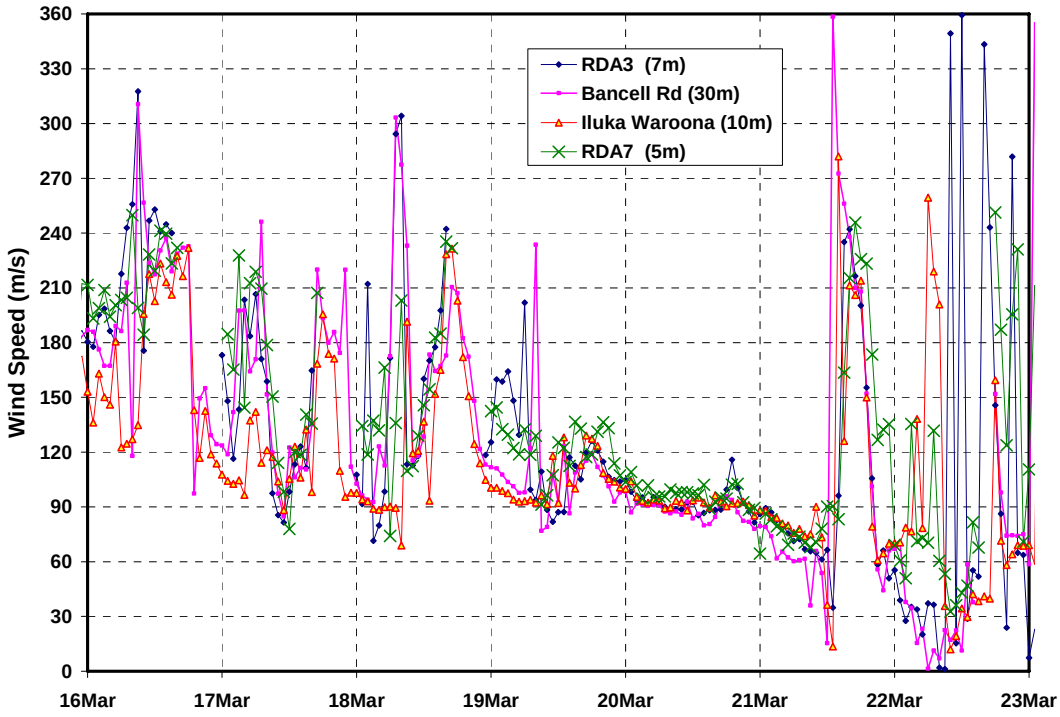


Figure 2.9 Wind Directions for the Period 16 to 23 March 2004

- Night of 26/27 January 2004. Strong easterly winds were recorded at Bancell road with two short periods of strong easterlies at the other monitors, though with the winds not as strong as at Bancell road. The wind directions at RDA3 and RDA7 tend to be more SE than the easterlies recorded at Bancell road, with Bancell road recording an hour of light south westerlies immediately after the strong wind event;
- Night of 17/18 March 2004. Moderate 8 m/s winds where recorded at the two monitors near the scarp, with these persisting the longest at the monitor closest to the scarp. At RDA7 and RDA3, light south easterly to southerly winds of around 2 /s were measured;
- Night of 18/19 March 2004. Strong (11 to 12/ms) easterly winds where recorded at both North Waroona and Bancell road, with lighter (2 to 6m/s) south easterly to southerly winds at the RDA7 and RDA3 site. At the end of the strong easterlies at Bancell road there was again an hour of light south westerlies at this site exclusively; and
- Night of 19/20 and 20/21 March. Strong and consistent easterly winds (up to 15 m/s) where recorded at the three sites closest the scarp. Winds at RDA7 are lighter due to the low measurement height, but are also lower as it located furthest from the escarpment.

Therefore, the above data indicates that:

- The strongest and most persistent easterly winds occur closest to the escarpment, with the frequency and intensity of the winds decreasing with distance from the escarpment in agreement with the aircraft observations and modelling work conducted by Pitts and Lyons (1988 and 1989) and Blockley and Lyons (1994);
- There can be periods of westerly winds associated during these events at some sites, with the winds changing in less than an hour from a strong easterly to light westerly (a possible rotor effect); and

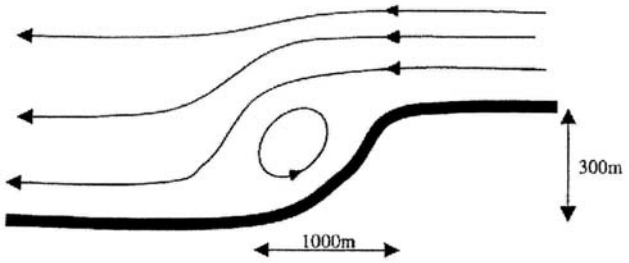
- Winds further to the west (the western extent of the strong easterlies) tend to be south easterly to southerly in direction.

2.1.3.2 Development of Rotors

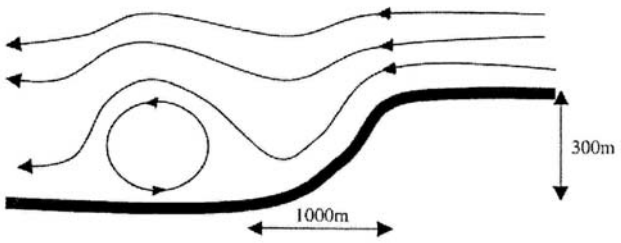
Rotors are often associated with the "foothill winds". A rotor is a region of rotating wind, where the wind direction reverses, becoming a westerly in the case of easterly winds. The presence of rotors in the immediate lee of the escarpment under moderate to strong easterly winds has been documented by Southern and MacNicol (1973) at Perth Airport, Dames & Moore (1977) at Pinjarra and Pitts and Lyons (1988) at Perth Airport and Pearce Aerodrome. In the four month study by Dames and Moore (1997) at the Pinjarra Refinery, eleven occurrences of rotors were identified.

A conceptual diagram of the development of the rotors in the lee of the escarpment is presented in **Figure 2.10**, illustrating the:

- Region where the wind is in the opposite direction to the general wind flow. For the easterly winds that flow across the escarpment, this typically results in a light to moderate westerly wind at the base of the escarpment; and
- The small area where the winds are light, but have an appreciable vertical motion. If a pollutant such as dust or smoke is emitted or entrained in this region it may be carried aloft.



(a) Rotor formed due to flow separation (note vertical exaggeration)



(b) Rotor formed due to development of hydraulic jump or a standing wave (note vertical exaggeration).

Figure 2.10 Possible processes leading to the development of rotors to the west of the Darling Scarp (from SKM, 2003b)

In **Figure 2.6** to **Figure 2.9** several possible cases of rotors at Bancell road are evident, with the development of south westerly winds immediately after a strong easterly wind event. A closer examination of the wind records for two such events on the morning of the 23 and 24 January 2004 are presented in **Figure 2.11**.

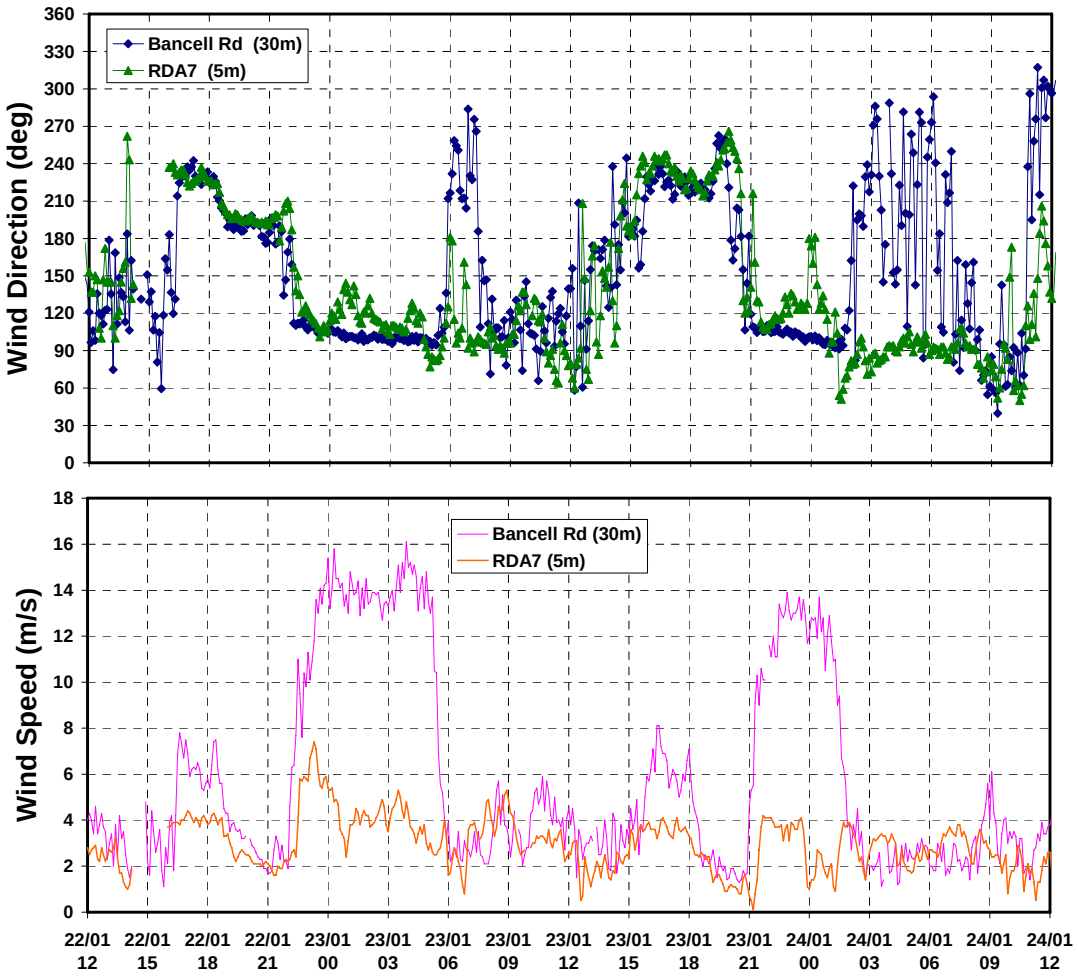


Figure 2.11 Six Minute Winds for the Period 22 to 23/1/04 at Bancell Rd and RDA7

Figure 2.11 indicates the following:

- A sea breeze on the afternoon of 22 January that finishes at 2200 WST;
- The sudden onset of easterlies at 2200 WST, reaching 14 m/s by midnight at the Bancell Rd site, with the winds remaining much lighter (4 m/s) at the RDA7 site, apart from the first few hours where wind speeds up to 7 m/s were recorded;
- At 0600 WST on 23 January, the wind shifts to a light WSW at Bancell Rd, with the winds at RDA7 (apart from a few 6 minute periods) remaining easterly. This indicates that a rotor is occurring near the scarp as indicated by the SW winds. It is considered that this rotor will occur in a similar manner to that shown in **Figure 2.10b**;

- After 815 WST, the wind shifts back to an easterly (consistent with the winds recorded at RDA7), with the winds remaining easterly until the development of the sea breeze in the afternoon;
- At 2130 WST on the 23 January, a strong easterly again develops at Bancell Rd whilst the winds stay light south easterly to southerly at RDA7; and
- At 0200 WST on the 24 January, the winds at Bancell road decrease to light (2 m/s) variable winds, swinging west to south southeast (average south southwest), whilst the winds at RDA7 were steady easterlies. This again may be due to a rotor, possibly in the form of that shown in **Figure 2.10a**, where flow separation at the top of the escarpment occurs.

Another example of a rotor process is indicated on the 18th and primarily the 19th June 2003 (see **Figure 2.12**), under north east synoptic winds, as indicated by the predicted 100m winds from TAPM. This shows, particularly for the 19th June, that the winds nearest the scarp (North Waroona) are light northerlies, further from the scarp at the residue area (RDA3), they are north easterlies, whilst at Bancell road between the two they tend to very light south westerlies.

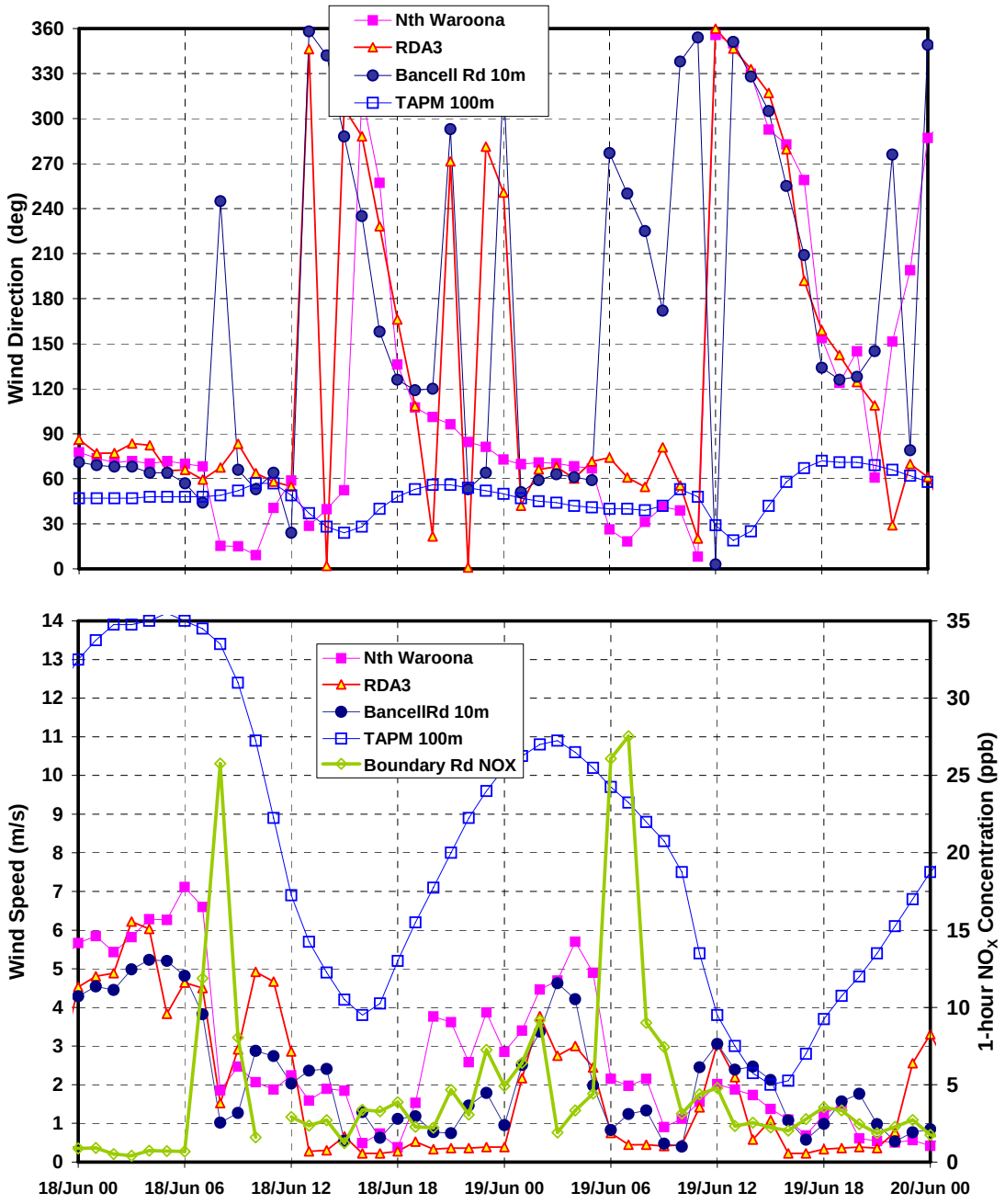


Figure 2.12 Wind speed and wind direction and Observed NO_X at Boundary Rd for 18 to 19 June 2003

On both these days reasonably high NO_X concentrations from the refinery, as determined by the Nth Waroona wind directions occurs at Boundary road. The above process therefore, is an important example of how rotors or complex winds may be bringing the plumes from the taller refinery stacks south, when the surface winds at Bancell road indicate light winds from another direction. An analysis of the NO_X data at Boundary road (summarised in **Appendix B**), indicates that up to five out of the top seventeen 1-hour NO_X events may be due to this process, with these events all occurring near sunrise, with light winds recorded at Bancell road. These events it is noted, do not result in the highest concentrations at Boundary road, with the maximum such event under these conditions, being only the

eighth highest 1-hour concentration. As such, they are not the dominant meteorological process leading to the highest concentrations at Boundary road.

Another illustration of the presence of generally easterly winds near the base of the escarpment and wind reversals, or at least marked changes in the winds further from the escarpment, is obtained by comparing scatter plots of the wind directions at the various sites. **Figure 2.13** presents the wind directions between RDA3 and Nth Waroona. This indicates the general good agreement with the wind observations, except for a large number of east south easterly winds at North Waroona (near the scarp) that are recorded as anywhere between south easterly and north westerlies at RDA3. These events occur primarily when the North Waroona winds are strong, indicating the very different wind regimes that can occur when the foothill winds occur. Similar relationships between the winds (though to a lesser extent), also occur between north Waroona and Bancell Rd winds and between the Bancell Rd and RDA3 winds.

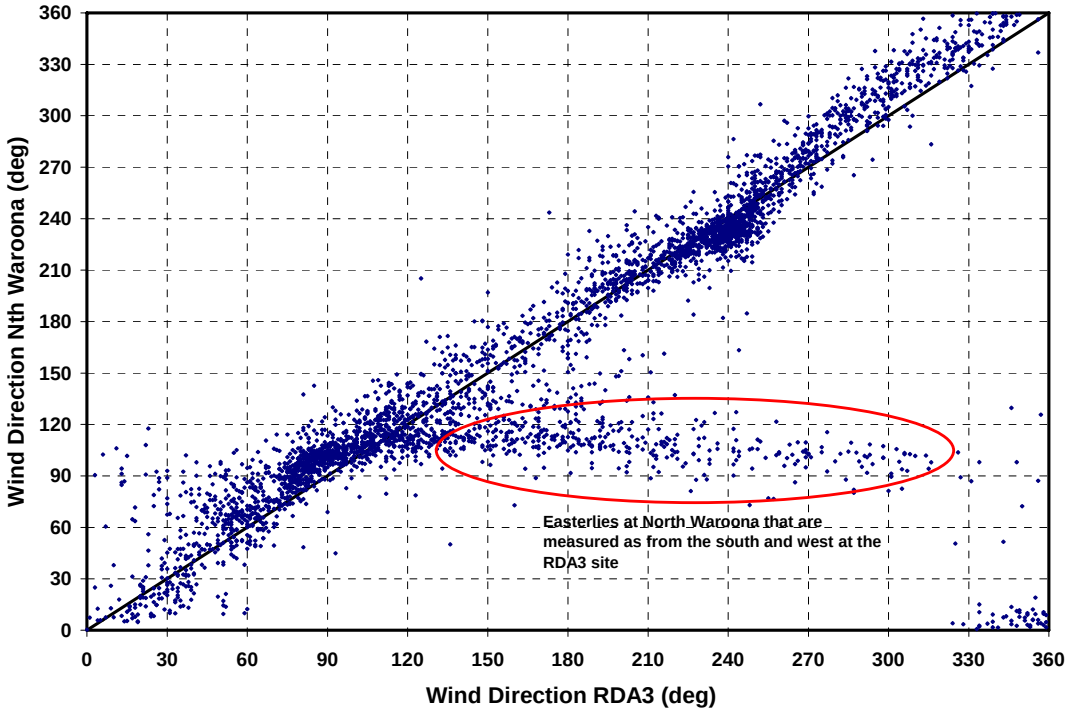


Figure 2.13 Scatterplot of RDA3 versus Nth Waroona wind directions for North Waroona winds greater than 4 m/s for 1/7/00 to 30/6/01

2.1.3.3 Channelling of Winds

Figure 2.13 also indicates that north westerly winds recorded at Bancell road are likely to be recorded as 20 degrees more northerly at North Waroona, or closer to the scarp. This may be due to channelling of the winds by the escarpment. This would particularly happen at night, for stable air, which would tend to flow around or along any barrier such as the escarpment. Therefore, north westerlies may tend to be channelled to northerlies by the escarpment.

2.1.3.4 Katabatic Drainage Winds

For conditions with light winds and clear skies at night, cooling of the air near the ground surface results in the denser, cooler air draining to areas of lower relief. For areas on the coastal plain, the

winds will generally drain down the escarpment with greatest flows occurring out of the valleys. These winds will be light due to the relatively small size of the escarpment and will occur predominantly in the winter months, when lighter synoptic winds generally occur.

2.1.4 Annual Wind Roses

Annual wind roses for the North Waroona, Bancell Road and RDA3 site for 2000/2001 are presented in **Figure 2.14**. These winds are presented to show the variation across the scarp as indicated in the preceding sections. The period 1 July 2000 to 30 June 2001 has been chosen as this contains the period with good quality data from the RDA3 site (before the anemometer stalling increases) and has good quality 10m data from Bancell road (apart from the sheltering from trees to the south and west, see **Section 2.1.2.1**).

Figure 2.14 indicates that:

- The strongest winds occur from the east to southeast at all three sites;
- North Waroona experiences the greatest frequency of winds from the east southeast to south easterly directions, with the percentage of east to southeast winds decreasing with distance from the escarpment. The higher frequency of these winds near the scarp is illustrated in **Figure 2.6** to **Figure 2.9,** indicating that these winds are more frequent and occur for longer during the night at North Waroona, decreasing in frequency at Bancell road and at RDA3;
- The RDA3 site records the greatest number of southerly winds. Examination of the data indicates that these southerly winds primarily occur when the winds at the other sites are south easterly, or sometimes south westerly;
- The RDA3 site records a similar number of north westerly and north easterly winds to the other two sites, but a lower number of direct northerlies. This may be due to channelling of winds to northerlies for the two sites closer to the scarp;
- The majority of light winds (<1.8 m/s) occur from the southwest through south to the southeast. That is, the light winds have a southerly component; and
- The RDA3 site generally measures much higher winds speeds than the Bancell Road site with wind speeds at the Bancell Road site generally being around 62% of the RDA3 weather station site. This large difference is due to exposure of the residue area as discussed in **Section 2.1.2.3**.

Annual wind roses for the RDA3 site are also presented in **Figure 2.15** as:

- Measured at RDA3 for 1/4/03 to 31/3/04;
- Predicted by the model TAPM for 1/4/03 to 31/3/04;
- Measured at RDA3 for 1/4/03 to 31/3/04, but corrected for the stalling problem as detailed in Appendix A; and
- Measured by the RDA3 sensor for the 3 year period 1/4/1998 to 31/3/2001 (where the stalling was less of an issue).

These indicate:

- Generally similar wind distribution between TAPM and the observed winds for 2003/2004, but with a much lower frequency of calm conditions predicted by TAPM;

- Generally a higher frequency of NNE to ENE winds for the three years of data, than observed or modelled in 2003/2004. A more detailed comparison is presented in **Section 2.1.6**; and
- Better agreement between data from the 3 year period with the corrected RDA3 winds, than with the uncorrected observations or the TAPM predicted winds.

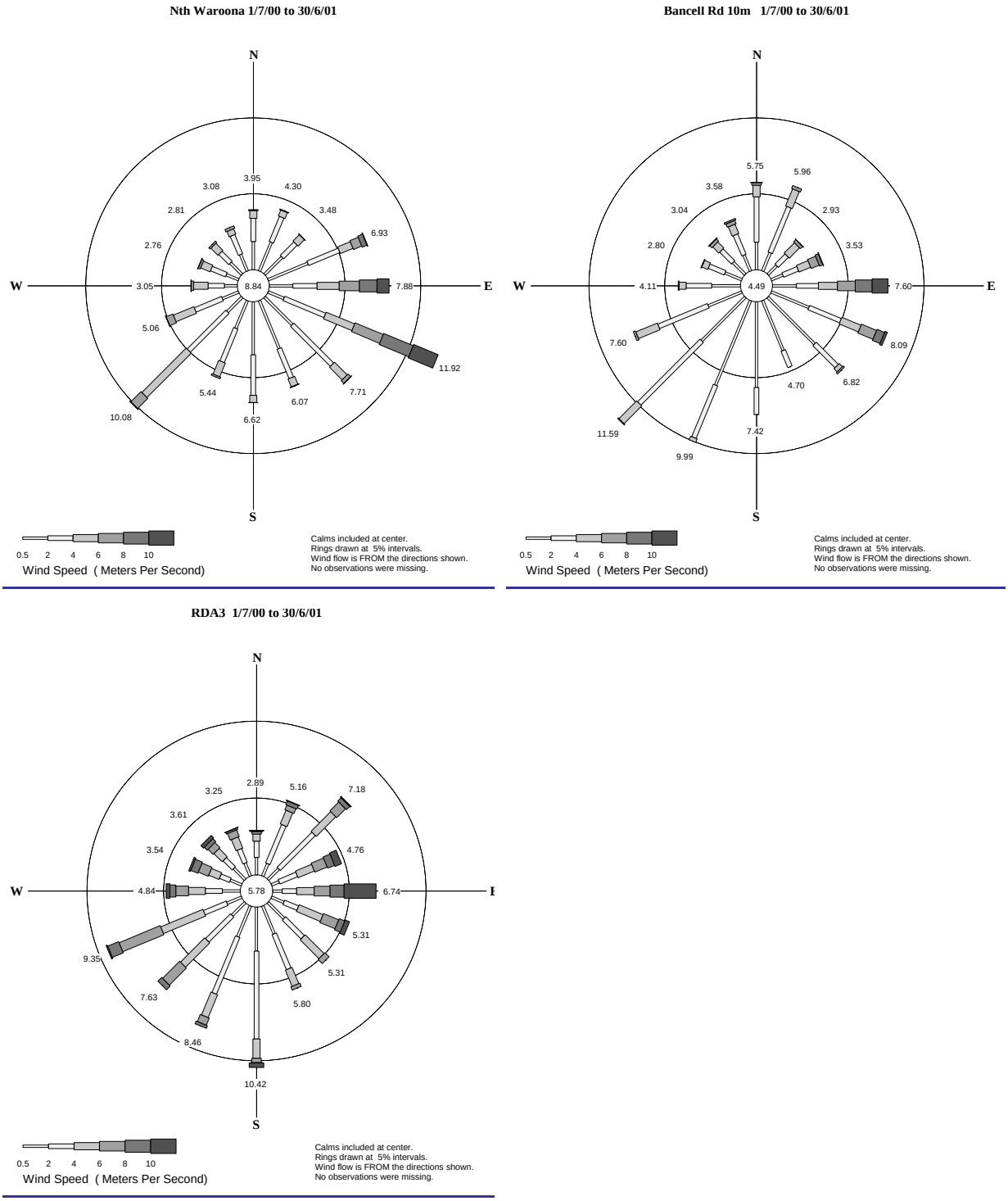


Figure 2.14 Annual Wind roses for 1/7/03 to 30/6/01 for Nth Waroona, Bancell Rd and RDA3

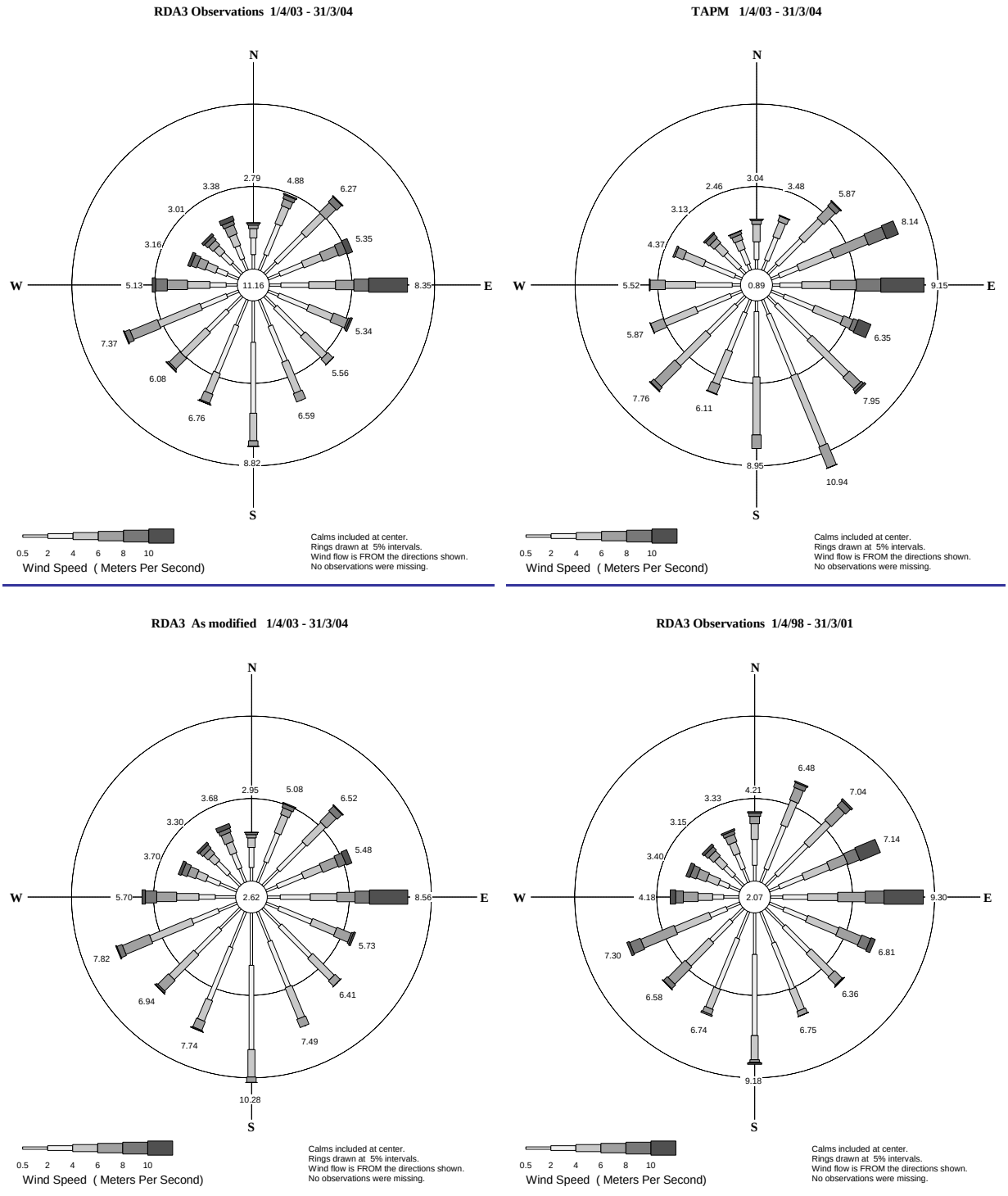


Figure 2.15 Annual Wind roses for 1/4/03 to 31/3/04 (the modelled period) for the RDA3 site

2.1.5 Seasonal and Hourly Wind Variation

Seasonal wind roses at the RDA3 site are presented in **Figure 2.16** with hourly wind roses for the winter and summer periods presented in **Figure 2.17** and **Figure 2.18**. The seasonal wind roses indicate a strong seasonal cycle. In summer, the predominant winds are from the west southwest to east northeast. Winds from the west through to the northeast being very infrequent. Strongest winds occur from the east northeast through to the east southeast and are the result of the frequent synoptic

easterlies at this time of the year and the development of the foothill winds. The south westerly winds are associated with development of the sea breeze. For the winter months, the winds are predominantly north to east northeasterly, due to synoptic weather patterns.

The hourly variation in winds for winter (**Figure 2.17**) indicates that the north easterly winds occur at night time through to the morning, with stronger westerlies occurring during the day time. That is, there is a land/sea breeze or possible drainage flow cycle superimposed on the synoptic winds that increases the frequency of the north easterlies at night and increases the frequency and strength of the westerlies during the day.

The hourly wind roses for summer (**Figure 2.18**) indicate that the strong easterlies occur particularly from early in the day (0300WST) until mid morning, tending to be easterly and slightly north of easterly as the night or morning progresses. Winds in the afternoon tend to be west south-westerly, associated with the afternoon sea breeze, with this wind moderating down to a lighter south-westerly to south-easterly wind by early evening before the arrival of the easterlies again.

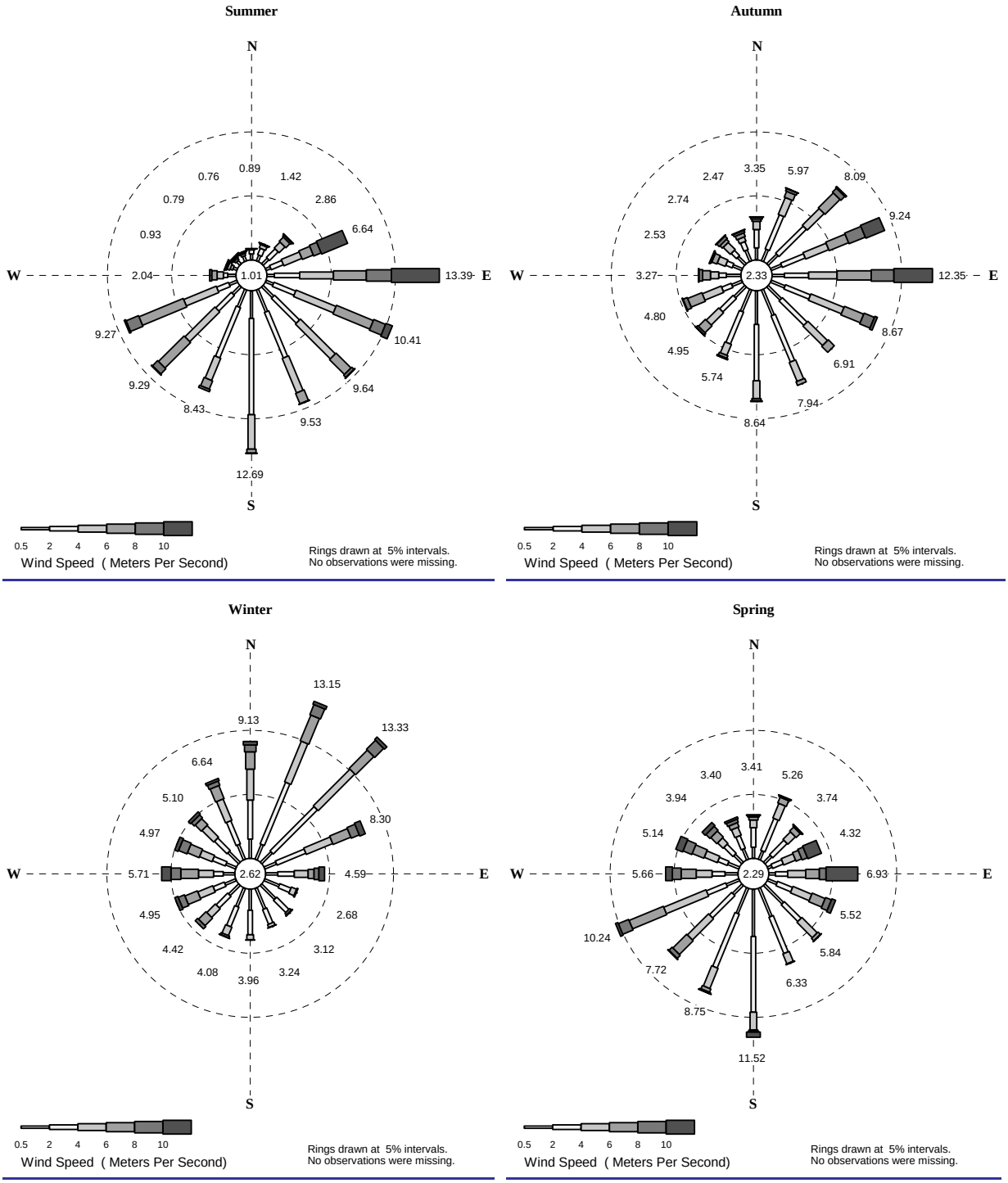


Figure 2.16 Seasonal Wind Roses at RDA3 (Data from April 1998 to March 2001)

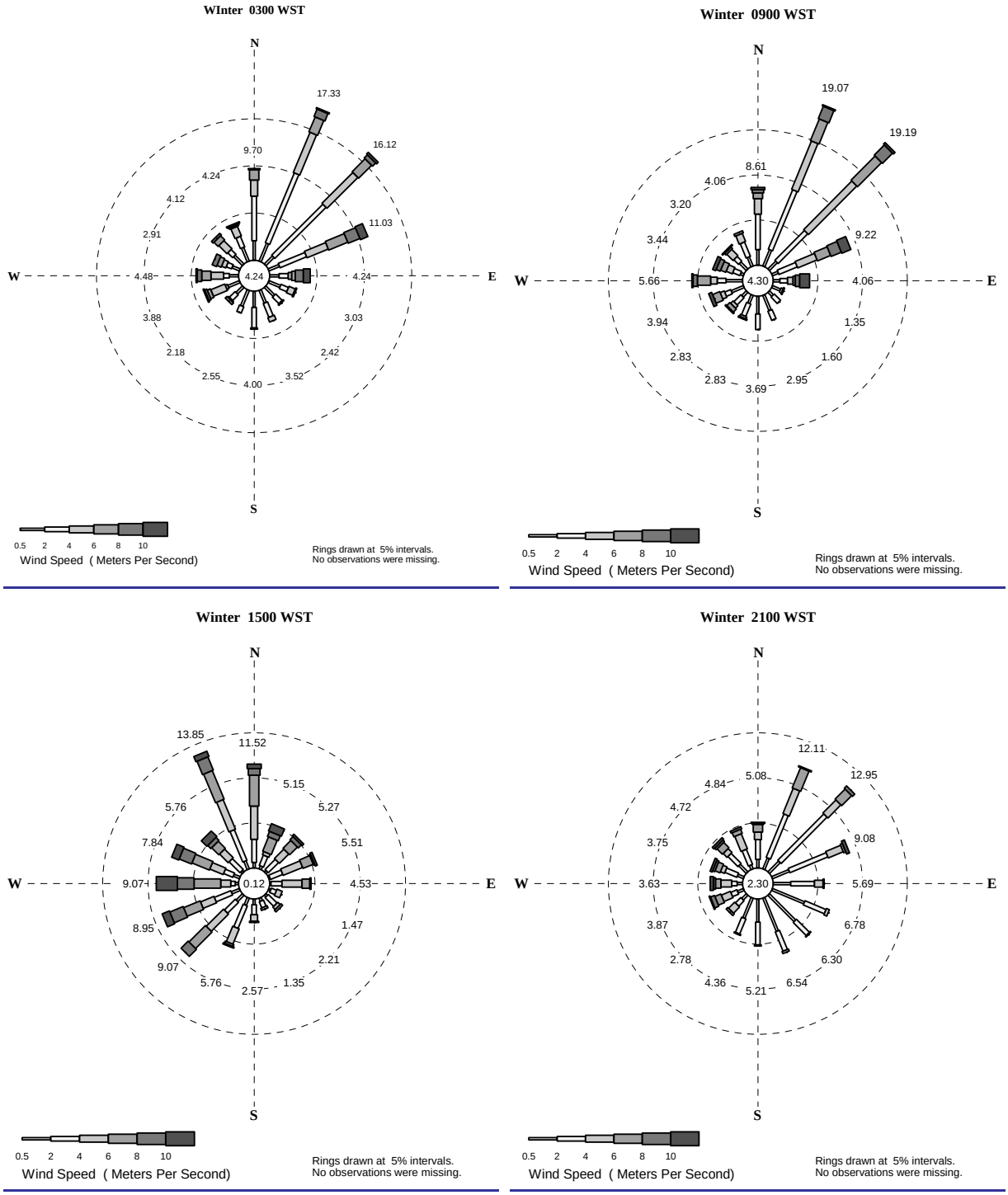


Figure 2.17 Winter Wind Roses by time of day for RDA3 (Data from April 1998 to March 2001)

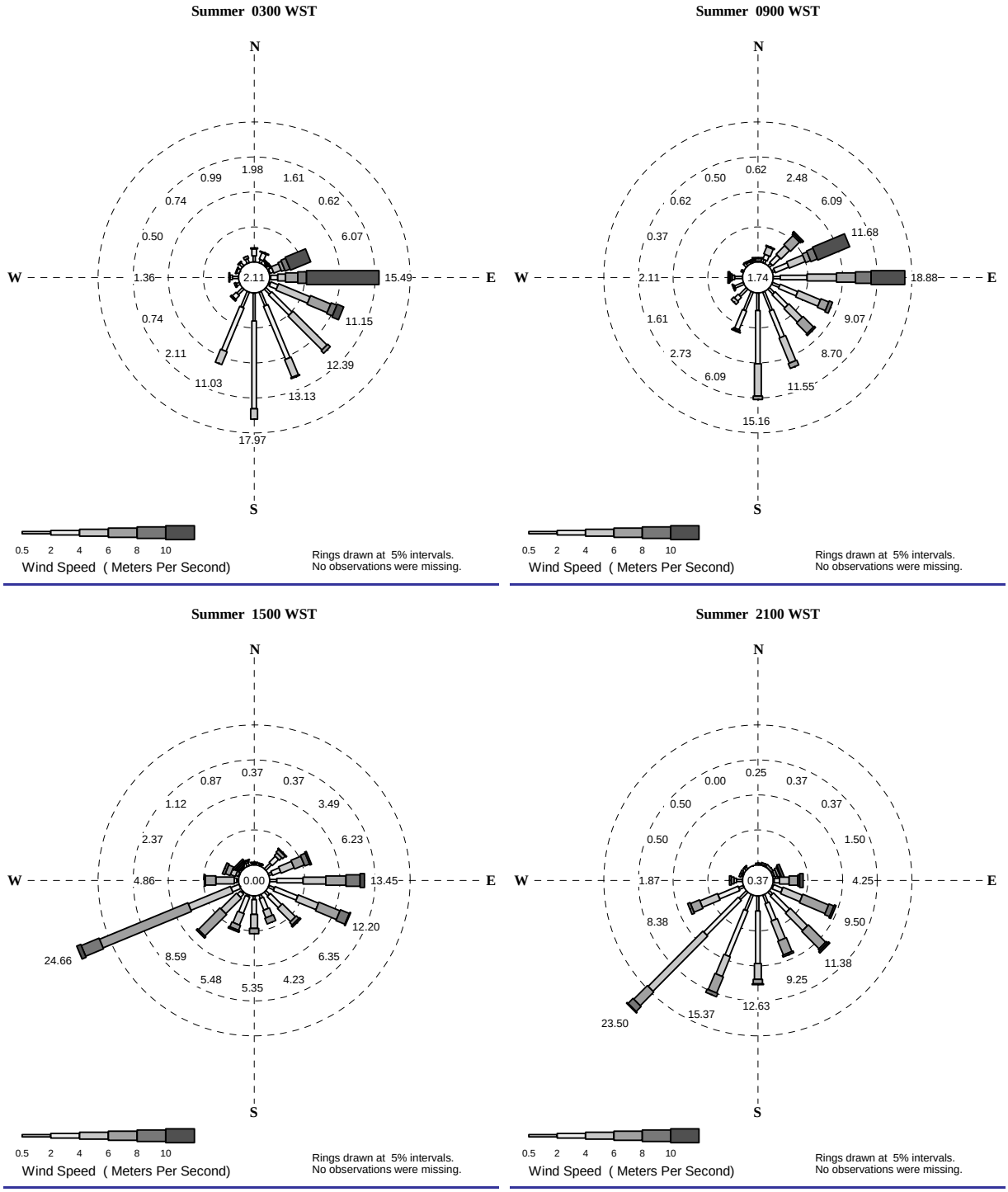


Figure 2.18 Summer Wind Roses by time of day for RDA3 (Data from April 1998 to March 2001)

2.1.6 Annual Variation - Representativeness of 2003/2004

For the modelling of the refinery VOC and PM_{10}, CSIRO selected the 12 month period from 1/4/03 to 21/3/04, as it contained the best meteorological data at Wagerup with the installation of the 30m tower

in July 2003 at Bancell road. To ensure compatibility in the model predictions, this period was also used for modelling fugitive dust and VOCs.

For fugitive VOC dispersion, conditions that will lead to the highest concentrations off site are light wind, stable conditions, whilst for modelling fugitive dust, the conditions leading to highest concentrations are strong winds where the dust is primarily generated. As such, it is the relative frequency of these two winds that are critical for determining whether the period is representative.

Figure 2.19 presents the frequency of all winds from the north and east using both the RDA3 and North Waroona data sets. The north and east directions are selected as they are the directions with the highest wind speeds as well as leading to the most frequent complaints regarding dust from the residue area. The North Waroona and RDA3 sites are used as they are the two sites with the longest period of wind measurements. Note, no statistics were estimated for North Waroona for 2003/2004 as there was a significant period (77 days) of missing data in this summer.

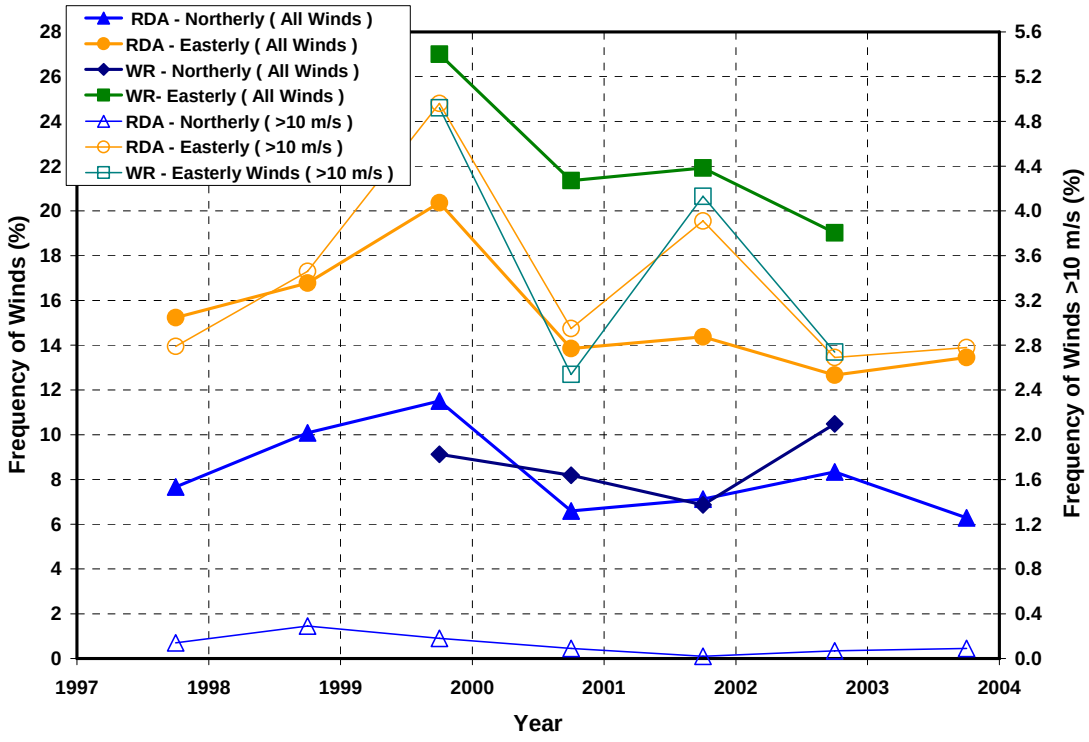


Figure 2.19 Wind Frequency for northerly and easterly winds for years from 1997 to 2004

Figure 2.19 indicates:

- Good agreement between the trends at the two sites as is expected;
- A much higher percentage of easterlies at the North Waroona site, though the frequency of easterly winds greater than 10 m/s is approximately the same. The higher percentage of easterlies at North Waroona is due to its close proximity to the scarp as discussed in **Section 2.1.3**. That the percentage of strong easterlies (>10 m/s) is approximately the same is considered to be due to the much more exposed nature of the RDA3 site,
- The year 1999/2000 and to a lesser extent 2001/2002 had a higher frequency of strong easterly winds than the other years, with 2003/2004 having a below average number of strong

easterlies. The 12 month period in 2003/2004 had 7% less easterlies and 17% less easterlies greater than 10 m/s than the average of the 7 years; and

- The year 2003/2004 had a low percentage of strong northerlies.

As such, for strong wind events that may generate dust from the residue area, it is considered that the twelve month period in 2003/2004 would have around 17% lower easterlies and a lower number of northerlies than on average.

A similar analysis was conducted by CSIRO (2005b) using the modelled winds from the Global Analysis and Prediction model (used as input to TAPM) as reproduced in **Figure 2.20**.

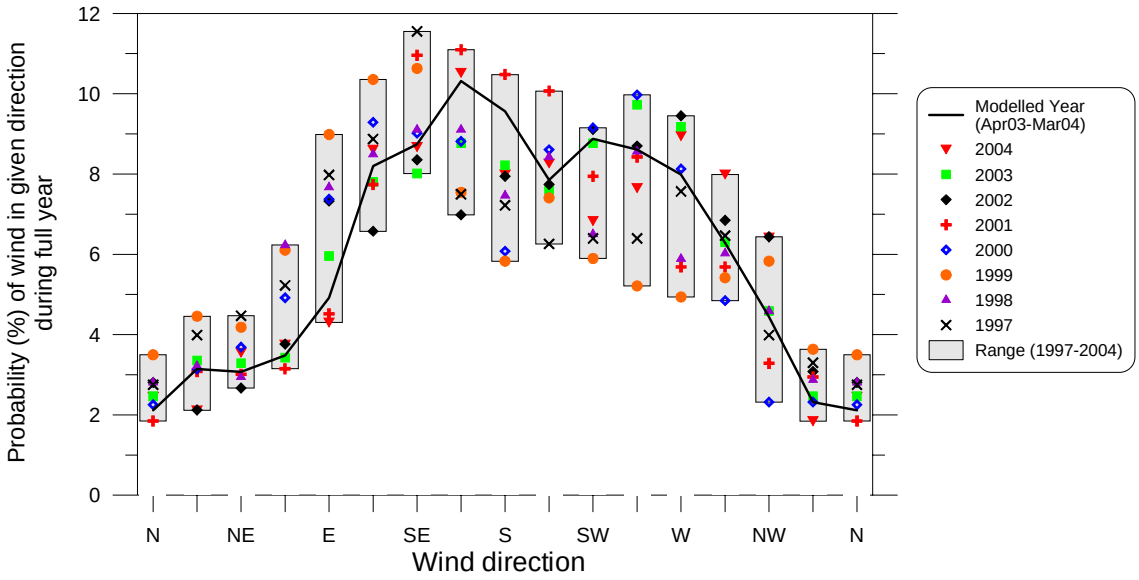


Figure 2.20 Probability distribution of 10-m wind directions from the Global Analysis and Prediction (GASP) model for Wagerup for the years 1997-2004 compared with those from the modelled year (from CSIRO, 2005b)

CSIRO (2005b) found that there was a typical ±30% variation about the mean in the frequency of winds from each wind direction and concluded that the modelled year was "seen to be a fairly average year, just with slightly fewer winds in the NE-N range and more winds in the SSE and SW directions than average". CSIRO (2005c) also comment that "for the modelled year the frequencies of occurrences of winds from all sectors are within ±20% of the respective median values, except for the frequency of the southerly winds, which is 24% higher than the median value, and the frequency of the easterly winds, which is 33% lower than the median value.

It is noted that the data in **Figure 2.20** are from a regional model and reflects primarily the synoptic winds and may not adequately resolve the finer scale wind fields due to the scarp etc, which are captured in the monitored data. Nevertheless it is in good agreement with the observations, indicating that 1999 was atypical, with a much higher frequency of easterlies and lower percentage of westerlies, whilst 2003/2004 selected for the modelling, had a below average frequency of easterly and northerly winds.

In terms of low wind speeds, data for a inter year comparison of the observed winds are not available, with the RDA3 wind sensor having stalling problems in the later years therefore biasing the data, the North Waroona data having a large 77 day gap in 2003/2004 and the change in the wind station at Bancell road resulting in the 10m wind sensor having a large sheltering effect from July 2003 onwards. The GASP winds for this period, though not ideal for low wind speeds, indicate that winds less than 1, 2 and 3 m/s for 2003/2004 were 9%, 5% and 3% higher than on average respectively. As such, 2003/2004 should be reasonably typical or slightly conservative for modelling VOC concentrations from low level fugitive sources.

3 Ambient Particulate and VOC data

3.1 Particulate

3.1.1 Particulate Monitoring Undertaken and Trends

A summary of the Wagerup dust monitoring network, as at 2004, is presented in **Table 2.1** with the locations of the monitors presented in **Figure 1.1**. Data collected from the network for the period 2000/2001 to 2003/2004 is summarised in

Table 3.1 and plotted in **Figure 3.1**. The period from 2000 is presented as it covers the time with similar dust controls and similar sized operations as occurs at present. Data earlier than 2000 is not considered as it does not reflect the current improved dust controls at the residue area and also the increased size of the operations. For example RDA6 was constructed from 1996 to 1998.

The data in

Table 3.1 indicate that:

- Sites such as the east and south east monitor, though reasonably close to the residue area have low to moderate dust levels. The east and south east monitors maximums for the four years are 89 and 116 μg/m^3, which are well below the Kwinana residential limit of 150 μg/m^3;
- The south east monitor has the lowest average levels of all sites with annual averages between 15.6 μg/m^3 to 19.7 μg/m^3. This occurs though the site is within 100m of the residue area (see **Figure 1.1**), as strong winds from the north west (the direction of the residue area) in the drier months are very infrequent;
- The annual background dust level (derived from the minimum 24-hour dust level for each day), vary between 13.4 to 16.8 μg/m^3, with typical maximum 24-hour concentrations in a year varying between 49 to 86 μg/m^3; and
- The highest 24-hour dust levels before 2003/2004 occur at the south, south west and west monitors. For 2003/2004, with the construction of RDA7 occurring, the new NE monitor has the highest dust concentrations.

Table 3.1 Wagerup Particulate Monitoring Results (µg/m^3) from 2000 to 2004

Statistic and Year	East TSP	SE TSP	West TSP	NW TSP	South TSP	SW TSP	NE TSP	BRW TSP	RDA7 TSP	Bkgd TSP	NE PM_{10}	BRW PM_{10}
Maximum												
2000/2001	73	116	222	110	217					63		
2001/2002	78	68	101	126	257	409				49		
2002/2003	89	103	99	89	471	348				86		
2003/2004	78		208	91	141	202	269 (1)	106 (1)	82 (1)	57	113 (1)	40 (1)
99 Percentile												
2000/2001	70	59	101	79	201					46		
2001/2002	73	46	69	83	119	165				36		
2002/2003	82	49	87	78	62	143				42		
2003/2004	69	37	124	69	84	125	199 (1)	81 (1)	67 (1)	43	106 (1)	39 (1)
95 Percentile												
2000/2001	57	41	64	55	81					35		
2001/2002	51	29	52	57	44	84				27		
2002/2003	65	38	65	63	42	69				29		
2003/2004	50	29	76	51	41	60	125 (1)	65 (1)	57 (1)	30	52 (1)	37 (1)
90 Percentile												
2000/2001	51	33	55	47	50					31		
2001/2002	46	25	46	43	33	47				23		
2002/2003	52	29	53	51	30	42				25		
2003/2004	44	25	61	44	32	36	108 (1)	57 (1)	48 (1)	27	45 (1)	33 (1)
Average												
2000/2001	29.8	19.7	30.3	27.4	28.8					17.4		
2001/2002	26.6	15.6	25.0	24.3	20.8	25.3				13.8		
2002/2003	28.6	17.0	27.2	26.1	18.8	24.6				14.5		
2003/2004	25.6		29.9	24.4	20.2	22.9	63.8 (1)	39.5 (1)	30.7 (1)	15.4	30.0 (1)	21.9 (1)

Notes:

1) The NE and BRW site have only 3.5 months data from the 17/12/03 to 31/3/04, with the RDA7 monitor having 4 months of data from 1/12/03. These sites have only been included to illustrate indicative concentrations at these sites.
2) Years are from 1 April to 30 March to be consistent with the modelling. Therefore 2000/2001 is the year 1 April 2000 to 30 March 2001.
3) Background values determined as the minimum of all TSP observations for each 24-hour period.
4) Data from Boundary Road has not been presented, as it is distant from residue area with local sources of dust such as the road due north of it.
5) For the period to 1 June 2004, the high volume filter papers were changed approximately around 3pm daily and recorded as the date on which the filter paper was retrieved. Since June 1, 2004 filter paper change outs now occur at around 9am. Data from the TEOM's for the data period (1 April 2000 to 30 March 2004) have been constructed from the 3pm to 3pm data to be consistent with the high volume sampler data.

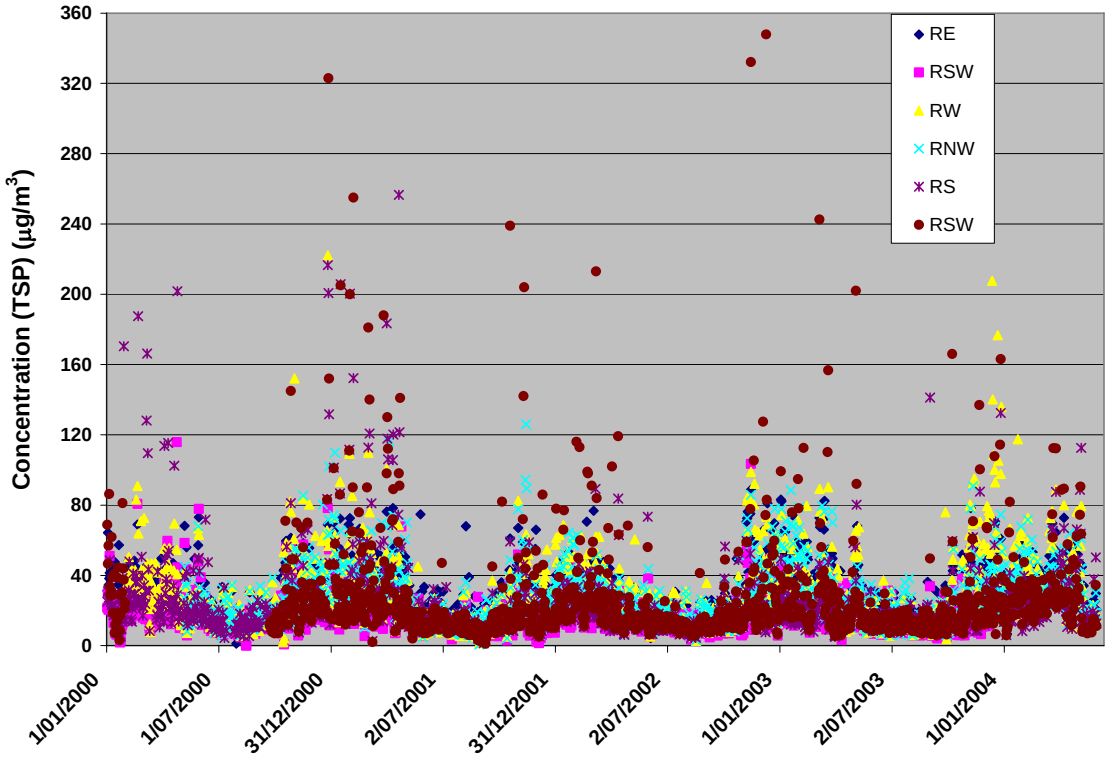


Figure 3.1 Wagerup TSP results from 1 January 2000 to 30 April 2004

Figure 3.1 presents the daily 24-hour concentrations from the sites that have operated since 2000, clearly indicating a seasonal pattern in dust levels with higher dust levels occurring in the drier summer months.

The data from 2000/2001 to 2003/2004 is also presented in **Figure 3.2**. This indicates that:

- TSP concentrations have tended to decrease from 2000 onwards for the south and south west monitor. This may be due to better dust control on the residue area;
- The west monitor had higher TSP concentrations in 2003/2004 than for other years. This is discussed later and is considered due to local sources there; and
- Other sites have reasonably constant TSP concentrations over the years.

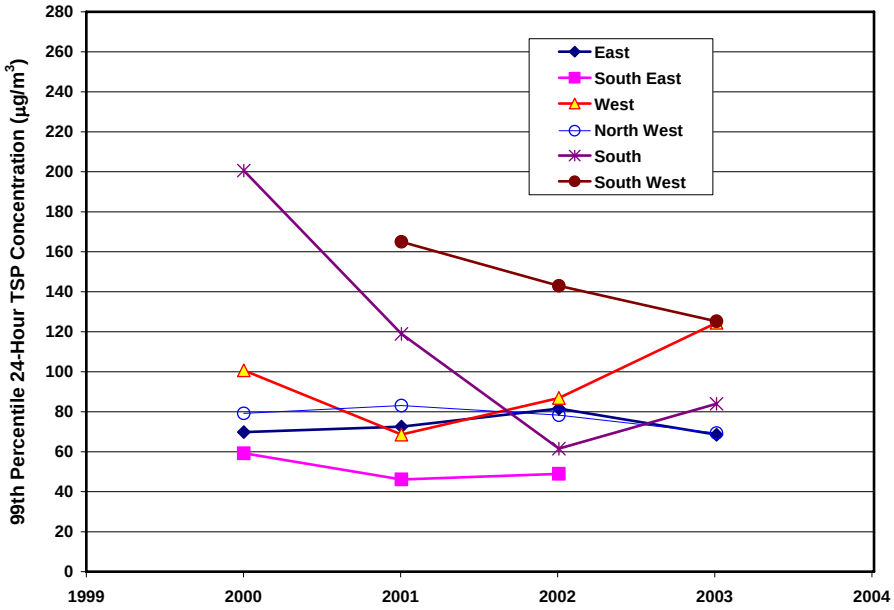


Figure 3.2 99th Percentile 24-hour Concentration Measured at Wagerup

3.1.2 Sources of Dust at the Monitors

Table 3.2 lists the top four to nine 24-hour TSP concentrations at the various monitors and presents an analysis of the likely sources of the dust. **Table 3.2** indicates that:

- For the south and south west monitor, all of the top dust events were due to the residue area, with these events occurring under strong easterlies at night or strong northerlies;
- For the north monitor, the residue area is the dominant dust source with the top events occurring on days with light to moderate sea breezes and southerlies. That the top dust events occur under lower wind speeds, indicates that wind erosion is not the dominant dust source, with the source of dust considered to be earth moving at the borrow pit used during the construction of RDA7 (see **Figure 1.1**). This is confirmed from discussions with Wagerup staff;
- The west monitor has a number of the top dust events due to source to the SW, though with one event on the 22/12/03, with 24-hour dust concentrations of 177 µg/m^3, due to strong easterly winds and dust from the RA;
- For the RDA7 monitor, the highest dust levels occur on days with predominantly south-westerly winds indicating another local source in the area;
- The SE monitor recorded only low dust concentrations with no 24-hour dust levels attributable to the residue area over 43 µg/m^3,
- BRW had no clear 24-hour events due to the residue area. All the top events were due to other local sources. Discussions with Alcoa Wagerup personnel and the contractor who maintains the high volume air sampler, both identified local cattle movement and the state of the immediate area near the high volume air sampler as a significant source of dust at this site;
- The highest 24-hour concentrations at the north west monitor are considered to be due to other sources, such as from the west and from the north; and

- The east monitor top dust events appear to be due to dust from the bauxite stockpile under strong winds, with some indication of dust from the residue area under lighter winds from the west.

Table 3.2 Highest Dust Levels for 2003/2004 and Probable Sources

Monitor	Conc. ($\mu g/m^3$)	Date	Source and Comments
BRW	106	27/3/04	Other local source - Winds not from residue area or refinery W/NW to S/SE
	80	17/12/03	Other source. Very strong easterly
	77	26/3/04	Possible contribution from residue area. Strong easterly also for 8 hrs from NNE through NW
	72	29/3/04	Other Source. Highest concentration of all sites. Winds from SW and East
	65	28/1/04	Winds southerly component
	65	25/3/04	Winds southerly component
	64	24/3/04	Winds southerly component
	60	18/2/04	Possible with a period of moderate northerly winds
RNW	91	12/11/03	Other source. No wind from residue area directions
	78	8/11/03	Other Source. SW and Southerlies for period
	75	27/12/03	Other Source. Strong northerly winds. Local source to north probably agricultural
	72	9/2/04	Other source NW
	68	29/1/04	Other source. Westerly with 2 hours of very light (near clam winds from SE at night
	68	17/12/03	Possible with a few hours of south easterlies
	65	19/3/03	Residue area with SE winds
	60	18/12/03	Other SW all period
	60	16/2/04	Residue area with SE winds
RW	208	13/12/03	Other. Winds predominantly from SW to SE. 1 hour of light winds from RDA
	177	22/12/03	Residue area. Moderately strong easterly 13/m/s at the RDA monitor
	140	14/12/03	Other SW to SE winds
	136	28/12/03	Other westerly to southerly winds
	117	24/1/04	Probable residue area contribution with lighter winds from east
	109	15/12/03	Other. SW to S/SE winds
RE	78	8/11/03	Probable other sources except for a few hours from SW
	70	20/3/04	Probably bauxite stockpiles. Strong easterlies
	69	17/12/03	Possibly bauxite stockpiles. Very strong easterly
	68	7/5/03	Possible residue area. Light winds in all directions
RSE	54	8/11/03	Lowest of all monitors. Background dust.
	43	12/11/03	Lowest of all monitors. Background dust.
RS	141	27/12/03	Residue area. Two events 14.3 m/s easterly at night and 12.3 m/s N/NW in morning
	138	3/09/03	Residue area. Northerly with RDA winds from 10 to 10.8 m/s at 1000 to 1300 WST
RSW	262	6/5/03	Residue area. Night time event with easterly winds at RDA up to 11 m/s
	236	27/12/03	Residue area. Two events 14.3 m/s easterly at night and 12.3 m/s N/NW in morning
	139	23/11/03	Residue area. Easterly with RDA winds up to 11.6 m/s
	138	3/9/03	Residue area. NNE up to 10.7 m/s
	120	17/12/03	Residue area. Strong easterly at time of event up to 15.4 m/s
	115	26/3/04	Residue area. Easterly up to 14.7 m/s
	106	10/10/03	Residue area. Strong easterly up to 15.3 m/s
RN	269	7/3/04	Residue area. Moderate sea breeze up to 7 m/s and SSE
	198	19/2/04	Residue area. Up to 12 hours of SW to W up to 6.7 m/s
	191	3/2/04	Residue area. Up to 8 hours of moderate sea breeze up to 4.8 m/s. i.e. not wind generated?
	168	22/2/04	Residue area Southerly SW wind
RDA7	82	15/01/04	Other. Winds were S to SW at the time
	67	18/01/04	Other. Generally high occurred for south and SW winds
	65	20/01/04	Other. Peaks due to S/SW winds
	61	29/1/04	Other. Occurs under westerly winds
	60	27/12/04	Approximate 40% due to easterly and 60% due to northerly winds (other source) on this day
	59	16/1/04	Residue area Strong SE
	57	23/12/04	Other, Occurs under south westerly

3.1.3 Examples of Short Term Dust Events from the TEOM Monitors

To further illustrate the nature of the dust events, two examples of high TSP concentrations from the TEOM monitors (which provide 6 minute average data) are plotted in **Figure 3.3** and **Figure 3.4**. **Figure 3.3** presents the dust concentrations on the 27 December 2003, which was a rare strong northerly late in the year. These strong winds resulted in high concentrations at the south and to a lesser degree southwest and RDA7 monitors. The first dust peak at the south and southwest occurred at night due to strong easterlies, with a second peak in mid morning with the occurrence of strong northerly winds. The high dust levels at the RDA7 monitor for the first peak is also considered to be due to the RA, whilst the second peak is due to another source to the north and west of this monitor.

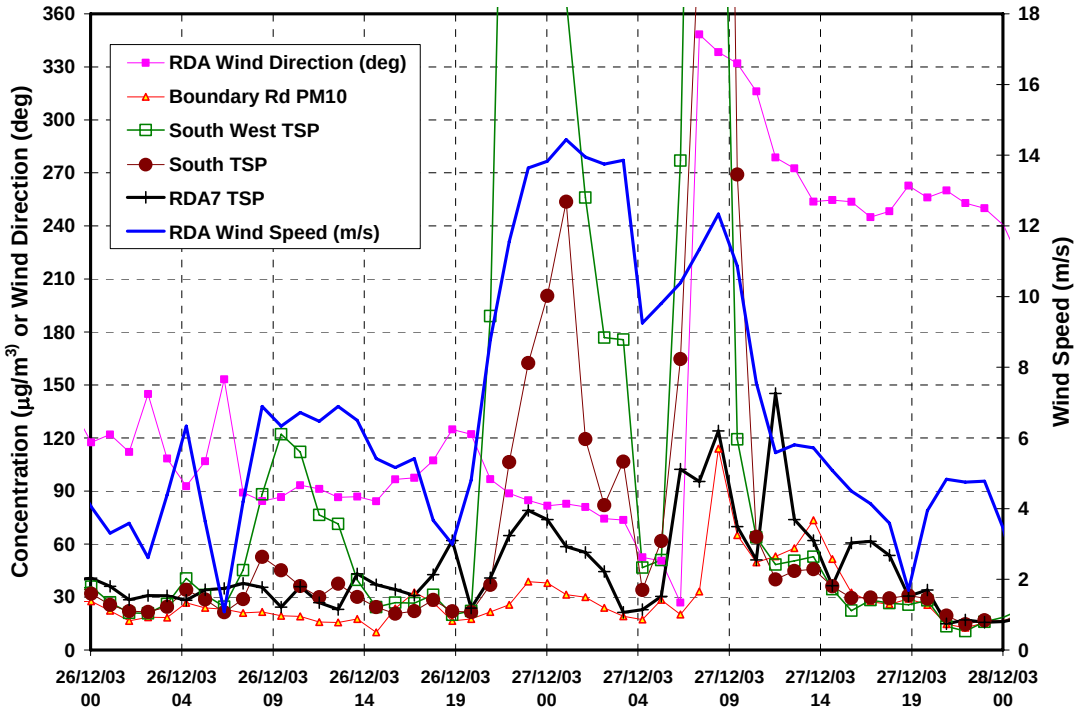


Figure 3.3 Dust Concentrations and Meteorological Conditions on the 26 and 27 December 2003

Figure 3.4 presents a dust event at the RDA 7 monitor on the 19 March 2004 due to strong E/SE winds generating dust from the RA. On the next night when the winds are again strong, but now slightly north of east, high dust levels occur at the south and south west monitor, but the RDA7 monitor now has low concentrations as it no longer down wind of the RA. This illustrates the importance of easterly winds having a southerly component to have an impact on the RDA7 site and the general short-term nature of the dust events.

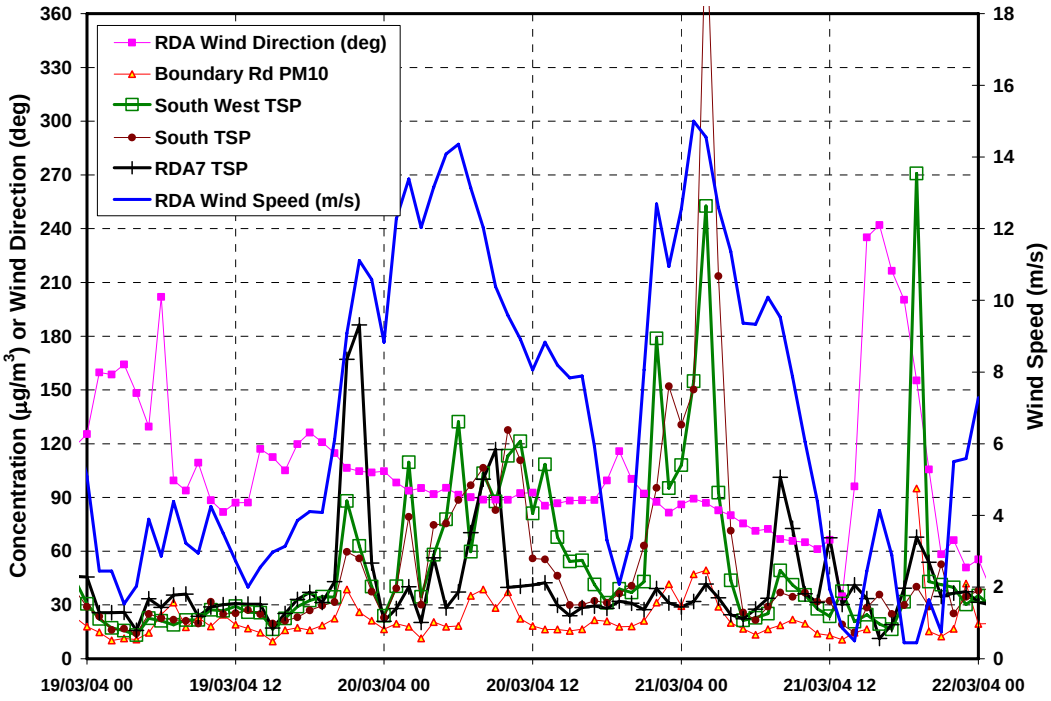


Figure 3.4 Dust Concentrations and Meteorological Conditions on the 19 to 22 March 2004

To illustrate the rareness of the strong northerlies that generated the dust levels on the 27 December 2003, all northerly, one hour wind speeds from 1996 to 2004 at RDA3 have been plotted in **Figure 3.5**. This indicates that strong northerlies occur predominantly from April through to September, with none before May. Only two strong northerly events have occurred from November onwards in this 9 year period, namely on 15 November 2002 (which caused very high dust levels that resulted in Alcoa being prosecuted under the Environmental Protection Act) and on the 27 December 2003.

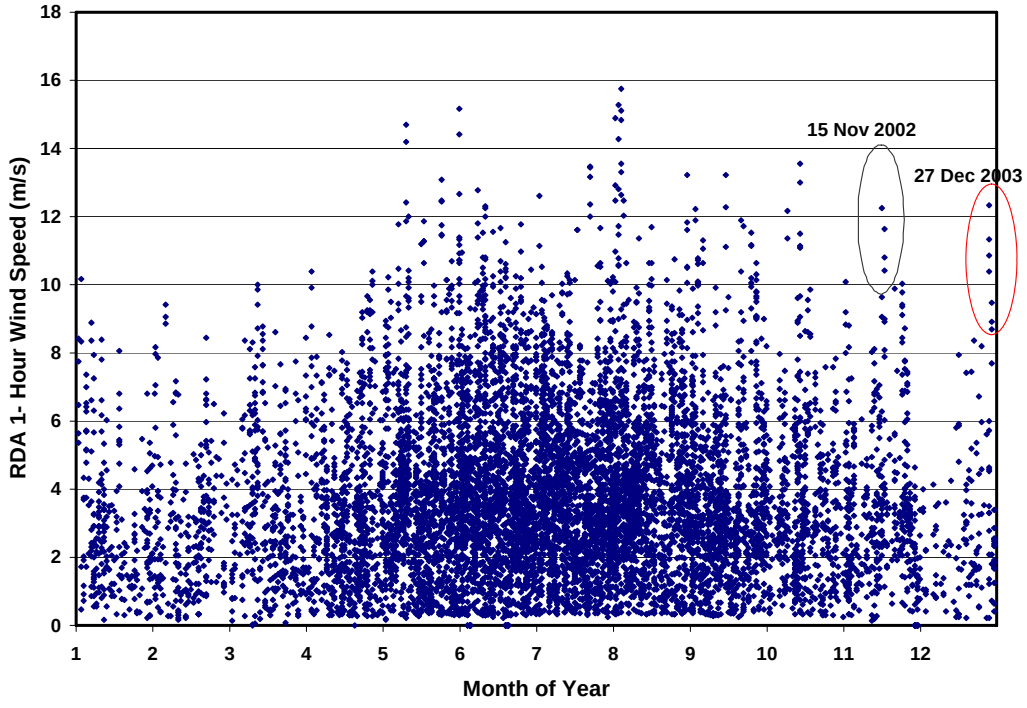


Figure 3.5 Wind Speeds for Northerly winds by Time of Year for the years 2000 to 2004

3.1.4 Background Levels

Background TSP and PM_{10} concentrations estimated for Wagerup are presented in **Table 3.3**. These were estimated by taking the lowest of the monitored concentrations for each day. On some days this will result in an overestimation of the background concentrations as all monitors may be impacted by the refinery operations to some degree. On the other hand, as there are small uncertainties/errors in sampling, taking the lowest of a number of samples may tend to underestimate the true background. For example, if all monitors sampled air with a concentration of 10 $\mu g/m^3$, and if there is a variation of the sampler results between 8 to 12 $\mu g/m^3$ due to measurement error, the background will be reported as 8 $\mu g/m^3$, 2 $\mu g/m^3$ lower than actual. This error will have a minimal impact on peak background levels but will be more significant for determining annual average concentrations.

Table 3.3 Background Particulate Concentrations at Wagerup

Statistic	Wagerup Background TSP	Wagerup Background PM_{10}	Collie (Bluewaters) PM_{10}
Years	4 years (2000/2001 - 2003/2004)	1 year (2004)	3 years (2001-2003)
Maximum	59 - 86 (64)	50.6	73
# of Exceedances of NEPM standard	NA	1	0.66 (ave for 3 years)
90th Percentile	23-31 (26.5)	21.8	23.6
70th Percentile	16-19 (17.8)	15.4	16.0
Average	13.8 - 17.4 (15.3)	12.1	14.1

Notes:

1) Wagerup background TSP concentrations are provided as the range of concentrations and the average (in brackets) of the 4 years of data. The Collie (Bluewaters) maximum is the maximum of the 3 years of data, whilst the other statistics are averages.

The results in **Table 3.3** indicate that background TSP at Wagerup are low, below the Kwinana EPP standard and limit. For PM_{10} there was one day with PM_{10} values just above the standard in the 12 month period, but this is well below the goal of no more than 5 exceedances per year. As a comparison to the Wagerup PM_{10} concentrations, the PM_{10} concentrations from the Bluewaters site (5 km NE of Collie and considered to be generally rural) are also presented from SKM (2005a). This shows similar, though slightly higher "background" concentrations than at Wagerup.

3.2 VOC Monitoring

Ambient VOC monitoring in the Wagerup region until 2004, focussed primarily on identifying possible species in the short term events associated with odour and other complaints. The studies include those conducted by the Chemistry centre of WA, Department of Environment and Alcoa. A review of the monitoring until May 2004 is provided in the Wagerup Air Quality Review (CSIRO, 2004b). In reviewing the data, CSIRO comment that

"many of the studies performed to date have been of limited sampling period and scope, involving the collection and analysis of only a small number of samples because of the specific objectives of these

particular studies. Hence, the conclusions drawn from them may not necessarily be generally applicable to the air quality in Yarloop".

CSIRO (2004b) in their summary and conclusions for the episodic sampling state:

S&C 10: …."*Apart from one elevated sample which remains unexplained, the rest of the carbonyl samples show low concentrations in which it is difficult to distinguish Refinery impact from background levels. The VOC samples show similar behaviour in which it is difficult to distinguish Refinery impact from background levels. Compounds detected in the samples collected within the Yarloop community were at concentrations well below odour thresholds reported in the literature. This suggests that the compounds causing the odour complaints in the community are either not targeted in the sampling and analysis methods used and/or that the detection limits were not adequate to detect compounds having very low odour thresholds.*

S & C 11: Two VOC samples had elevated methylene chloride concentrations and the source of the methylene chloride is unexplained. The concentrations measured do not exceed the WHO guidelines.

In 2004 Alcoa in association with the Department of Environment, the WA Chemistry Centre and the community undertook a campaign of regular VOC, carbonyl and other ambient gaseous sampling in two intensive monitoring campaigns. The campaign was in response to the recommendation by CSIRO that there be a more intensive and focussed sampling effort concentrating on events.

This monitoring was conducted in two phases; Phase 1 - a 15 week study undertaken from May to September 2004 and Phase 2 - a 6 week study conducted from August to October 2004. Phase 2 is considered to be of better quality data, through better monitoring techniques and consisted of:

- Passive sampling using Radiello diffusion samplers located at 11 locations. These were placed in the field for periods of 7 days and collected weekly average samples. This sampling recorded a range of VOCs, though with only five; formaldehyde, acetaldehyde, propanal, butanal and benzaldehyde measured above their method detection limits. Of these formaldehyde and acetaldehyde were the only two compounds to return values frequently above their detectable limit and show measurable variation between the different sampling sites; and
- Active sampling using pumps at 5 sampling locations to sample using USEPA methods TO-11A and TO-5A for aldehydes and ketones, TO-17 for VOCs, TO-13 for SVOCs, NIOSH 7903 for inorganic acids and NIOSH 6011 for halogens. These were sampled 3 times per week for 8 hours each from 8 am to 4pm. For the VOC sampling, using method TO-11A, a total of 12 aldehydes and ketones were detected with formaldehyde and acetaldehyde recorded consistently above their MDLs at each of the 5 locations. The inorganic acids and chlorine and bromine all recorded levels below the detection limits or negligible concentrations just above MDLs.

The study as summarised by van Emden and Power (2005) concluded that, "*The overall air quality was found to be typical of rural environments in both the nature and the levels of chemical compounds detected, except for acetaldehyde which was at levels more typical of urban environments".* The

concentrations measured were well above those which are predicted from the refinery, with the levels showing *"little spatial variation and for the most part appeared to be randomly distributed limiting the ability to attribute to specific sources. Elevated levels of both carbonyls and VOCs were found at the Waroona and Yarloop township sites, consistent with the effects of human activities associated with the use of fossil fuels".*

Of the VOC data collected, the formaldehyde and acetaldehyde were detected at concentrations consistently above the method detection limits to enable average "weekly" concentrations to be calculated. These are presented in **Table 3.4** and show no real apparent spatial variation in the concentrations for a particular sampling method, Comparison between the TO-11a concentrations and the Radiello samples however, show significant differences, with the TO-11a results being significantly higher. No firm conclusion can be drawn on the accuracy or otherwise of the data however, because the sampling regimes were different, with the Radiello samples being a weekly average concentration, whilst the TO-11a results are an average of three, eight hour (8 am to 4pm) values. This data is used for comparison to model predictions of formaldehyde and acetaldehyde in **Section 7.2.1**.

Table 3.4 Monitored Average Formaldehyde and Acetaldehyde Concentrations (µg/m^3) for 23 August to 1 October 2004 at Wagerup from van Emden and Power (2005)

Site	Formaldehyde TO-11A (three x 8 hours from 8 am to 4pm	Formaldehyde Radiello (1 week)	Acetaldehyde TO-11A (three x 8 hours from 8 am to 4pm	Acetaldehyde Radiello (1 week)
Bremnar Road	2.68	0.34	1.84	0.26
Residue Area	-	0.68	-	0.34
Residue South	-	0.42	-	0.30
Boundary Road 2	3.27	0.80	2.60	0.37
Boundary Road 1		0.41		0.32
Hoffman Rd	3.15	0.45	2.36	0.25
Yarloop Neighbour		0.60		0.48
Yarloop Lawn Bowls	2.57	0.93	1.73	0.43
Willowdale Mine		0.77		0.28
Waroona Lawn Bowls	-	1.3	-	1.0
Hamel Training centre	2.22	0.70	1.68	0.32

3.3 Metals Monitoring

As part of the phase 2 measurement program, metal speciation of seven day TSP filter samples collected from four locations in the Wagerup area was undertaken. The metals were analysed using Method AS 2800-1985, which is for the determination of lead, with the lead component determined by Atomic Flame Mass Spectroscopy (AFMS), as per AS 2800-1985, with the other metals analysed by the method most appropriate for that metal, using either AFMS or vapour generation and Inductively Coupled Plasma Spectroscopy (ICP) (van Emden and Power, 2005). The data is summarised in **Table 3.5**.

Table 3.5 Summary of Metal Monitoring from 23 August to 2 October 2004

	MDL ($\mu g/m^3$)	Average Concentration ($\mu g/m^3$)			Maximum Concentration ($\mu g/m^3$)		
		Hoffman Rd	Bremnar Rd	Hamel Training Centre	Hoffman Rd	Bremnar Rd	Hamel Training Centre
TSP		13	9.0	16	16	9.6	19
Lead	4.1E-06	2.7E-04	4.9E-04	4.4E-04	6.6E-04	8.0E-04	6.4E-04
Aluminium	1.6E-05	5.6E-01	2.1E+00	7.6E-01	7.8E-01	2.1E+00	1.3E+00
Arsenic	4.1E-06	3.8E-05	9.0E-05	5.2E-05	7.5E-05	1.4E-04	7.2E-05
Boron	8.2E-05	6.3E-02	4.4E-01	1.8E-01	1.1E-01	4.4E-01	2.5E-01
Barium	8.2E-06		1.2E-02			1.2E-02	
Beryllium	4.1E-07	8.3E-06	1.9E-05	4.5E-06	1.0E-05	2.6E-05	4.5E-06
Cadmium	4.1E-07	9.6E-06	5.3E-06	7.5E-06	1.5E-05	6.0E-06	7.5E-06
Cobalt	1.6E-05	3.3E-05	1.6E-04	6.6E-05	5.1E-05	1.6E-04	1.0E-04
Chromium	8.2E-06	9.3E-04	2.1E-03	2.7E-03	1.3E-03	2.3E-03	3.4E-03
Copper	1.6E-05	2.8E-04	6.1E-04	6.9E-04	6.7E-04	1.1E-03	8.6E-04
Galium	4.1E-07	3.4E-04	9.4E-04	3.0E-05	3.4E-04	9.4E-04	3.0E-05
Mercury	1.5E-05			5.0E-07		0.0E+00	5.0E-07
Lithium	1.6E-05	3.2E-04	1.6E-03	8.1E-04	6.3E-04	1.6E-03	1.2E-03
Molybdenum	8.2E-05	3.4E-05	1.2E-04	1.1E-04	3.4E-05	1.2E-04	1.2E-04
Nickel	4.1E-05	4.2E-04	6.4E-04	1.2E-03	9.4E-04	6.8E-04	1.7E-03
Selenium	4.1E-05	9.4E-05	1.2E-04	7.0E-05	1.7E-04	1.2E-04	9.0E-05
Thallium	4.1E-07	7.2E-06	5.9E-06	4.2E-06	1.9E-05	7.4E-06	5.3E-06
Vanadium	1.6E-05	1.3E-03	1.3E-03	1.3E-03	1.6E-03	2.3E-03	2.2E-03
Zinc	1.6E-05	1.0E-03	9.4E-03		1.7E-03	9.4E-03	

Notes:

1) Of the six 7 day sampling periods there were 6 valid samples at Hoffman rd, 3 at Bremnar rd and 4 at the Hamel training centre. There was also one sample at Boundary rd which recorded generally below detection which has not been summarised above

4 Modelling Methodology

4.1 General Overview

To provide predictions from fugitive (uncontrolled) sources from the residue area, bauxite stockpile area and lower dam, the dispersion modelling system Calmet/Calpuff was used. Calpuff (the Californian Puff model) is the US regulatory model for assessing long range transport of pollutants and their impacts and also for use on a case-by-case basis for certain near-field applications involving complex meteorological conditions. Calmet is the meteorological pre-processor to Calpuff for generating the wind and turbulence fields for the dispersion of the pollutants. Calpuff is considered the best model for modelling dispersion from the fugitive sources as the following issues are considered important and can be handled within this modelling system:

1) Releases from large ground or water areas. These can be modelled as area or volume sources within Gaussian plume and Gaussian puff models;
2) Model dispersion under light wind conditions where the winds may stagnate and meander. Under these conditions Gaussian puff models can better represent the dispersion of the plumes than Gaussian plume models such as Ausplume, which assume that the plume extends in a straight line to the end of the model domain for each hour. These stagnating conditions are important for modelling VOC emissions from area sources;
3) Incorporate variable winds and land uses across the region. Variable land uses will result in different dispersion rates of the plumes as the plumes are blown across them. For example there can be large differences between the dispersion over a forested area compared to a grassland or lake; and
4) Incorporate the effects of terrain. This can be important in the turning of low level winds, such as occurs with blocking of stable airflow by elevated terrain.

Other general modelling issues that need to be addressed in an air quality assessment are:

1) Representativeness of the meteorological data period being modelled. For this assessment it was necessary to model the year April 2003 to March 2004 to match that modelled for the Refinery emissions as conducted by CSIRO (2005a and b). This was required to enable addition of the predicted concentrations on an hour by hour basis, to estimate the cumulative concentrations for the health risk assessment (HRA). A brief analysis of the representativeness of the year is provided in **Section 2.1.6** with the implications discussed in **Section 8.5**.
2) Deriving realistic emission rates for dust, metal and VOC emissions from the RA and bauxite area as a function of the meteorology and other important parameters. In this study, it is considered that the uncertainty in estimating emissions will lead to the greatest source of uncertainty in the modelled concentrations (see **Section 8.5**) ; and
3) Determining the appropriate size distribution of the particulate and the speciation of the metals in the particulate. This is described in **Sections 5.6** and **5.7**.

4.2 Development of Meteorological Files

Two meteorological files were developed for modelling. One was based on using the TAPM generated wind fields by CSIRO (2004a), to enable generation of wind fields within Calmet which are consistent with TAPM. Estimates of the heat fluxes and turbulence fluxes for this file were derived using the Calmet methodology and therefore these will be not as used within TAPM. As such, the winds will be consistent, but there will be some differences in the heat fluxes, mixing depths and therefore turbulence properties of the flow. This meteorological file is used for the concentrations predictions within this report. The second file was based primarily on surface observations and used only the TAPM winds at essentially several hundred metres above the surface. This file was developed as a check on the first file given that there are some concerns to the representativeness of the TAPM predicted winds (see **Section 2.1.3**).

4.2.1 Surface Wind Data

4.2.1.1 Data Used

Meteorological data available for use in modelling for the period 1 April 2003 to 31 March 2004 include that from:

- Bancell road;
- The RDA3 site;
- The RDA7 site;
- North Waroona from Iluka; and
- Predictions by TAPM.

For the development of the primary modelling file, only TAPM winds were used.

For the development of the file based on surface observations, data from Bancell road, RDA3 and North Waroona were used. These data were used to generate wind fields as significant differences can occur in the winds between Bancell road and RDA3, particularly for strong easterlies where the easterlies may not extend out to the RA (see **Section 2.1.3**). Therefore, local winds at the RA are considered necessary to determine the correct emissions from the site (particularly for dust which is very wind speed dependent) and to correctly simulate the dispersion of the plumes. Of the wind measurements, only the RDA3 site is considered appropriate for this purpose. Data from the RDA7 site was not used as did not cover the entire period (this commenced in December 2003) and as it is sheltered somewhat for westerly winds by nearby trees. In addition, RDA7 did not sample correctly northerly winds due to an averaging problem with the logger (see **Section 2.1.2**).

4.2.1.2 Use of data in Calmet

For developing the TAPM met file, the TAPM winds were entered using the CSUMM format as an initial guess field. These winds were not altered by specifying the options of kinematic effects and Froude number adjustment or slope flows in developing the step one wind fields were switched off. As such, the winds were essentially preserved.

For the development of the meteorological file from the observations, as there were two anemometers at the Bancell road site after 17 July 2003, two separate wind stations were specified, though with data only provided for one of these at any hour. As the 30m winds are considered to be of better quality, this was used as the first preference, with the 10m winds only provided when the 30m winds were not available.

As the RDA3 wind measurements had a reasonably high stalling speed, the RDA3 data was corrected as detailed in **Appendix A**.

4.2.2 Upper Winds and Temperature

For the TAPM derived meteorological file, the upper wind and temperature profile required in Calmet was predicted using TAPM for the location of the RDA3 site. For the file derived from observed winds, both the TAPM profile and Perth airport sounding were trialled and used to predict NO_X impacts at the Boundary road an Upper Dam monitoring sites. This comparison is not presented in this report and was part of an assessment on the suitability of Calmet/Calpuff for use in predicting refinery impacts. The results of this assessment indicated that the use of the Perth airport data provided the better results, presumably as it provided a better resolution of the surface inversions, as has been documented previously at Wagerup in SKM (2003a). In this study, as Calpuff is being used to predict dispersion from surface releases, the choice of the upper wind and temperature profiles should have minimal effect.

4.2.3 Cloud Observations

Cloud observations required from Calmet for the estimation of heat fluxes were obtained from TAPM predicted at the Bancell road site. Apart from the TAPM data, there is minimal local data with twice daily observations taken at Harvey (20 km south) of limited cloud parameters, with the nearest quality measurements throughout the day undertaken at Perth airport, 130km north.

4.3 Calmet Set Up Options

The pre-processor model Calmet (v 5.542) was setup with the following:

- A 28 by 29 grid with SW grid cell centre at 389,883m Easting and 6,351,676m Northing, with 0.5 km interval over the region and 9 vertical levels. The Calmet grid was selected to match the grid cells used in TAPM by CSIRO (2005a), but extended further to the east than the inner TAPM pollution grid to cover a larger area of the scarp than used in the Calpuff dispersion modelling to resolve any drainage flows. The 9 vertical levels are specified in **Table 4.1**. The vertical extent within Calmet was limited to 2250m as the data supplied by CSIRO from TAPM was limited to 1500m. This limit to the vertical extent of the profile is less than optimal for modelling tall stacks, but should have no bearing on dispersion from surface releases;

Table 4.1 CALMET Vertical Cell and Wind Weighting Factors

Cell Number	Cell Face Height (m)	Cell Centre (m)	Weighting Factor (Only for Met file derived from Observations)
1	20	10	-1.0
2	50	35	-1.0
3	100	75	-0.9
4	150	125	-0.7
5	250	200	-0.4
6	400	375	0.0
7	700	550	0.7
8	1450	1025	1.0
9	2250	1850	1.0

- Topographical data in AMG84 coordinates, was obtained from 5 m contour interval data supplied by Alcoa (DLI Geo Spatial information, reproduced with permission of the Department of Land Information, P339). Note, conversion from AMG84 to the current GDA94 grid requires the addition of approximately 139m to the easting and 149m to the northing;
- For the derivation of the meteorological file from the observations, the biases presented in **Table 4.1** were used to weight the observational surface and upper winds. These biases were chosen to rely heavily on the surface observations for the lower atmosphere and minimise the effect of the winds from the profile measurements. This was done as the winds from either TAPM or from Perth airport, 130km distant, will at times be quite different to the local surface wind observations. If a weighting is chosen that changes from surface to upper dominated winds over the lowest 200m, a large artificial wind shear can be created that will increase the dispersion of any plumes in that range. As it is considered that many of the differences between the upper profiles used and the surface observations are not real (see **Section 2**), the weighting has been selected to preserve the surface winds and minimise the wind shear until above the region where the plumes normally disperse. A trial with the above weighting and a weighting which changed from surface to upper winds at a lower height resulted in poorer prediction of NO_X concentrations at Boundary road for the latter option, which was considered to be due to either the TAPM upper winds being less representative or increased artificial shear;
- Choice of Bowen ratios (for use in predicting sensible heat fluxes) that varied by time of the year and land type are presented in **Table 4.2**, **Figure 4.1** and **Figure 4.2**. In summer a value of 3 and 1.5 was used for agricultural/cleared area and forests respectively with a value of 1.0 used for both in winter. These values were derived to approximately match the heat flux measurements over forest and agricultural land in the south west as reported in Ray et al (2003). Values for the residue area, though barren, were chosen to reflect the coverage of wet residue, whilst the refinery was chosen to reflect an industrial area with little vegetation;

Table 4.2 Landuse, Bowen Ratio and Roughness Lengths used

Land Use Number	Category	Sub Category	Roughness length (m)	Bowen Ratio Winter	Bowen Ratio Summer	Bowen Ratio Autumn/Spring
10	Urban or built up	Refinery	1.0	2.0	2.5	4.0
		Waroona	0.5	1.0	1.5	1.5
-20	Agricultural land irrigated		0.15	1.0	1.2	1.5
20	Agricultural land un-irrigated	West of Rwy.	0.15	1.0	1.5	3.0
		East of Rwy.	0.25	1.0	1.5	3.0
40	Forrest Land		0.6	1.0	1.2	1.5
50	Water		0.01	0.0	0.0	0.0
70	Barren Land	Residue Area	0.05	1.0	1.5	2.0

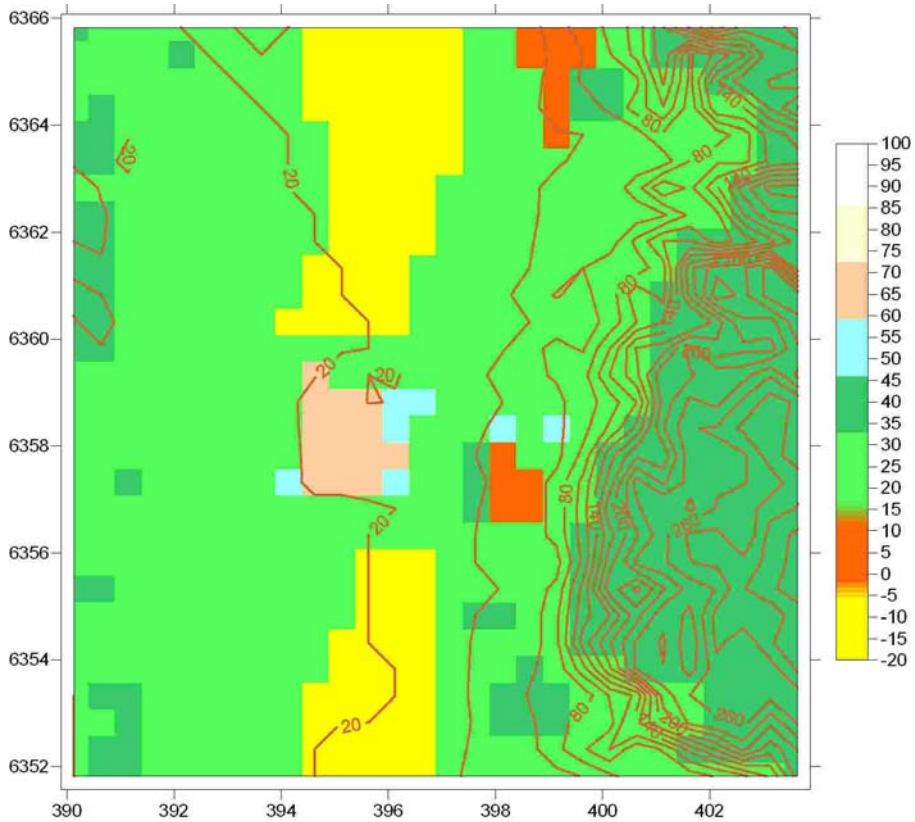


Figure 4.1 Land Use Modelled for the Wagerup Area. The Land use Classification is Presented in Table 4.2

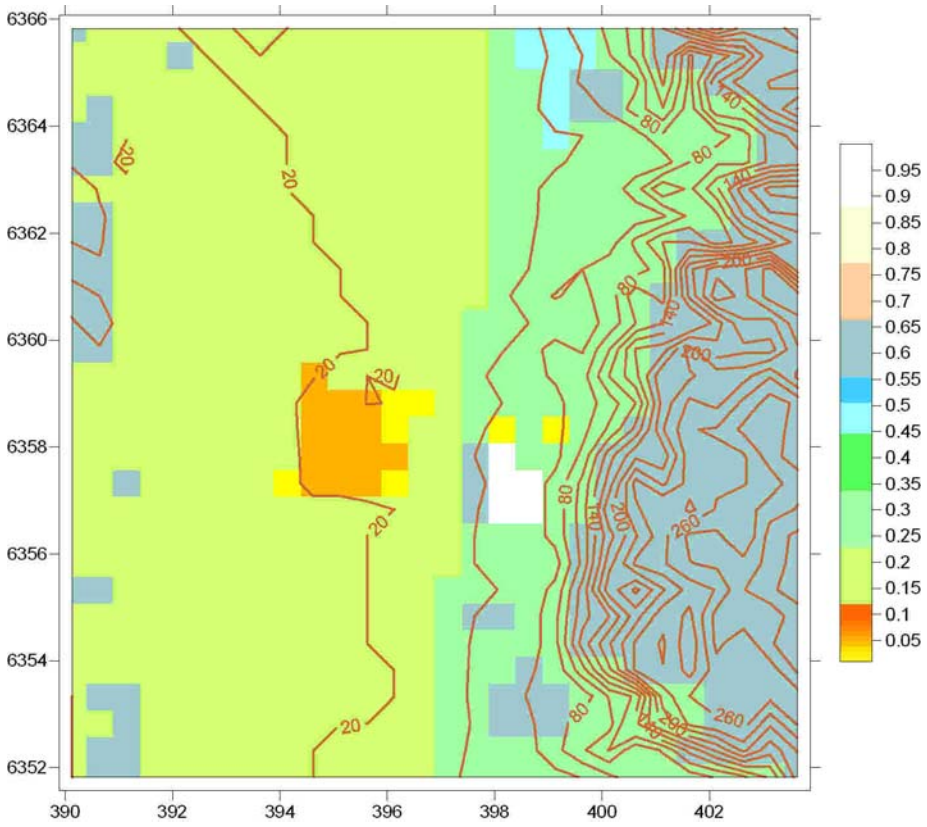


Figure 4.2 Roughness Length Used for the Wagerup Area

- The albedo was set to a constant of 0.18 for all surfaces for the year;
- Estimate of roughness lengths were as detailed in **Table 4.2**, which are based on observations of the land uses and the land use roughness categories as presented in Ausplume;
- The neutral mechanical and stable mixing height constants (CONSTB and CONSTN) were set to 0.7 and 1000 respectively, with the minimum potential temperature lapse rate in the capping inversion set to 0.01 deg K/m;
- Incorporation of surface heat fluxes for the refinery area and the cooling pond. The total surface heat flux for the refinery was estimated in CSIRO (2004a) as 224 MW. For this study this was assumed to be uniformly spread over an area of 75ha (three cells of 500 by 500m) resulting in a heat flux of 300 W/m^2. For the cooling pond the heat flux was calculated using similarity theory for over water surfaces as detailed in the Calmet manual (Scire et al, 2000), based on the TAPM predicted temperature at 10 m, the estimated surface temperature of the pond and the RDA3 corrected wind speed. The surface temperature of the cooling pond water was taken as 35 degrees Celsius, as an approximate weighting of the inlet and outlet temperature of 55 and 27 degrees Celsius respectively, similar to that used by PAE for the CFD modelling (PAE, 2005). This resulted in heat fluxes that varied from -28 to 547 W/m^2 with an annual average of 111 W/m^2. For the cooling lake, with an area of 14.9 ha, this equates to 17 MW on average of sensible heat lost. This figure is considered approximately correct in that Alcoa's water balance of the cooling pond indicates that up to an average of 20mm/day may be evaporated from the pond, which gives a latent heat flux of 79 MW. The total of 96MW of heat lost (17 MW sensible and 79MW latent), is in reasonable agreement with the estimate of heat load to the cooling pond of 121 MW (15% of

809MW as provided in CSIRO, 2004a, figure 7). As the area used to represent the cooling pond in the model was one cell of 500 by 500m (22.5ha) a value of 75 W/m^2 was used such that the overall heat flux of 18.75MW was comparable to the lake heat flux of 17 MW;

- Radius of influence of surface layer and upper layer observations are as detailed in **Table 4.3** for the meteorological file developed from surface winds. The maximum radius of influence was specified as small such that the Perth airport winds would have no influence on the derived step 1 winds. For the TAPM file, the locations of the surface and upper file were assigned a point well off the grid to have no influence on the step 2 wind, to preserve the initial guess field winds from TAPM; and
- For the meteorological file developed from surface observations, a wind barrier was included to limit the influence of the observations on the step one winds on the scarp as specified roughly by the 100 m contour line. This was not required for the file developed from the TAPM winds.

Table 4.3 CALMET settings for wind field determination

Parameter	Value
Maximum radius of influence over land in the surface layer (RMAX1)	5 km
Maximum radius of influence over land aloft (RMAX2)	0.01 km
Maximum radius of influence over water (RMAX3)	500 km
Relative weighting of the first guess field and observations in the surface layer (R1)	3 km
Relative weighting of the first guess field and observations in the layers aloft (R2)	3 km
Radius of influence of terrain features (TERRAD)	9 km

4.3.1 Resultant Meteorological File and Dispersion Meteorology

The resultant meteorological file from Calmet consisted of 366 days over the period 1/4/2003 to 31/03/2004. Wind roses for the two files are presented in **Figure 2.15** with resultant stability class distribution using the Turner method of wind speed and cloud cover as used within Calmet presented in **Table 4.4**. This shows the TAPM file has less A and F class stabilities as the TAPM winds have a tendency to under-predict low wind speed conditions.

Table 4.4 CALMET settings for wind field determination

Stability Class	Meteorological File with TAPM Winds	Meteorological File with Observed Winds
A	0.71	1.53
B	7.57	9.56
C	18.37	16.43
D	41.29	34.53
E	16.84	11.93
F	15.22	26.02

A summary of the meteorological data is also presented in **Appendix C** showing the distribution of wind speed and direction, stability class, mixing height and Pasquill Gifford stability class for both the two meteorological files.

4.4 Calpuff Model Setup

For this study, Calpuff (v5.714) has been used as follows:

- Concentrations were predicted on a 250m grid over 53 by 53 grid points (13 by 13km), with the SW corner at 390,633m Easting and 6,351,826m Northing, with NW corner at 403,633m Easting and 6,364,826m Northing. This grid was selected to match the TAPM inner pollution grid used by CSIRO (2005a and b) for the refinery sources, as required for the merging of the TAPM predicted concentrations;
- No chemical transformation of gaseous releases. This has been omitted as they are generally small except for formaldehyde and are not easily modelled within Calpuff. An estimate of the conservatism can be made, noting the shortest half life (at 25 degrees C) of the VOCs modelled are: 1 to 3 hours for formaldehyde, 6 to 12 hours for acetaldehyde and approximately 17 days for benzene (Chemfate, 1994). For conditions leading to the highest concentrations, (eg low wind speeds at night time), the travel time to the nearest receptors will be of the order ½ to 1 hour. In such time, formaldehyde may have decayed by up to 50% (assuming a 1 hour travel time and 1 hour half life), but more probably by around 20% (assuming a ½ hour travel time, 2 hour half life and an exponential decay). For acetaldehyde, in the presence of hydroxyl (OH) radicals which are primarily generated by photochemical reactions in the day time, the half life is approximately 6 hours. For the night time/early morning conditions, the half life will be greater (up to 12 hours). Using the night time half life as more representative of the worst case dispersion conditions and travel times of 0.5 and 1 hours, it is estimated that the concentrations may reduce by 3 and 6% respectively. Therefore, the predicted concentrations at the locations with highest concentrations may be 30 - 50% overstated for formaldehyde and 3 - 6% overstated for acetaldehyde;
- Meteorological file using the 3 dimensional wind and turbulence fields generated by Calmet;
- Calm wind speeds defined as less than 0.5 m/s;
- Dispersion estimates using the Pasquill Gifford dispersion curves with roughness length adjustment. In the assessment of the dispersion from the refinery stack sources, SKM (2003a) found that the micro-meteorological dispersion provided better estimates of dispersion under stable conditions at night from short stacks and vents. However, for modelling the VOCs from the RDA, where there are lower roughness lengths, it was found that Calmet limited the surface friction velocity to 0.05 m/s, which affected the size of the Monin Obukhov length and therefore the frequency of very stable dispersion conditions. This limit could be altered in the model code, but given the time frame and the time required to ensure that we had not introduced errors into the program, was not attempted. This apparent limitation of the model has been raised with the model developers (E-mail to Joe Scire, Earthtec on 14 March 2005), but as yet, we have not received a response. As such, the Pasquill Gifford curves were used as they are an accepted standard dispersion method;
- Modelling of fugitive sources using the variable area source within Calmet. This requires coordinates of the vertices of the area, an initial vertical dispersion, source height and allows for plume rise from a source of finite diameter and initial temperature and exit velocity. To ensure that the plume rise would be negligible and not influence dispersion, the temperature was set to the

ambient temperature, with exit velocity and diameter set to 0.000001 m/s and 0.000001 m respectively;

- The initial vertical standard deviation of the plume from an area source was set to equal the dispersion that would occur for the plume travelling half the distance across the area using the Pasquill Gifford dispersion curves and the stability at the time. For area sources from water bodies, the stability class was limited to D class as an approximation. Comparison to CFD modelling results indicates that this will provide a conservative approximation (see **Section 7.3**);
- Initial plume heights for the sources were set to 1m above the surface for the large area sources. The exceptions to this were the elevated sources; the super-thickener, which was set to the tank height (5m), dust from the bauxite stockpiles (2.5m) and dust from the sand lake stockpiles (5m). For the liquid surfaces the choice of 1m will be conservative as the CFD modelling indicates that plume rise can occur from warm surfaces. For example the cooling pond plume rise is typically greater than 25m for southerly and northerly winds (see **Section 7.3**);
- No adjustment for sampling time was added to increase the horizontal plume spread. This is in line with that used by the USEPA in models such as ISC3, though in Australia and in general, it is accepted that the Pasquill Gifford dispersion curves relate to 3 minute averages and that the horizontal dispersion should be increased when predicting 1-hour averages. The non adjustment of the horizontal dispersion curves will therefore result in conservative estimates for these large area sources; and
- Calpuff terrain adjustment scheme. This is considered to be the more theoretical correct scheme within Calpuff. For surface releases it will have negligible effect on the predicted concentrations.

For modelling odour, based on the CFD modelling results, some of these parameters were further varied (see **Section 7.3** for a description of the changes).

5 Fugitive Dust Emissions

5.1 Overview

The assessment by CSIRO (2005a and b) included the modelling of particulate from all stack and vent sources at the refinery. This study covers the fugitive dust sources from the Wagerup refinery operations. Fugitive sources are uncontrolled sources such as from vehicles on paved and unpaved roads, dust from the material handling operations such as stacking and reclaiming at the bauxite stockpiles and wind generated dust. In this study, the two major sources of particulate, the RA and the bauxite stockpile area are estimated and modelled. It is noted that emissions of fugitive dust from vehicles at the refinery itself on paved roads and from wind erosion at the refinery are not modelled as they are considered relatively minor when compared to the two larger sources at the residue area and bauxite stockpiles.

The modelling additionally also only looks at quantifying and modelling the Alcoa sources at Wagerup and does not include other potentially significant local sources in the area including: - the "mothballed" nearby mineral sands mine to the north of the refinery (see **Figure 1.1**), farming operations, which dependent on the time of year can be a significant source; and particulate from burning off and wildfires. These sources are not modelled though they are to some degree taken in to account in determining background dust levels if the source impacts onto all monitors for that day.

5.2 Residue Area Dust Emissions

In the development of residue area dust emissions, it is stressed that any emission method can only be indicative due to the complexity of the surfaces and how they vary with time. For example, for any area within the residue area the dustiness is very dependent on the stage of the drying process, how the operators have dozed the surface, whether certain areas could be dozed, which may be due to wetter areas, failures in equipment, such as pumps and water cannon, accuracy of weather forecasts to enable pre-wetting of surfaces and the availability of personnel. An example of how dependent dust emissions are on these factors, is the event of 10 November 2002, with the high dust levels considered to be a result of the combination of extreme weather, which was not forecast, the shortage of residue drying areas at the time resulting in thicker residue pours, which hindered access to areas by the dozers and failure/maintenance of some areas of water cannon. Such difficulties ensure that any estimate of the emissions can only be indicative for a given area at a given time. With this in mind, a broad approach is developed where the emissions are given as a function of the wind speed.

5.2.1 Previous Studies on Dust Emissions from Alcoa Residue Areas

Sources of dust emissions from the residue area occur due to:

- Wind erosion under high winds;

- Normal operations such as dozing of surfaces, light vehicle movement and construction of walls; and
- Construction of new residue drying areas where major earthworks occur.

Of these, wind erosion is considered to be the largest source and hardest to control. Wind erosion has been examined in a number of studies for Alcoa including:

- Wind tunnel studies using Agwest's large portable wind tunnel to investigate the wind erosion potential of various residue surfaces at the Pinjarra refinery, as reported in Bell (1984) and later by Scott (1994);
- Dust dispersion modelling by Aust-Environ (1984) for the Kwinana residue area;
- Dust estimation and modelling of dust levels by Steedman Science & Engineering (1994), followed by the development of a linked water cannon control/dust emission model by Halpern Glick Maunsell (1996);
- Dust estimation and modelling for the Pinjarra residue area by SKM (2001d), as also reported in Pitts (2000);
- Evaluation of the wind speed up of the current and future residue area at the Wagerup refinery by SKM(2001b); and
- A recent study by SKM (2004a) of dust emissions and modelling of dust levels for the Kwinana residue area.

The erodibility testing conducted in 1984, used Agwest's portable wind tunnel to investigate the dust lift off potential from six specially prepared surfaces. These were:

- Residue sand covered with a layer of rock mulch;
- Washed fine residue, with the surface treated with dust suppressant Nopcoseal M1303;
- Untreated reside sand;
- Rain washed residue sand treated with Nopocoseal CE40;
- Crushed gypsum amended fine residue;
- Untreated fine residue; and
- Fine residue.

As reported in Scott (1994), the data demonstrated that the residue sand was highly erodible, though the residue fines tested showed little susceptibility to wind erosion. The results from the residue fines however, were noted to be low due to the state of the prepared residue fines surface, which had formed a hard compact surface, unlike the actual residue fines in the drying areas and therefore was considered unrepresentative.

Aust Environ (1984) used the model Ausplume to predict the likely extent of buffer areas around the then residue area. Dust emission estimates were derived from the wind tunnel residue sand results

reported in Bell (1984) that were fitted to Bagnold's (1941) soil flux equation to estimate the saltating flux per unit area (Q) as:

$$Q\ (kg/m^2/s) = 0.09\ u_*^3 \qquad \textbf{(Eq. 5.1)}$$

Where u_* is the surface friction velocity (m/s).

By assuming that 7% of the saltating flux would remain as suspended dust and assuming a likely particle size distribution, Aust-Environ predicted that annual average TSP levels would exceed 90 $\mu g/m^3$ for distances up to 1 to 1.3 km to the north east of the residue area. These concentrations and the subsequent extent of the required buffers were noted to be to a degree qualitative, but did indicate that the greatest requirement for a buffer would be to the north east and to a lesser extent to the west of the drying areas.

The Steedman Science & Engineering (1994) study of the Kwinana residue area dust utilised the data from the above earlier studies, along with limited site measurements of short period (less than 1 hour) dust events to derive equations for the dust fluxes for sand areas, residue fines and sodium carbonate areas. These emissions were parameterised using the surface friction velocity (u_*) and threshold friction velocity (u_{*t}) of that material, but are presented here in terms of the 10m wind speed (WS) and the threshold wind speed threshold for saltation and dust generation (WS_T) as:

$$TSP\ (kg/m^2/s) = C\ (WS - WS_T)^3, \qquad WS > WS_T \qquad \textbf{(Eq. 5.2)}$$

$$TSP\ (kg/m^2/s) = 0, \qquad WS < WS_T$$

Where:

C were coefficients of 0.000183, 0.000051 and 0.00094 kg/m^3 for sand, dry pulverised residue fines and carbonate surfaces; and

where the wind speeds have been estimated as 21.3 times the surface friction velocity, based on using a surface roughness length of 2mm (as used by Steedman Science & Engineering, 1994).

The wind speed thresholds for the various surfaces were parameterised as a function of the surface moisture content, with the threshold increasing with moisture content. Additionally, for the sodium carbonate surface, the threshold had a humidity dependence, where at high humidity, the threshold increased substantially, resulting in saltation and dust lift off ceasing. The surface moisture for the residue drying areas was calculated by a model developed by Halpern Glick Maunsell that specified the moisture as a function of the time since the residue surface was laid, the rainfall and evaporation, and on the water deposition from water cannon which was based on the water cannon layout and the wind speed. Details of the surface moisture model, which is a critical component of the methodology, are not available. Halpern Glick Maunsell (1996) later refined the work by Steedman Science and Engineering (1994) to develop a very site specific model which appeared to predict dust events well, but which contained a number of empirical factors making it difficult to extrapolate to other sites.

Using these emission rates and the model Ausplume, Steedman Science & Engineering (1994) predicted TSP concentrations that were in fair agreement with the observations, though tending to under-predict the concentrations to the west of the residue area and tending to over predict the dust concentrations at the very high wind speeds. It was considered that the over-prediction at the high winds speeds was due to the dust emissions being parameterised as dependent to the cube of the wind speed and that a modified equation of the form proposed by Shao et al (1994) and Shao et al (1996) as listed in **Equation 5.3** below may be more applicable.

$$PM_{10}\ (g/m^2/s) = k\ [WS^{3}{}_{x}\ (1 - WS_T{}^2/WS^{2})], \qquad WS > WS_T \qquad \textbf{(Eq. 5.3)}$$

$$PM_{10}\ (g/m^2/s) = 0, \qquad WS < WS_T$$

Where k is a constant dependent on the surface.

SKM (2001d and 2004a) used portable DustTrak monitors to profile the dust plumes from the Pinjarra and Kwinana residue areas under high winds and estimated the emission rates using a back-calculation technique that accounted for the depletion of particles. The emissions were then parameterised using **Equation 5.3** with the values of the derived wind speed thresholds and k listed in **Table 5.1**.

Table 5.1 Dust Emission Fluxes from Various Alcoa Fugitive Dust Studies

Surface	Source	k ($g/m^2/s$)	WS_T (m/s)	Annual Average PM_{10} (kg/ha/hr)
Residue Area				
Pinjarra (SKM, 2001d)	Wind	1.32E-07	9.8	0.03 (0.05)
	Operations	NA	NA	0.047
	Total			0.077
Kwinana (SKM, 2004a)	Wind	1.59E-07	6.5	0.039
	Operations	NA	NA	0.013
	Construction (new RDA)	NA	NA	0.038
	Total			0.090
This Study	Wind	0.674E-07 (Obs wind) 0.548E-07 (TAPM wind)	6.0 6.0	0.153 0.181
	Operations	NA	NA	0.041
	Total	(Obs Wind) (TAPM Wind)		0.194 0.222
Bauxite Stockpile Area				
Pinjarra (SKM, 2001d)	Wind	$3.39e^{-7}$	7.4	0.31 (0.48)
	Operations	NA	NA	1.24
	Total			1.55
This Study	Wind	1.88E-07 (Obs wind) 2.50E-07 (TAPM wind)	7.4	0.28
	Operations	NA	NA	0.22
	Total			0.50

Notes:

1) Pinjarra estimates based on stockpile and erodible residue areas of 21.6 ha and 265 ha respectively with Kwinana estimates are for erodible residue area of 207 ha. Wagerup estimates are for an erodible area at the residue area of 168 ha based on active RDAs and sand stockpile area and a bauxite stockpile area of 14.5ha.

2) The Pinjarra wind speed threshold was specified at 11.25 m/s and 8.5 m/s for the residue area and bauxite stockpile respectively based on the super-thickener winds. This has been reduced to 9.8 m/s and 7.4 m/s as the super-thickener records around 15% higher winds than for areas surrounding the residue area.

3) Values in brackets assume that there is no rainfall that controls dust emissions.

5.2.2 Other Wind Erosion Emission Methods

Other methods available for estimating PM_{10} emissions from wind erosion include:

- The National Pollutant Inventory equation (NPI, 2001) used to estimate annual total suspended particulate (TSP) emissions from bare areas with:

  $$E = 1.9\ (s/15)365(365-p)/(235)\ (f/15)\ kg/ha/hr \qquad \textbf{(Eq 5.4)}$$

  Where s = silt content (%);

  p = number of days when rainfall is greater than (0.25 mm);

  f = percentage of time that wind speed is greater than 5.4 m/s at the mean height of the stockpile; and

  PM_{10} emissions are estimated as 50% of the TSP emissions.

  This empirical equation was developed from limited measurements around coal stockpiles in the US USEPA (1995) and is considered approximate. As a default for Australian conditions, the NPI (2001) recommends a PM_{10} value of 0.2 kg/ha/hr for uncontrolled bare areas based on this equation, the meteorology of the Hunter valley and a typical Hunter valley coal silt content (SKM, 2005b). For areas with water cannon used as a dust control, the NPI provide a rough control factor of 50%, such that the PM_{10} emissions would be 0.1 kg/ha/hr.

  In comparison to the NPI estimates, the measured PM_{10} emission rates for the various studies at the Alcoa refineries listed in **Table 5.1** are, 0.03 kg/ha/hr and 0.039 kg/ha/hr for the residue area at Pinjarra and Kwinana and 0.31 kg/ha/hr for the Pinjarra bauxite stockpiles. The residue area values are therefore approximately 2.5 times lower than the default NPI value for a bare surface controlled by water cannon of 0.1 kg/ha/hr. The bauxite emissions are approximately 50% higher than the default 0.2 kg/ha/hr for an uncontrolled surface, which is most likely due to the high winds that develop at the base of the scarp where the Pinjarra bauxite stockpiles are situated.

- For NPI reporting, Alcoa has developed a methodology based on the measured ambient 24-hour TSP concentrations and hourly wind speed and direction (Coffey and Evans, 2000). This method accepted by the WA DoE and the NPI is used to assign the dust contribution from the residue area or bauxite stockpile to each monitor surrounding the area, which with a simplified Gaussian model is used to back calculate the dust emissions. The disadvantages of this method are:
  - It is dependent on the number and spacing of the monitors and is less accurate as the number of monitors decreases and the spacing increases;
  - The use of 24-hour monitors requires assumptions on the distribution of wind direction incident on each monitor in order to assign the dust within the 24 hours; and
  - It can only provide 24-hour dust emission estimates.

- Other methods that could estimate dust emissions include models used in the agricultural sciences or in the prediction of large scale dust storms. Examples of these are:
    - The Wind Erosion Equation (WEQ), which is an empirical equation for wind erosion developed by Woodruff and Siddoway, (1965). This has been used in Australia for large areas such as the Pilbara Airshed Study (SKM, 2003a), the Bunbury Airshed study (SKM, 2003b) and for Victoria (Ng, 2004);
    - The Revised Wind Erosion Equation (RWEQ) (Fryrear et. al, 1998);
    - The Wind Erosion Prediction System (WEPS) developed by Hagen and others (e.g., Hagen, 1995) and intended to replace the WEQ and RWEQ; and
    - Wind erosion models based on the sand saltation scheme of Shao et al (1996). This has been implemented into models for Australia by Shao et al (1996) and recently into the Australian Air Quality Forecasting System (AAQFS) by Lee et al (2003 and 2004).

These models all have limitations and are also not considered applicable to a residue area due to the highly variable nature of the surface, the continual progression of the drying cycle, variations in operations and failure in equipment.

5.2.3 Wind Speed up over the Residue Area

As the residue area is an elevated area above the coastal plain, it will be subject to higher winds as the air flows up and across it. This affect has been studied in a preliminary assessment by SKM (2001b) using the Wind Atlas Analysis and Application Program (WAsP) that is used extensively in wind energy studies. This study found that:

- Approximately half the 2000 residue area, would have wind speeds 0 to 10% higher than winds on the surrounding plain; and
- For the two future residue area options proposed at the time for the year 2050, increasing the height of the residue area was predicted to increase the wind speed further and therefore increase the potential for wind erosion. This increase was predicted to be greater for the higher, narrower plateau option than the lower broader residue area option modelled.

5.2.4 Wind Erosion Estimates for the Wagerup Residue Area

For this study, wind erosion for the Wagerup residue area were initially estimated using the relationships derived on a unit area basis for the Kwinana and Pinjarra residue areas (**Table 5.1**). These relationships were then modified by a soil wetness function to account for the effect of rainfall on emissions. These emissions were then input into the dispersion model Calpuff, used to predict the dust concentrations and then adjusted if needed to provide better agreement with the Alcoa dust monitoring. This approach calibrates the model using the emissions and is required as sites will differ due to differences in dust control effectiveness and importantly to differences in the anemometer siting. The adjustment for the wind speed siting is necessary as a small 10% change in the wind speed recorded at a site corresponds to a large change in dust emissions as emissions are related to approximately the square or cube of the wind speed.

5.2.4.1 Base Case- 2003/2004 Pre RDA7

For the residue area, the revised equation that was developed is listed in **Table 5.1**, with the emissions (pre construction of RDA7) assigned based on Alcoa residue operations personnel as:

- Approximately 15 % of the estimated dust emissions were from the sand stockpile area;
- 6 % of the dust emissions were from ROCP1;
- 10 % of the dust emissions were from the sandy exposed areas in RDA2; and
- The remainder (69%) was from the dry stacked areas within the residue area.

For the 69% of emissions from the dry stacked areas, the proportion from each RDA was assumed to be proportional to the area without dust control in each RDA, i.e. the area not wetted by the water cannon. These "uncontrolled" areas are due to either, less than 100% coverage afforded by the water cannon design and/or that some of the water cannon may not be operational at the time.

The control achieved by the water cannon are a function of the design, spacing, water cannon parameters, water pressure, watering time, time between watering, with the effectiveness dependent on the weather, notably the wind speed, wind direction and the evaporation rate. For this project, estimates of the water cannon control were provided by ENVIRON (2005) using a model based on water deposition profiles as a function of wind speed and an evaporation drying model. Using an extreme wind event and a 1-hour wetting cycle, the percentage coverage was estimated for the existing 65m by 90m spacing and a new 60m by 60m spacing. The use of an extreme wind speed was selected as this corresponds to the time with greatest potential dust lift, when the water cannon coverage is the lowest.

The area "uncontrolled" due to water cannon not being operational was estimated from the percentage of lateral failures in the pipes along which the water cannon are connected. Lateral failures occur due to the pipe work corroding, due to the caustic water used, with these pipes being replaced periodically. Other reasons why water cannon may not operate such as individual breakage of individual cannon were not considered as unlike laterals, they are quickly fixed.

The resultant estimates of the drying area not controlled for the extreme wind events are listed in **Table 5.2** and have been estimated using the following equations:

Dust control (%)= [water cannon control (%)/100 x (1 - lateral failure (%)/100)] x 100

Area not wetted (ha) = area dry stacked (ha) x (1 - Dust Control (%)/100)

Percentage of area not wetted = area dry stacked (%) - (1 - Dust Control (%)/100)

Table 5.2 Estimated Dust Contribution from the Residue Drying Areas

Source	Area (ha)	Area as percentage of total dry stacked area in 2003 (%)	Lateral Failure (%)	Water Cannon Control (%)	Overall Dust Control (%)	Area not Controlled (ha)	Percentage of 03/04 area not wetted (%)	Percentage relative to 2003/2004 dry stacked area dust (%)	Percentage of total 2003/2004 RA dust (%)
2003/2004 Pre RDA7									
RDA1	10.53	6.5	0	61	61	4.11	2.55	5.2	3.6
RDA3a	43.87	27.3	21	61	48	22.85	14.19	29.1	20.1
RDA3b	21.61	13.4	0	61	61	8.43	5.23	10.7	7.4
RDA4	40.7	25.3	27	61	44	22.64	14.06	28.8	19.9
RDA5	19.0	11.8	29	61	44	10.72	6.66	13.6	9.4
RDA6	25.3	15.7	0	61	61	9.87	6.13	12.6	8.7
Total	161.02	100				78.6	48.82	100	69.0
Base Case with RDA7 operational									
RDA1	10.53	6.5	0	61	61	4.11	2.55	5.2	3.6
RDA3a	32.74	20.3	14	61	52	15.62	9.70	19.9	13.7
RDA3b	32.74	20.3	14	61	52	15.62	9.70	19.9	13.7
RDA4	40.7	25.3	27	61	44	22.64	14.06	28.8	19.9
RDA5	19.0	11.8	33	61	41	11.27	7.00	14.3	9.9
RDA6	25.3	15.7	0	61	61	9.87	6.13	12.6	8.7
RDA7	25.5	15.8	0	77	77	5.87	3.64	7.5	5.1
Total	186.52	115.8				85.0	52.79	108.1	74.6
Expansion Case									
RDA1	2.9	1.8	3	77	75	0.73	0.46	0.9	0.6
RDA2	10.5	6.5	3	77	75	2.66	1.65	3.4	2.3
RDA3a	22.7	14.1	3	77	75	5.75	3.57	7.3	5.0
RDA3b	22.7	14.1	3	77	75	5.75	3.57	7.3	5.0
RDA4	27.1	16.8	3	77	75	6.86	4.26	8.7	6.0
RDA5	10.2	6.3	3	77	75	2.58	1.60	3.3	2.3
RDA6	16.3	10.1	3	77	75	4.13	2.56	5.2	3.6
RDA7	18.4	11.4	3	77	75	4.66	2.89	5.9	4.1
RDA8	30.7	19.1	3	77	75	7.77	4.83	9.9	6.8
RDA9	36.7	22.8	3	77	75	9.29	5.77	11.8	8.2
RDA10	36.3	22.5	3	77	75	9.19	5.71	11.7	8.1
RDA11	40.0	24.8	3	77	75	10.12	6.29	12.9	8.9
Total	274.5	170.48				69.5	43.1	88.4	61.0

5.2.4.2 Base Case- 2003/2004 with RDA7 Operational

Estimated dust emissions with RDA7 operational, relative to the base case without RDA7 are also listed in **Table 5.2**. These have been estimated using:

- The lateral failure percentages for RDA1 to 6 based on that at mid 2004, with RDA7 assumed to have zero lateral failures as it is a new RDA. Generally the lateral failure rate increases with age of the RDA, and
- An increased water cannon coverage of 77% during the extreme wind event modelled, based on the new 60m by 60m sprinkler spacing. This new spacing it is noted reduces the area not covered from 39% to 23%, which is a reduction of 41% in the area not wetted.

Based on these assumptions, the resultant emissions from wind erosion from the drying areas with RDA7 included are estimated at 108.1% of the 2003/2004 emissions.

5.2.4.3 Expansion Case

For the expansion case, dust emissions were estimated based on the following:

- Existing RDA areas 3, 4, 5 and 6. The older steel pipes (and poly pipes for RDA1) are replaced with new poly pipes in the new 60 by 60m spaced arrangement that will increase water cannon coverage under the extreme wind conditions from 61 % to 77 %.
- RDA2. This will be replaced with a new dry stacked area using the new water cannon arrangement;
- RDA7 and RDA8 to RDA11. These will have the new water cannon arrangement; and
- Lateral failures. With the new poly pipes it is anticipated that the failures at any given time will be much lower as they do not corrode like the existing steel pipes when used with caustic water. For the expanded case, an overall lateral failure rate of 3% was provided by Alcoa (Alcoa, 2005a). With over 100 laterals in the residue area in the future, this equates to 3 or more lateral failures at any time.

Based on the above assumptions it is predicted that dust emissions from the dry stacked areas for the expanded case will be 88.4 % of the current dry stacked emissions, or 81.8% of the base case emissions. For other sources such as the sand stockpile and ROCP1, no change to the dust emissions has been assumed. Though the amount of sand pumped to the residue area is forecast to increase significantly from 5,806 tpd to 13,353 tpd, due to shifting the coarse/fines split, the sand stockpile area is not considered to increase as new pumps are being installed that will enable the sand to be pumped directly out to all walls for construction. It is estimated that in future, 97 % of the sand will be able to be directly pumped out compared to only 90% at present. For the ROCP1, no change in its operation has been assumed.

The total dust emissions from wind erosion as a percentage of the 2003/2004 emissions case are presented in **Table 5.3**. This indicates that dust emissions from wind erosion for the expanded case will be 82% of the 2003/2004 case or 78.4% of the base case.

Table 5.3 Estimated Contribution (%) from the Various Wind Generated Sources at the Residue Area as a Percentage of the 2003/2004 Emissions

Source	Sand Stockpiles	ROCP1	Sand Areas at RDA2	Dry Stacked Areas (RDAs)	Overall Dust Emissions as a percentage of 2003/2004 Emissions
2003/2004	15	6	10	69	100
Base Case	15	6	10	74.6	104.6
Expanded Case	15	6	0	61	82

5.2.5 Operation Dust Emissions

Normal operations at the residue area that can contribute to dust include the use of bulldozers to work the drying areas, light vehicles on the road and vehicles used for the construction of the bund walls.

Dust emission from dozing is very dependent on the moisture content of the surface material and silt content. As the moisture content of the drying areas will vary substantially, both spatially and temporally, the emissions cannot be accurately estimated. As an estimate, PM_{10} emissions of 2.3 g/s of PM_{10} are obtained per dozer using the NPI relation (NPI, 2001, section A1.1.15), a residue silt content of 80 % (Steedman, Science & Engineering, 1994) and an estimated moisture content of 10 %. Other emissions, including that from the trucking of sand that occurs on an episodic basis, are also difficult to quantify, but considered to be generally low, due to the very well maintained roads in the residue area. As an estimate of the dust emissions, a value of 6 g/s was assumed for this study for the times of 7 AM to 5 PM weekdays, and 7 AM to 3 PM Saturday. Light vehicle dust emissions are considered negligible, due to the low vehicle speeds and the well controlled roads and have been set to a nominal low value for the entire residue area of 1 g/s. For the Pinjarra refinery, a value of 4 g/s of PM_{10} was used from 7AM to 7PM and from midnight to 1AM to account for all operational activity (SKM, 2001d).

5.2.6 RDA 7 Construction

The construction of a RDA, involves the removal of the top 200 to 300mm of sandy material, laying a clay liner, construction of a bund wall from sand and the laying of piping etc. Prior to the construction of RDA7, the last RDA (RDA6) was constructed in 1996 and 1998. The construction of RDA7 commenced in December 2003 and was finalised in May 2004. The operation involved:

- An average of 4 dozers;
- Three graders;
- From the end of January 2004, the cartage of clay from the borrow pit just north of the old borrow pit (see **Figure 1.3**) by up to 8 earthmovers;
- From March 2004, cartage of sand from the sand stockpile area using 70 tonne capacity trucks. These trucks were loaded by one FEL with cartage along internal RDA roads over a 2.5 km route from the sand stockpile area, to out along the RDA7 wall;
- An average of 2 water trucks; with
- The area potentially exposed to wind erosion minimised by the gradual expansion of the area, with this are covered “tied down” with tar and blue metal as much as practicable.

To parameterise the dust emissions from wind erosion during construction, the emissions per unit area from RDA7 and the borrow pit were approximated as 25 % and 50 % of the bauxite stockpile emissions respectively. This is above the level of emissions per unit area from the RDAs that are controlled by water cannon. The overall area disturbed at RDA7 and the borrow pit were taken as 30 ha and 4.5 ha respectively. As construction started in December 2003 and cartage only towards late January 2004, the area within RDA7 subject to wind erosion at a given time was taken as 20 % of the overall area in December 2004, 50% in January 2005, 80% February and 100% from March onwards (see **Table 5.4**).

Estimation of dust emissions from operational activities during construction is problematic, as the emissions are highly dependent on the moisture content of the road and the material being handled.

Instead of estimating emissions using NPI equations and estimates of these parameters, emissions for the whole operations were estimated based on calibrating the dust model to the concentrations of the nearest monitor to these operations (the north monitor and to a lesser degree the north-west monitor). From these a dust emission of 26 g/s for the whole operation was obtained.

Table 5.4 Summary of Fugitive Dust Emissions

Source	Sources	Units	PM_{10} Emissions	Comments
Residue Area Wind	Dry stacked, Sand Stockpile, ROCP1, RDA2	($g/m^2/s$)	5.48E-08 x WS^3 x (1- $36/WS^2$) *6.74E-08 x WS^3 x (1- $36/WS^2$)*	Split by RDA areas and sand stockpile according to Table 5.1. For 2003/2004, 168 ha, Base case 193.5 ha and expanded case 281.5 ha
Residue Area Operations	Dozing, cartage Light Vehicles	(g/s)	6 1	7am to 5pm weekdays, 7am to 3pm Saturday All other times
RDA7 Construction Vehicles	Dozers, haulage, earth movers, graders	(g/s)	26 *50*	7am to 5pm weekdays 7am to 3pm Saturday. Assigned to 20% RDA7 area, 60% Borrow Pit, 20% roads in between
RDA7 Construction Wind	RDA7 Borrow Pit	($g/m^2/s$)	1.125E-07 x WS^3 x (1- $30.25/WS^2$) 3.375E-07 x WS^3 x (1- $54.8/WS^2$)	RDA7 area, 15 ha overall Borrow Pit, 6 ha With 20%, 50%, 80% and 100% of area being worked, subject to wind erosion for Dec, Jan, Feb and March
Bauxite Stockpiles Wind	Bauxite stockpiles and surrounds	($g/m^2/s$)	2.31E-07 x WS^3 x (1- $54.8/WS^2$) *1.87E-07 x WS^3 x (1- $54.8/WS^2$)*	For 2003/2004 and base case, 14.5 ha and for expanded case 19.28ha
Bauxite Stockpiles Operations	Stackers, reclaimers, transfers and vehicles	(g/s)	0.348 x max (2, $0.452WS^{1.37}$) *0.261 x max (2, $0.452WS^{1.37}$)*	Continuous

Notes: Values in italics are as used when using the observational meteorological file. If not specified values are the same as when using the TAPM file winds

5.3 Bauxite Stockpile Emissions

5.3.1 Wind Erosion

The equation for PM_{10} emissions from the Wagerup bauxite stockpiles are listed in **Table 5.4** and are based on the equation per unit area developed at Pinjarra in SKM (2001d). For 2003/2004 and the base case, the area of stockpiles and surrounds at Wagerup were estimated at 14.5 ha, whilst for the expansion case, the area was increased to 19.28 ha to account for an additional "emergency" stockpile.

5.3.2 Bauxite stockpile operations

Sources of dust include all the material handling operations such as stackers, reclaimers, conveyor transfers, vehicle movement, FELs used for emergency reclaim and the trucking of left over rock from the reclaiming to the residue area (see **Section 1**).

The equation for dust emissions from the bauxite stockpiles are presented in **Table 5.4** and are given with a small wind speed dependence, as found for activities where material is being dropped, such as stacking, reclaiming and conveyor transfers (SKM, 1997). These emissions were initially scaled from

the Pinjarra measurements (bauxite throughputs of 7.8 Mtpa to 10.09 Mtpa at the time of the measurements, 1997). However, as these were observed to result in dust emissions that were too high, they were reduced by multiplying by 0.45 to match the observations at the downwind (east monitor). The reduction is primarily considered necessary to account for the use of dust suppressant that is added to the ore before stacking at Wagerup, which was not done at Pinjarra during the original emission study. To a lesser degree it is considered to be due to the lower amount of trucking of rocks at Wagerup than at Pinjarra.

For the expansion case, the emissions from bauxite operations have been increased by the ratio of the bauxite handled, which will increase from 8.76 Mtpa (wet) to 17.04 Mtpa (wet) (Alcoa, 2004a).

5.4 Rainfall

Depending on the material and the amount of rainfall, rainfall not only suppresses dust during the rainfall event, but dependent upon whether a crust is formed, can result in no erosion occurring for a matter a months until the surface is next disturbed. To account for the affect of rainfall in this study, a simple scheme that approximates that used in RWEQ (Fryrear et al, 1998) was used, that defines a soil wetness factor that is used to multiply the erosion rate. Here, the soil wetness is defined as:

$$SW = \text{maximum}(0, R - Evap) \qquad \textbf{(Eq 5.5)}$$

Where

SW is the soil wetness factor which can vary between 0 and 1 (Here limited to a lower value of 0.075 to allow some dust generation for hours with light rain and very strong winds;
R is the sum of the rainfall for that hour and the residual rainfall that has not evaporated previously; and
Evap is the evaporation rate for that hour, determined from the monthly daily average evaporation rate divided by 24.

This scheme it is noted is a simple approximation, but is considered acceptably realistic given the complexities in that:

- Erosion from the residue is dependent on the humidity; and
- The formation and breakdown of crusts is critical in determining dust generation and these depend on rainfall events, the ability of the soils to crust and the frequency of disturbance of the materials which depends on operational activities.

The results of this scheme and its effect on dust emissions can be seen in the annual distribution of estimated dust emissions in **Figure 5.2**. This can be compared to the annual distribution of dust levels presented in **Figure 3.1**.

5.5 Other Dust Sources

Other sources of dust in the area are:

- Agricultural activities, notably tillage and wind erosion from open areas. These have been noted as a significant local sources on occasions by Alcoa personnel;
- The mineral sands mine to the north of the refinery. This was "mothballed" during the modelling period, 1 April 2003 to 31 March 2004, but has since been reopened in late 2004. During the modelling period it was considered to be a small source of dust as the areas were treated to suppress dust, but since reopening has been observed as a source of dust that can affect the north monitor under easterly winds (Alcoa, 2005b); and
- Dust from traffic on unsealed roads in the farmlands around as well as in the general area.

In this modelling assessment, these sources have been neglected as the modelling presents dust concentrations only from the Alcoa operations.

5.6 Particulate Size Distributions

Particulate size distribution data from various sources are summarised in **Table 5.5**.

Table 5.5 Particle Size Distributions

Source	<2.5 µm	2.5-5.0 µm	5.0-10.0 µm	10-15 µm	15-30 µm	30-50 µm	50-90 µm	90-150 µm
Expressed as <30µm								
USEPA Wind erosion	20	30		10	40			
Expressed as Full TSP								
USEPA wind converted to<50µm	14.8	11.1	11.1	7.4	29.6	26		
USEPA Batch/Continuous Drop	11	9	15	13	26	24		
SPCC Operations Iso-kinetic Sampler	4	9	17	11	22	17	13	7
SKM (1997) Pinjarra - Wind erosion	15	8	11	9	22	15	13	8
SKM (1997) Pinjarra - Vehicle	18	9	12	12	27	13	7	2
Adopted This Assessment	**15**	**9**	**12**	**11**	**24**	**14**	**10**	**5**

Notes

1) USEPA TSP percentages were estimated from the PM_{30} based on 74% of wind erosion material and 76% of batch drop dust being below PM_{30}.
2) The percentages may not tally to 100% due to rounding

These are provided for the distribution below 30µm (PM_{30}), which corresponds to the size used in the USEPA emission factors and also for total suspended particulate (TSP), or that which is measured by a TSP sampler.

PM_{30} is generally used in the US for emission factor work. It *"is often used as a surrogate for TSP, and is defined as particulate matter with an aerodynamic diameter no greater than 30 μm. SP may also be denoted as PM_{30}"* (MRI, 1998). TSP on the other hand is the actual particulate that is measured by a TSP sampler and does not have a fixed upper particle size limit, but has a cut off that varies with the wind speed and the orientation of the sampler to the wind. Under strong winds and over rough surfaces, particles with aerodynamic diameters up to 100 μm can remain suspended, whilst under lighter wind conditions these particles will typically fall out within several minutes. Therefore, dependent on the wind speed and orientation, the 50% cut off from a TSP sampler can vary between 30 and 80 μm. PM_{30} is used in the US emission factor work as it removes this problem. However, for modelling against observed TSP levels, the full particle size distribution is required, other wise the modelled TSP will be less than that monitored.

As such, **Table 5.5** also presents the data from the USEPA that has been converted to TSP by noting that in earlier literature the PM_{30} fraction was given as 0.74 and 0.76 of the TSP. This converted data is reasonably similar to that measured by SKM (1997) at Pinjarra from wind and vehicular generated dust and is also similar to that measured by the SPCC (1986) using an iso-kinetic sampler. The SKM data was obtained from dust on filter papers that was sized using a Malvern particle sizer and converted to aerodynamic size, based on a particle density of bauxite dust of 2.87 g/cm^3 and a shape factor of 1.1, as determined for the generally irregular rectangular shapes. That is, the aerodynamic particle size is equivalent to the particle diameter multiplied by 1.59.

For this study, the average of the SKM (1997) results for Pinjarra bauxite have been used as they are for the material of concern and are similar to the re-derived USEPA distributions. This particle size distribution indicates that 36% of the TSP is PM_{10}. This is slightly lower than that used by Alcoa for their NPI calculations of 42% PM_{10} based on measurements in their ambient monitors, as 36% is the particle size distribution collected near the source. At distances further from the source, the ratio of PM_{10} to TSP increases as the larger particulate are preferentially removed.

For application in this study, emissions in 7 size categories were obtained by multiplying the PM_{10} emission rate by the proportion of particulate in a given size fraction to that below 10μm. For example the $PM_{2.5}$ emissions were estimated by multiplying the PM_{10} emissions by 15/36 (0.42). Particulate greater than 50μm, which comprised 15% of the total particulate, was grouped as one fraction with a mean particle size of 67μm.

5.7 Particulate Metal Speciation

The metal speciation within the fine and coarse residue and the bauxite ore used for the dust are listed in **Table 5.6** as provided by Alcoa (Alcoa 2005c). These are typical average concentrations from samples of the bauxite, coarse residue and fine residue.

Table 5.6 Composition of Bauxite, Fine Residue and Coarse Residue

Element or Chemical Composition	Units	Bauxite	Coarse Residue	Fine Residue
Al_2O_3	%	37	10	21
SiO_2	%	23	56	27
Fe_2O_3	%	16	26	28
K_2O	%	0.4	0.14	1.1
CaO	%	<0.001	0.64	4.4
MgO	%	0.09	0.11	0.44
Na_2O	%	0	0.4	2.6
TiO_2	%	1.2	1.1	2.9
P_20_5	%	0.031	0.02	0.088
MnO	%	**0.02**	0.03	**0.03**
LOI	%	20	4.6	11
SO_3	%	0.17	0.13	0.48
Cr	ppm	123	166	269
Zn	ppm	4	2	12
Y	ppm	7	9	17
Sn	ppm	11	14	22
V	ppm	278	419	419
Cd	ppm	**0.03**	0.03	**0.03**
Co	ppm	-	-	7
Ga	ppm	67	55	89
Zr	ppm	594	489	1379
Ba	ppm	89	32	304
Se	ppm	**3**	3	**3**
As	ppm	**22**	15	**48**
Ni	ppm	**<5**	<5	**5**
Rb	ppm	24	11	68
Nb	ppm	34	20	85
Pb	ppm	9	7	18
Th	ppm	194	170	400
Hg	ppm	0.04-**0.07**	0.01-0.04	0.02-**0.05**
Cu	ppm	11	17	22
Sr	ppm	2	40	243
Mo	ppm	9	7	12
U	ppm	13	8	34
Ag	ppm	<2	<2	<2

Notes:

1) No chromium VI is present in the bauxite or residue material.
2) Concentrations below the detection limit have been set to equal the detection limit.
3) Numbers in bold have been modelled for the Health Risk Assessment
4) Cadmium value as supplied by Alcoa (2005d). This was based on the maximum value actually detected in recent sampling and not the detection limit as in Alcoa (2005c)

Table 5.6 indicates that the coarse and fine residue consist primarily of alumina, silica and iron oxides. The fine residue also contains higher percentages of trace metals than the coarse residue material. For modelling dust, the highest concentration recorded from either the coarse or fine residue has been used to define the residue area dust composition, whilst the bauxite data have been used to define the bauxite area dust composition. Metals required for the health risk assessment (ENVIRON et al, 2005) that have been modelled are bolded.

It is noted that the compositions listed in **Table 5.6** are derived from bulk samples, and as such may neglect the enrichment of some elements in the fine particulate. To a degree this is already seen in the differences between the fine and coarse residue fraction. However, as the fine fraction is for material below 150µm (80% is less than 63 µm, SSE, 1994), it is similar in size to the PM_{10} fraction and little further "enrichment" of metals may be expected. The exception to above argument is for sodium. As detailed in **Section 1.3.3**, during drying of the fine residue a "powder" of sodium carbonate decahydrate can form on the surface due to the mobility of the sodium ion. As such, sodium and carbonate can be "enriched" relative to other materials dependent on the amount on the nature of the surface being eroded. If such sodium carbonate surfaces develop, the percentage of other metals measured in ambient air samples from the residue area would be expected to be slightly lower than the bulk composition of the residue material.

5.8 Consideration of the Gustiness of Winds

The formulae to estimate dust emissions are based on dust emission measurements undertaken at night and in the early morning that have been related to the corresponding hourly average wind speeds. As these conditions generally have reasonably steady winds, it is considered that such relationships may under-predict the dust emissions for conditions when the winds are more gusty. Such gusty conditions are thought to occur especially for pre-frontal, north to north-westerly winds that are associated with a deep unstable atmosphere. These conditions have been associated with dust events at Wagerup, with periods within the hour (up to 5 or 10 minutes) of very strong winds, though the hourly winds are not overly strong. An example of this is the dust event on the 15th November 2002, where the 1-hour winds would not suggest the high dust emissions that occurred.

This affect of the variation in gustiness has been noted in Countess (2002) and has been included in the Texas Erosion Analysis Model (TEAM) (Singh et. al., 1997) and the Columbia Plateau PM_{10} Project model (Claiborn et. al, 1998).

To parameterise this effect for this study, the ratio of the maximum wind gust in the hour to the 1-hour average wind speed from the Bancell road 30 m tower were plotted for all hourly winds greater than 8 m/s (**Figure 5.1**). This data was used as it was the only data available at the time.

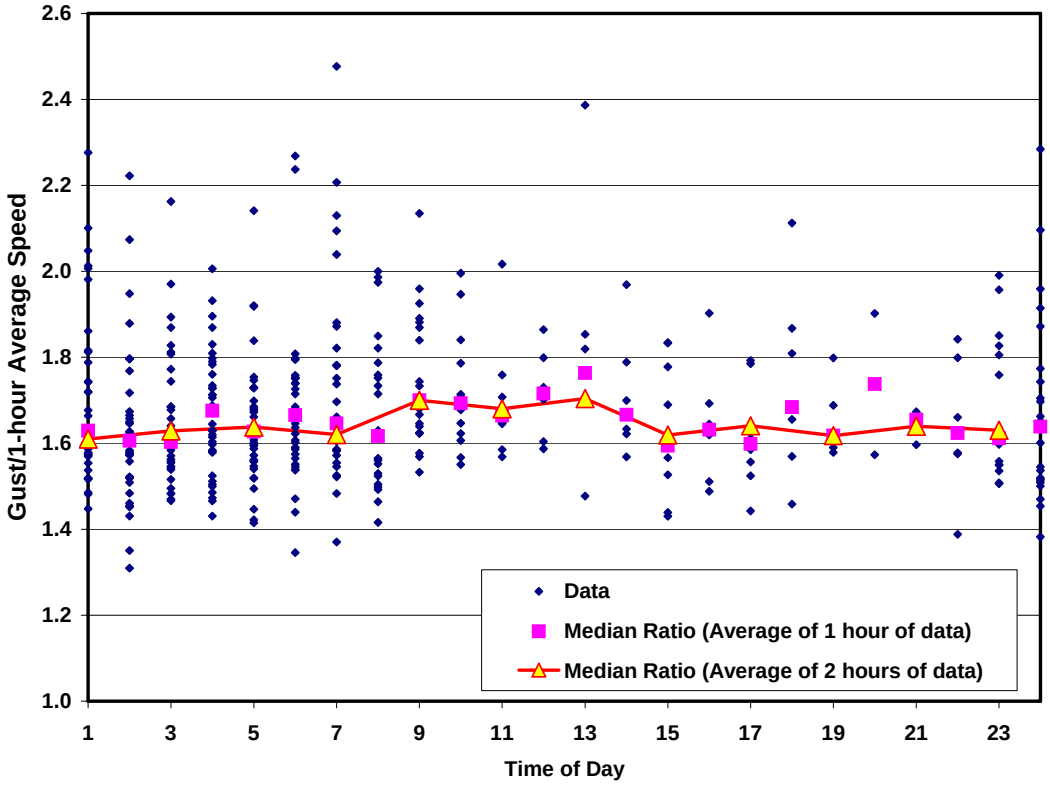


Figure 5.1 Gust to 1-hour wind speed ratios by time of day for Bancell Road 30m winds greater than 8 m/s

Figure 5.1 shows that on average, higher gust to 1-hour wind speed ratios (gustiness) occurs during the hours from 8am to 2pm. An analysis of gustiness by wind direction was also attempted, but there was insufficient data for the various wind directions. Therefore, to include this variation by time of day, wind speeds within the model for the time from 8 am to 2 pm were increased by 20%. This increase is to reflect that the top 2 minute winds in the hour (which generates the majority of the dust), may be 20% higher than for an hour with steadier winds. In the current US EPA wind estimation methodology, the fastest mile of wind (approximately a 2 minute event) is used to estimate dust erosion as it is within these 2 minutes that the majority of dust lift off occurs. It is noted that the above is an approximation, but to neglect this affect would underestimate the dust emissions particularly for the northerly, day time winds. To further quantify this, maximum 1-minute to hourly average data is required for a longer time period.

5.9 Predicted Emissions

5.9.1 PM_{10} Emissions

Table 5.7 presents a summary of the estimated emissions from the residue area, bauxite stockpiles and construction activity for the 12 month period from 1 April 2003 to 31 March 2004. **Table 5.7** indicates that maximum hourly emissions will arise from wind erosion sources, with much smaller emissions from operations. On an annual basis, wind erosion is still the largest source, though with an increased contribution from sources such as vehicle and ore movement, as these sources are generally

continuous for the year unlike wind erosion. **Table 5.7** also indicates that although the RDA 7 construction only occurred for around 3 ½ months of the 12 month period, it was responsible for a substantial contribution of 121.3 tpa (22%) to the annual emissions of 557 tpa.

Table 5.7 Estimated PM_{10} Emissions from Wagerup Fugitive sources for 2003/2004

Source	Units	Normal Operations					RDA Construction		
		Stockpile Wind	Stockpile Activity	Residue Area Wind	Residue Area Activity	Total	Wind	Construct. Activity	Total
Maximum	g/s	159	8.2	469	6.0	637	154	26	180
99 Percentile	g/s	55.9	5.5	177	6.0	240	40.5	26	44.2
95 Percentile	g/s	10.6	3.4	44.5	6.0	60.8	7.2	26	26
90 Percentile	g/s	1.7	2.5	15.2	6.0	22.6	1.5	10.4	18.2
Average	g/s	2.2	1.3	8.4	1.9	13.8	1.5	2.3	3.8
Minimum	g/s	0.0	0.4	0.0	0.54	0.9	0.0	0.0	0.9
Annual	tpa	70	40.3	266	60	436.3	48.5	72.8	121.3

Note: As derived using the TAPM meteorological file and related emission estimates.

Table 5.8 presents a comparison of the emission estimates developed in this report and the Alcoa NPI estimates derived using the methodology detailed in Coffey and Evans (2000) (see **Section 5.2.2). Table 5.7** indicates that the annual PM_{10} emissions estimated in this report (557 tpa) are higher by a factor of 2 than that estimated for the NPI (272 tpa). The major difference is the much higher emissions from the bauxite stockpiles estimated in this report and the dust from RDA construction. The reasons for these differences may be that the Alcoa methodology is dependent on the coverage of the dust monitors around the sites and that the coverage around the bauxite stockpiles and RDA construction in particular, may be insufficient.

Table 5.8 Comparison of PM_{10} Estimates (tpa) from various Sources

Source	Residue Area	RDA Construction	Bauxite Stockpile	Total
Wagerup This Study (Excluding RDA Construction)	326 (286)	-	110 (84)	436 (370)
Wagerup This Study (Including RDA Construction)	326 (286)	121 (167)	110 (84)	557 (538)
Wagerup (NPI 03/04)	261	NA	11	272
Pinjarra (NPI 03/04)	419	NA	90	509
Pinjarra (SKM, 2001d)	314	NA	179	493

Notes:

1) Emission estimates for this study are for the period 1/4/03 to 31/3/04 whilst the NPI estimates are for the period 1/7/03 to 30/6/04.
2) The erodible area of the residue area without RDA 7 was taken as 168 ha.
3) Wagerup values for this study are given using the TAPM winds, without brackets and using the observed winds (in brackets)
4) Emission estimates for the residue area and bauxite stockpile include both wind erosion and operational activities.

Table 5.8 also presents a comparison of the PM_{10} emissions using the observed meteorological file and the TAPM file. This indicates that use of the observations results in slightly lower emissions than that predicted using the TAPM winds, though still being above the NPI estimates.

The annual variation in daily dust emissions is presented in **Figure 5.2** which shows a seasonal trend which is very similar to that for the concentrations as presented in **Figure 3.1**.

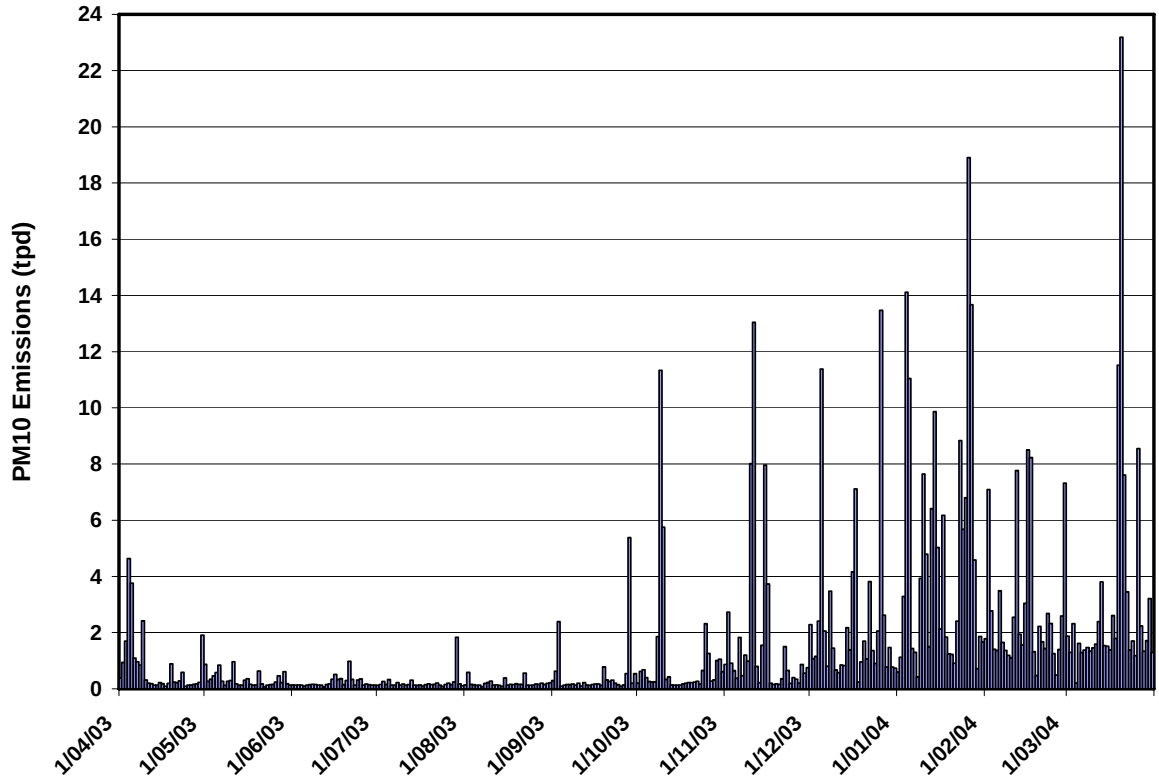


Figure 5.2 Estimated Daily PM_{10} emissions from the Wagerup Residue and Stockpile Areas

5.9.2 PM_{10} Metal Emissions

Table 5.9 presents a summary of the predicted metals in the emitted PM_{10} for the base and expansion case using the TAPM meteorological file and the meteorological file from the observations. Also presented are the Alcoa NPI 2003/2004 emissions.

Table 5.9 Comparison of Annual PM_{10} and Metal Estimates within the PM_{10} from various Sources

Source	Residue Area (tpa)	Bauxite Stockpiles (tpa)	Total (tpa)	Mn (kg)	Cd (kg)	Se (kg)	As (kg)	Ni (kg)	Hg (kg)
TAPM Winds									
Base Case	343	110	453	96.6	0.014	1.36	18.9	2.27	0.025
Expanded Case	319	173	492	100.9	0.015	1.48	19.1	2.46	0.028
Ratio Expanded/Base	0.93	1.57	1.09	1.04	1.09	1.09	1.01	1.09	1.13
Observed Winds									
Base Case	302	63	366	79.9	0.011	1.10	15.9	1.83	0.020
Expanded Case	287	102	389	82.3	0.012	1.17	16.0	1.94	0.021
Ratio Expanded/Base	0.95	1.61	1.06	1.03	1.06	1.06	1.01	1.06	1.10
Alcoa 03/04 NPI	261	11	272	46.6	0.0076	1.26	10.2	1.13	0.0034

Note: Alcoa NPI estimates from Alcoa (2005) with metals converted from TSP fraction to PM_{10} fraction by multiplying by 0.42, the fraction ALCOA uses for PM_{10} in their NPI reporting,

Table 5.9 indicates:

- A small increase in the emissions of PM_{10} and most metals for the expansion case;
- Slightly lower emissions were predicted for the observed winds compared to the TAPM winds; and
- Generally the estimates here are equal to twice that reported in the NPI. Of the metals, the major difference is with mercury, with these estimates around 6 to 8 times higher than estimated using the NPI methodology. These differences will be due to differences in the PM10 estimates, the metal speciation used and how they are applied.

5.10 Mercury Emissions

Table 5.9 indicates that the emissions of mercury in PM_{10} will be 0.025 and 0.028 kg/year for the base case and expanded case respectively. This is much less than the estimated 55.1 kg/year of mercury vapour (53.93 and 1.2 kg/year respectively from the cooling pond and lower dam) for the base case, and 0.481 kg/year for the expansion case (emissions from the lower dam only) as estimated by Alcoa (2005h). Therefore, the particulate mercury will comprise only a negligible fraction of the predicted mercury "concentrations".

6 Fugitive VOC Emissions

6.1 Selection of Sampling Methodology

Emissions of odour to air from area sources are generally determined by three methods within Australia. These are:

- Hood/chamber methods (static and dynamic);
- Tunnel methods; and
- Windward/downwind sampling.

The emission rates derived from these methods can then utilised within standard dispersion models to predict the odour levels around the location of interest. Unlike odour modelling of area sources, modelling of VOCs from large area sources has to the authors knowledge, not been attempted within Australia, but could be undertaken using the above approaches used for odour. Additionally, beside the above methods used for odour, individual VOCs could be determined using a mass balance approach or a mass transfer approach based on the transfer coefficients of the species to air.

Dynamic flux (isolation flux) chambers have typically been used throughout Australia for the determination of odour emissions rates from ponds and land surfaces. This method is not an official USEPA method, though it is often incorrectly stated as such. As stated by (Hartman, 2003) *"There is currently no published or official U.S. EPA method for surface flux chambers. There is a published study performed under contract with EPA that gives a recommended protocol, but it is not regulatory guidance. There is no right way to perform a flux chamber survey. Like any field technique there are variations in the method - the suitability of each depends on the project goals*".

Isolation flux chambers are specified in the NSW sampling for determination of gaseous emission rates from land surfaces (for sampling of odour from diffuse sources, NSW EPA, 2001). The draft policy specifies that this method must be used though other methods *"may be substituted for this method where there is either a valid Australian or overseas method, or sufficiently detailed protocol available for its use*" (NSW EPA, 2001, page 58).

The US dynamic flux chamber method consists of a small chamber where dry nitrogen is released through 4 ports located 7 inches above the surface with air inflow of 5 L/min. Exit air, at a flow rate of 2 l/min, is drawn from a perforated plunger within the chamber to the outside sample line where it is sampled. The system is designed to be *"effectively isolated from most external environmental conditions such as wind speed. Therefore, the measurement data are not strongly dependent on the meteorological conditions present at the site on the days of sampling. The data are thus directly comparable from day to day and site to site*" (Eklund, 1992).

Wind tunnels are commonly used for assessing odours from lagoons in Australia (FSA Environmental, 2000 and Galvin et al, 2003). In the tunnel, odour free air is drawn across the surface with a small

representative part of the air stream sampled. Typical wind speeds 0.1 m above the surface are 0.3 m/s. The advantage of this method is that it measures emissions, which for liquid surfaces such as ponds and solid surfaces such as feedlots, have been shown to be a function of the wind speed. The disadvantage of wind tunnels is that with the larger flow rates, the method does not have the sensitivity of flux chambers.

Downwind sampling with back calculation utilises measurements taken downwind of the sample, followed by the use of an appropriate dispersion model to back-calculate the emissions. In Australia, the model STINK (a Gaussian plume model) has been used for a number of studies (Smith, 1995 and Galvin et al. 2004), with recently the model Windtrax (a particle trajectory method based on Similarity Theory) also being used (Galvin 2004). The advantage of the down wind sampling/back calculation method is that it does not interfere with the emission rates and provides an areal average of the emissions. This is unlike the flux chamber and wind tunnel measurements where a number of measurements should be undertaken to derive a statistically valid sample (Eklund, 1992 and Galvin et al, 2003). The disadvantage of the down wind sampling method is the reduced sensitivity, as concentrations down wind will be lower than those measured just above the surface of a pond as measured from a flux chamber.

The mass balance approach can be utilised when the flows into and out of the system can be quantified, leaving the unknown flow to be estimated as the difference of the known flows. Of the sources at the Wagerup refinery, the cooling pond will probably be the most amenable to this approach as it is a lined storage pond, with the only loss of VOCs to air. Difficulties however will occur with reactions of the species lowering their concentrations.

The mass transfer approach requires mass transfer coefficients of the species to be determined along with a model of the release to air. For this study, a preliminary investigation was made of emissions from the cooling pond, but with limited success due to the large uncertainties in determining appropriate transfer coefficients.

6.2 Comparison of Flux Chamber, Wind tunnel and Downwind sampling Emission Estimates

In the following a brief review of the current status of the three methods used in determining odours from area sources is presented. This is undertaken as there is no consensus on the correct method and if and how to correct the data.

Jiang and Kaye (1996) undertook a comparison of flux chamber and wind tunnel methods for liquid surfaces, for three VOC's; acetone, methyl ethyl ketone and toluene. Jiang and Kaye found that the ratios of the emission rates from the wind tunnel (wind speeds of 0.3 m/s at 0.1m), to the emission rates from the flux chamber were 6.15, 1.92 and 1.03 for these three VOCs respectively. Jiang and Kaye (1996) argued that the differences in the ratios were due to whether the vapour emissions where liquid phase or gas phase controlled. VOCs with Henrys law constants greater than 250 Pa m^3/mol are liquid phase controlled and increasing the turbulence in the liquid increases the evaporative emissions, whilst changes to the air flow do not. For VOCs with a Henry Law constant below 2.5 Pa m^3/mol, the

volatisation process is gas phase controlled, with increases to the air flow resulting in greater evaporative emission rates. For toluene, the Henrys law constant is 644 Pa m^3/mol and therefore it will be liquid phase controlled, whilst acetone with a Henrys law constant of 4.3 Pa m^3/mol will be gas phase controlled. From this study, Jiang and Kaye (1996) therefore concluded:

- *"The use of isolation chambers for sampling VOCs which exhibit gas phase controlled volatisation processes will result in substantial underestimations of emission rates"*; and
- Because of the dependence of the emission flux on the type of VOC that "*There can be no overall correlation between emission rates determined by isolation chambers and wind tunnels".*

It is noted that the ratios quoted in Jiang and Kaye (1996) are dependent on the experimental conditions, which where for a liquid temperature of 20 degrees Celsius and wind speed within the wind tunnel of 0.3 m/s at 0.1m above the surface. At higher liquid temperatures, such as 40 or 50 degrees Celsius, this ratio will be different. Also, if a wind speed of 0.05 m/s at 0.1 m was used, instead of 0.3 m/s and assuming an emission velocity dependency of 0.5 (see **Section 6.3**) for the gas phase controlled species, the wind tunnel emissions will be 2.45 lower. Therefore, the acetone ratio between the wind tunnel and flux chamber will be lower at 2.51, whilst the ratio for toluene will probably remain similar to its previous value of 1.03.

Pollock (1997) in a brief review of wind tunnel and flux chambers results, cited work by Smith and Watts (1993) that showed that the emissions from wind tunnels (wind speeds of 0.3 m/s at 0.1m) were typically a factor of 10 higher than that from flux chambers. Smith and Watts (1993) concluded that the difference was due to the quiescent conditions within the chamber unlike that within the wind tunnel. Pollock (2005), recently conducted further comparison work for odours from waste water treatment ponds and found that the agreement was much better, if the flux chamber results are considered representative of 0.05 m/s at 0.1 m. It is noted that a wind speed of 0.05 m/s at 0.1 m is equivalent to a wind speed of 0.63 m/s at 10m under F class stability conditions, based on the standard power law for the wind speed dependence with height (Scire et al, 2000) of:

$$V_h = (h/10)^p V_{10} \qquad \textbf{Equation 6-1}$$

Where:

V_h and V_{10} are the wind speed at height h and 10m respectively; and

p is an exponent that varies with the stability and roughness of the area. For rural areas values of 0.07 for A and B class stability, 0.1 for C class, 0.15 for D class, 0.35 for E Class and 0.55 for F class are recommended.

Therefore, there is some evidence that flux chamber emissions are representative of emissions that occur for the worst case dispersive conditions allowed in models such as Ausplume, of a wind speed of 0.5 m/s at 10m height and F class stability.

CH2M Beca (2000) presented result for waste water treatment lagoons in which the ratios of wind tunnel measurements (0.05 m/s at 0.1 m) to flux chamber (dynamic flux chamber though stated as

static in the report) ranged from 5 to 9 (average of 7 from 3 samples) for a quiescent source and 0.8 to 8 (average of 1.9) for a turbulent source. They concluded that *"these results indicated there was no consistent ratio between the two hood types"*. These results however do indicate that increasing the turbulence in the liquid increases the emissions, therefore indicating according to the findings of Jiang and Kaye (1996) that the dominant VOCs in terms of odour are liquid phase controlled.

Lakmaker et al (2003) presented uncited data from Sinclair Knight Merz of measured ratios between a wind tunnel and isolation flux chamber for two sewage treatment plants, with measured ratios of between 60 and almost 200. Lakmaker et al (2003) in reviewing this and other data, argued that wind tunnel measurements (wind speed of 0.3 m/s at 0.1 m) should be divided by a factor of 15 to convert to equivalent flux chamber measurements when comparing against the NSW odour guidelines. It is noted that if a standard wind speed of 0.05 m/s instead of 0.3 m/s at 0.1m is used, the ratios decrease to 6.1.

In comparison to the relationship between the wind tunnel and flux chamber emissions, Galvin et al (2004) found good agreement between wind tunnel measurements and that estimated using down wind sampling and subsequent back calculating using the model STINK. This good agreement indicating the equivalency of the methods and supporting the idea that they both provide representative emissions estimates from liquid surfaces.

6.3 Wind Speed Dependence of Emissions

The current practice for modelling odours from flux chambers is to use the data as is, without a wind speed correction. For odour modelling of surface area sources, applying a wind speed correction to flux chambers results is not critical, as the highest concentrations occur for light 0.5 m/s winds and F class stability, at which there is some evidence that flux chamber emissions are representative. Additionally, the odour criteria used in the NSW odour guidelines have been developed using emissions from flux chambers, such that they are self consistent.

Wind tunnel results are generally used with a wind speed dependence using the formula (Pollock, 1997 and Galvin et al, 2004) of:

$$ER_2 = ER_1 (V_2/V_1)^n$$ **Equation 6-2**

Where:

ER_1 and ER_2 are the emission rate (or flux) at wind speed 1 and 2;
V_1 and V_2 are the wind speeds; and
n is a dimensionless exponent.

For feedlots and manure piles an exponent (n) of 0.63 is generally used based on measurements reported by Smith and Watts (1993) from wind tunnel testing. For liquid surfaces an exponent of 0.5 is generally used (Pollock, 1997 and Galvin et al, 2003). This liquid exponent is cited from the paper

by Jiang and Kaye (1996), which references unpublished preliminary work at the time. This work is reported in Bliss et al (1995) which show that ammonia emissions from a wind tunnel approximately matched the theoretical wind speed to the power of 0.5 relationship derived in that paper. Galvin et al (2004, page 10) however, note that the exponent is a little uncertain, reporting values between 0.5 and in excess of 1.0. In chemical engineering a value of around 0.76 to 0.78 is generally used (Cavanaugh et al, 1993), based on work by Sutton (1953). The above variation in the exponents is consistent with the work of Jiang and Kaye (1996) in that the VOC emissions are dependent on whether the VOC is liquid phase or gas phase controlled. As such, VOCs which are gas phase controlled will probably have a wind speed dependence to a value of 0.78, whilst those which are liquid phase controlled will have little if any wind speed dependence.

6.4 VOC Emissions

6.4.1 Emission data per Unit Area

For estimating VOC emissions for this study, flux chamber measurements have been used as the primary source as it has the greatest sensitivity of the methods (lowest MDLs), and the VOC emissions rates were considered likely to be low from these surfaces. The method was also specifically recommended in the independent audit of air quality conducted at Wagerup (AWN, 2003) and by CSIRO (2004b). As a check on the emission rates, some back calculation work was also undertaken to verify the emissions for the species that could be detected by the ambient monitors.

Flux chamber data using the GHD (2005) data as summarised by Alcoa (2005e) are presented in **Table 6.1** for the major fugitive sources.

Table 6.1 Flux Chamber Results

Source	BaP Equivalents	Acetone	Acetaldehyde	Formaldehyde	2-Butanone	Benzene	Toluene	Xylenes	Odour
	($\mu g/m^2/min$)								($ou/m^2/min$)
Lower Dam		0.25	0.07	0.55					3.29
ROCP		0.25	0.07	0.55					1.85
RDA2 - Liquor Southern		11.60	8.70	0.13	1.47	0.05	0.16		37.0
RDA2 - Wet Residue - North		2.52	0.87	0.44	0.28	0.05	0.03		**16.78**
Super Thickener	1.38E-04	77.35	56.73	0.78	7.63	1.10	4.50	0.71	86.8
Cooling Pond	9.00E-06	13.24	9.94	0.08	1.97	0.21	0.30	0.07	42.6
Oxalate Pond		0.25	0.07	0.55	0.00				0.37
ROWS		0.25	0.07	0.55	0.00				0.36
Wet Residue		2.52	0.87	0.44	0.28	0.05	0.03		**16.78**
Dry Residue 1		0.11	0.42	**0.90**		0.01	0.01		0.60
Dry Residue 2		0.42	0.05	**0.08**		0.01	0.06		**1.46**
Composite RDA(winter)		0.25	0.45	0.87	0.02	0.01	0.01		1.57
Wet Sand		2.52	0.87	0.44	0.28	0.05	0.03		**16.78**

Notes:
1) Emissions bolded are from equations 6.1 to 6.4 and are presented at an ambient temperature of 25 degrees Celsius.
2) Due to a lack of data from some sources, emissions from the lower dam, ROCP and oxalate pond have been set equal to the ROWS pond emissions, with the wet sand and wet RDA2 area emissions set equal to the wet residue emissions (Alcoa, 2005a).

Emission fluxes from the drying residue has been presented for three surfaces dependent on the dryness of the residue; wet residue (up to several days after laying depending on the condition), dry residue 1 (the period following this) and dry residue 2 (towards the end of the drying cycle). Emissions have then been derived for the composite drying area based on estimates of the proportions of these areas (Alcoa, 2005f) as provided in **Table 6.2** for winter and summer. Summer was taken as from December to April and winter from June to September. Other months were linearly interpolated between these values.

Table 6.2 Percentage of Dry Stacked Areas Covered by the Three Residue Classes

Source	Wet Residue (%)	Dry Residue 1 (%)	Dry Residue 2 (%)
Summer	8	66	26
Winter	6	94	0

For the majority of the sources, the emissions in **Table 6.1** have been given at a constant rate with no dependence on the ambient air temperature, or time of day, or time of year. Exceptions to this are the following areas and substances given as a function of air temperature as determined from an analysis of the data as summarised in Alcoa (2005e):

Formaldehyde

Dry Residue 1 ($\mu g/m^2/min$) = max (0, 0.12 x AT - 2.1) **Equation 6-3**

Dry Residue 2 ($\mu g/m^2/min$) = max (0, 0.01 x AT - 0.17) **Equation 6-4**

Odour

Dry Residue 2 ($ou/m^2/min$) = max (0, 0.4975 x AT -10.97) **Equation 6-5**

Wet Residue ($ou/m^2/min$ = max (0, 1.1724 x AT -12.53) **Equation 6-6**

With wet sand and wet residue in RDA2 = Wet Residue

Where AT is the air temperature in degrees Celsius.

Therefore **Equations 6-3** to **6-4** predict that at temperatures below 17.5, 17, 22.1 and 10.7 degrees Celsius respectively, there will be negligible emissions of formaldehyde and odour from these sources.

6.4.2 Estimated Emissions on an hourly basis

Estimated VOC emissions from the fugitive sources were derived from the emission measurements in **Table 6.1** by the following:

- VOC emissions from the "dry" stacked areas (wet residue, dry residue 1 and dry residue 2) were independent of the wind speed. This was assumed as it is considered that the emissions will be controlled by diffusion through the soil (Eklund, 1992);
- Emissions from wet areas are wind speed dependent to the power of 0.5, as given by Jiang and Kaye (1996) in **Equation 6.1,** with the flux chamber results taken to represent a wind speed of 0.05 m/s at 0.1m above the surface This assumes that the VOCs emissions are predominantly vapour phase controlled; and
- There is no temperature or solar radiation dependency apart from that specified for the residue drying areas as defined in **Section 6.4.1**.

The resultant emissions for the base case are presented in **Table 6.3**. These are presented at a temperature of 25 degrees Celsius, for a winter RDA mix of the various drying areas and with no correction for wind speed.

Table 6.3 Estimated VOC Emissions for the Base Case

Source	Area	BaP Equivalents	Acetone	Acetaldehyde	Formaldehyde	2-Butanone	Benzene	Toluene	Xylenes	Odour
	(ha)	(g/s)								(ou/s)
Dry Stacked Areas	186.52	0	7.91E-03	1.39E-02	2.71E-02	5.22E-04	3.85E-04	3.48E-04	0	48,800
Lower Dam	17.7	0	7.38E-04	2.07E-04	1.62E-03	0	0	0	0	9,710
ROCP1	8.217	0	3.42E-04	9.59E-05	7.53E-04	0	0	0	0	2,530
ROCP2	4.58	0	1.91E-04	5.34E-05	4.20E-04	0	0	0	0	1,410
RDA2 - Wet Residue - North	7.36	0	3.09E-03	1.07E-03	5.40E-04	3.43E-04	6.13E-05	3.68E-05	0	20,600
RDA2 - Liquor Southern	8.0	0	1.55E-02	1.16E-02	1.73E-04	1.96E-03	6.67E-05	2.13E-04	0	49,300
Super Thickener	0.461	1.06E-08	5.94E-03	4.36E-03	5.99E-05	5.86E-04	8.45E-05	3.46E-04	5.46E-05	6,670
Cooling Pond	15.52	2.33E-08	3.42E-02	2.57E-02	2.07E-04	5.10E-03	5.43E-04	7.76E-04	1.81E-04	110,200
Oxalate Pond	1.888	0	7.87E-05	2.20E-05	1.73E-04	0	0	0	0	116
ROWS	33.28	0	1.39E-03	3.88E-04	3.05E-03	0	0	0	0	2,000
Sand Cannon	0.5	0	2.10E-04	7.25E-05	3.67E-05	2.33E-05	4.17E-06	2.50E-06	0	1,400
Sand Lake	4.34	0	7.63E-03	5.64E-03	1.20E-04	9.64E-04	3.62E-05	1.05E-04	0	25,100
Total		3.39E-08	7.72E-02	6.31E-02	3.43E-02	9.50E-03	1.18E-03	1.83E-03	2.36E-04	277,850

Notes:

1) Emissions are presented uncorrected from the flux chamber, at 25 degrees Celsius in winter.
2) Individual items may not add to the total due to rounding.

The expansion case emissions are based on the following changes as supplied by Alcoa (2005g):

- The super thickener emissions will increase by 20% of the equivalent VOC load of the Lower Dam;
- Cooling Pond emissions will increase by 50% of the current VOC load;
- ROWS Pond emissions will increase by 100% of the current VOC load;
- RDA areas will accept 80% of the load diverted from Lower Dam, distributed across all active surfaces;
- Sand Lake. An increase in the wet sand area of 50% for the expected 3 times increase in sand;
- RDA2 will be converted to dry stacking;
- Addition of RDAs 8, 9 , 10 and 11;and
- Oxalate ponds. An additional 1 ha pond will be constructed in the SE corner of RDA1.

The resultant emissions for the expansion case are presented in **Table 6.4**.

Table 6.4 Estimated VOC Emissions for the Expansion Case

Source	Area	BaP Equivalents	Acetone	Acetaldehyde	Formaldehyde	2-Butanone	Benzene	Toluene	Xylenes	Odour
	(ha)	(g/s)								(ou/s)
Dry Stacked Areas	275	0	1.22E-02	2.06E-02	4.12E-02	7.69E-04	5.67E-04	5.12E-04	0	79,630
Lower Dam	17.7	0	7.38E-04	2.07E-04	1.62E-03	0	0	0	0	9,710
ROCP1	8.217	0	3.42E-04	9.59E-05	7.53E-04	0	0	0	0	2,530
ROCP2	4.58	0	1.91E-04	5.34E-05	4.20E-04	0	0	0	0	1,410
Super Thickener	0.461	1.06E-08	6.09E-03	4.40E-03	3.84E-04	5.86E-04	8.45E-05	3.46E-04	5.46E-05	8,610
Cooling Pond	15.52	3.49E-08	5.14E-02	3.86E-02	3.10E-04	7.64E-03	8.15E-04	1.16E-03	2.72E-04	165,300
Oxalate Ponds	2.888	0	1.20E-04	3.37E-05	2.65E-04	0	0	0	0	178
ROWS	33.28	0	2.77E-03	7.77E-04	6.10E-03	0	0	0	0	3,990
Sand Cannon	0.5	0	2.10E-04	7.25E-05	3.67E-05	2.33E-05	4.17E-06	2.50E-06	0	1,400
Sand Lake	4.59	0	7.74E-03	5.68E-03	1.38E-04	9.76E-04	3.83E-05	1.06E-04	0	25,800
Total		4.55E-08	8.18E-02	7.05E-02	5.12E-02	1.00E-02	1.51E-03	2.13E-03	3.26E-04	298,500
Percentage of Base Case Emissions		134	106	112	149	105	128	117	138	107

Notes:

1) Emissions are presented uncorrected from the flux chamber, at 25 degrees Celsius in winter

Table 6.4 also presents the expansion results as a percentage of the base case and indicates that the VOC emissions will be 105 to 149% of the base case. Odour emissions will be 107% of the base case.

Table 6.5 and **Table 6.6** present the annual emissions from the base case and expanded refinery along with the emissions from the base case refinery. These are based on estimating the emissions for each hour based on the wind speed and temperature for that hour. For the liquid surfaces, as the emissions increase rapidly with wind speed, they have a much greater relative contribution at higher wind speeds and therefore to the annual contribution than indicated in the preceding tables. This indicates that for acetaldehyde, 2-butanone and acetone that the residue area contributes 79.5%, 47.7% and 36.6% of that emitted from the refinery for the base case. For all other substances the emissions are less than a tenth of the refinery emissions. For odour, **Table 6.5** and **Table 6.6** indicate that on average the fugitive emissions are comparable to the average emissions from the refinery. It is noted however, that at lower wind speeds when the dispersion from the fugitive sources is less, the emissions are also less, so comparing the two average emissions can be misleading.

Table 6.5 Estimated Annual VOC Emissions for the Base Case

Source	BaP Equivalents	Acetone	Acetaldehyde	Formaldehyde	2-Butanone	Benzene	Toluene	Xylenes	Odour
	(kg/yr)								(ou/s)
Dry Stacked Areas	0	3.18E+02	3.92E+02	2.37E+02	1.94E+01	1.26E+01	1.81E+01	0	37,830
Lower Dam	0	1.41E+02	3.96E+01	3.10E+02	0	0	0	0	58,840
ROCP (1 and 2)	0	1.02E+02	2.85E+01	2.24E+02	0	0	0	0	23,880
RDA2 - Wet Residue - North	0	9.74E+01	3.37E+01	1.70E+01	1.08E+01	1.93E+00	1.16E+00	0	10,070
RDA2 - Liquor - South	0	2.96E+03	2.22E+03	3.31E+01	3.75E+02	1.27E+01	4.07E+01	0	298,700
Super Thickener	2.03E-03	1.14E+03	8.33E+02	1.14E+01	1.12E+02	1.61E+01	6.61E+01	1.04E+01	40,400
Cooling Pond	4.45E-03	6.54E+03	4.91E+03	3.96E+01	9.75E+02	1.04E+02	1.48E+02	3.46E+01	666,500
Oxalate Pond	00	1.50E+01	4.20E+00	3.31E+01	0	0	0	0	703
ROWS	0	2.66E+02	7.41E+01	5.83E+02	0	0	0	0	12,100
Sand Cannon	0	4.01E+01	1.39E+01	7.01E+00	4.45E+00	7.97E-01	4.78E-01	0	4,710
Sand Lake	0	1.46E+03	1.08E+03	2.29E+01	1.84E+02	6.92E+00	2.01E+01	0	152,100
Total	6.48E-03	1.31E+04	9.62E+03	1.52E+03	1.68E+03	1.55E+02	2.95E+02	4.50E+01	1,306,000
Refinery Total	3.60E-01	3.56E+04	1.21E+04	1.71E+04	3.52E+03	2.05E+03	3.27E+03	7.15E+02	1,356,300
Percent of Base Case Refinery	1.8	36.7	79.5	8.9	47.7	7.5	9.0	6.3	96.3.

Note: Odour emissions from the refinery are at the average emission rate.

Table 6.6 Estimated Annual VOC Emissions for the Expanded Case

Source	BaP Equivalents	Acetone	Acetaldehyde	Formaldehyde	2-Butanone	Benzene	Toluene	Xylenes	Odour
	(kg/yr)								(ou/s)
Dry Stacked Areas	0	4.86E+02	5.82E+02	3.89E+02	2.86E+01	1.85E+01	2.66E+01	0	63,430
Lower Dam	0	1.41E+02	3.96E+01	3.10E+02	0	0	0	0	58,840
ROCP (1 and 2)	0	1.02E+02	2.85E+01	2.24E+02	0	0	0	0	23,880
Super Thickener	2.03E-03	1.16E+03	8.41E+02	7.34E+01	1.12E+02	1.61E+01	6.61E+01	1.04E+01	52,170
Cooling Pond	6.67E-03	9.82E+03	7.38E+03	5.92E+01	1.46E+03	1.56E+02	2.22E+02	5.20E+01	999,800
Oxalate Pond	0	2.30E+01	6.44E+00	5.06E+01	0	0	0	0	1,080
ROWS	0	5.29E+02	1.48E+02	1.17E+03	0	0	0	0	24,200
Sand Cannon	0	4.01E+01	1.39E+01	7.01E+00	4.45E+00	7.97E-01	4.78E-01	0	4,710
Sand Lake	0	1.48E+03	1.09E+03	2.64E+01	1.87E+02	7.32E+00	2.03E+01	0	156,400
Total	8.69E-03	1.38E+04	1.01E+04	2.30E+03	1.79E+03	1.99E+02	3.35E+02	6.24E+01	1,384,400
Percent of Base Case Refinery	2.4	38.7	83.7	13.5	50.8	9.7	10.2	8.7	102.1

Note: Odour emissions from the refinery are at the average emission rate.

Table 6.7 and **Table 6.8** present the percentage contribution from the individual fugitive sources to the fugitive emissions total. This indicates that the largest source for the majority of the VOCs is the cooling pond. With the expansion and the conversion of RDA2 to "dry" stacking, the percentage contribution from the cooling pond is estimated to be greater, with between 70 and 80% of most substances being emitted from this source.

Table 6.7 Percentage Emissions (%) from the Various Fugitive Sources for the Base Case

Source	BaP Equivalents	Acetone	Acetaldehyde	Formaldehyde	2-Butanone	Benzene	Toluene	Xylenes	Odour
Dry Stacked Areas	0.0	2.4	4.1	15.6	1.2	8.1	6.1	0.0	2.9
Lower Dam	0.0	1.1	0.4	20.4	0.0	0.0	0.0	0.0	4.5
ROCP1	0.0	0.8	0.3	14.8	0.0	0.0	0.0	0.0	1.8
RDA2-2 Wet Residue - North	0.0	0.7	0.4	1.1	0.6	1.2	0.4	0.0	0.8
RDA2-1 Liquor - Southern	0.0	22.7	23.0	2.2	22.3	8.2	13.8	0.0	22.9
Super Thickener	31.3	8.7	8.7	0.8	6.7	10.4	22.4	23.2	3.1
Cooling Pond	**68.7**	**50.0**	**51.0**	2.6	**58.0**	**67.0**	**50.3**	**76.8**	**51.0**
Oxalate Pond	0.0	0.1	0.0	2.2	0.0	0.0	0.0	0.0	0.1
ROWS	0.0	2.0	0.8	**38.4**	0.0	0.0	0.0	0.0	0.9
Sand Cannon Area	0.0	0.3	0.1	0.5	0.3	0.5	0.2	0.0	0.4
Sand Lake	0.0	11.2	11.2	1.5	11.0	4.5	6.8	0.0	11.6

Note: Largest source for each substance bolded

Table 6.8 Percentage Emissions (%) from the Various Fugitive Sources for the Expansion Case

Source	BaP Equivalents	Acetone	Acetaldehyde	Formaldehyde	2-Butanone	Benzene	Toluene	Xylenes	Odour
Dry Stacked Areas	0.0	3.5	5.8	16.9	1.6	9.3	7.9	0.0	4.6
Lower Dam	0.0	1.0	0.4	13.4	0.0	0.0	0.0	0.0	4.2
ROCP1	0.0	0.7	0.3	9.7	0.0	0.0	0.0	0.0	1.7
Super Thickener	23.3	8.4	8.3	3.2	6.3	8.1	19.7	16.7	3.8
Cooling Pond	**76.7**	**71.2**	**72.9**	2.6	**81.5**	**78.5**	**66.1**	**83.3**	**72.2**
Oxalate Pond	0.0	0.2	0.1	2.2	0.0	0.0	0.0	0.0	0.1
ROWS	0.0	3.8	1.5	**50.6**	0.0	0.0	0.0	0.0	1.7
Sand Cannon Area	0.0	0.3	0.1	0.3	0.2	0.4	0.1	0.0	0.3
Sand Lake	0.0	10.7	10.7	1.1	10.4	3.7	6.0	0.0	11.3

Note: Largest source for each substance bolded.

6.5 Comparison to Back Calculated Emissions from Down Wind Sampling

To verify the representativeness of the emission fluxes from the flux chamber, a series of down wind concentration samples and back calculation of the emission fluxes were undertaken using different sampling techniques. The results are summarised in **Table 6.9**. The sampling was undertaken using:

- The portable gas chromatograph mass spectrometer (GCMS) of the Chemistry Centre;
- Pumps to draw ambient air through TO-11A tubes; and
- Field odour surveys to determine the odour concentration by use of the odour intensity relationship for that odour (see Environmental Alliances, 2005).

Table 6.9 Comparison of Back Calculated Emission Fluxes versus Flux Chamber Emissions

Source	Sampling Method	Date	Time	Species	Back Calc ($\mu g/m^2/s$) or ($ou/m^2/s$)	Wind Speed (m/s)	P.G. Class	Wind Speed @ 0.1m (m/s)	Back Calc Cor. to 0.05 m/s @ 0.1m ($\mu g/m^2/s$) or ($ou/m^2/s$)		Flux Chamber Results ($\mu g/m^2/s$) or ($ou/m^2/s$)	Ratio of Back Calc @ 0.05 m/s @ 0.1m to Flux Chamber	
									Exponent 0.5	Exponent 0.78		Exponent 0.5	Exponent 0.78
Cool Pond	Portable GCMS	2/12/04	1315	Acetone	6.58	7.3	D	4.4	0.7	0.20	0.22	3.2	0.91
		2/12/04	1345		8.63	8.6	D	4.4	0.92	0.26	0.22	4.2	1.20
		3/12/04	0930		1.46	1.6	B	0.9	0.34	0.15	0.22	1.5	0.68
Cool Pond	Portable GCMS	2/12/04	11315	2-Butanone	0.604	7.3	D	4.4	0.06	0.02	0.032	2.0	0.58
		2/12/04	1345		1.43	8.6	D	4.4	0.15	0.04	0.032	4.8	1.36
		3/12/04	0930		0.302	1.6	B	0.9	0.07	0.03	0.032	3.0	0.97
Cool P North	TO-11A	4/01/2005	1100-1200	Acetone	2.44	4.1	B	2.97	0.32	0.10	0.22	1.4	0.46
Cool P South	TO-11A	27/02/05	1939-2015	Acetone	0.696	2.7	E-F	0.34	0.267	0.156	0.22	1.2	0.71
							C	1.96	0.389	0.139	0.22	1.8	0.63
Cool P North	TO-11A	27/02/05	2026-2050	Acetone	0.663	2.6	E-F	0.32	0.261	0.155	0.22	1.2	0.70
							C	1.85	0.381	0.139	0.22	1.7	0.63
											Mean, (SD)	2.36, (1.25)	0.80, (0.28)
Cool Pond	Field Odour Survey- Onsite	27/02/05	2003, 2035	Odour	0.3	2.5	E-F	0.31	0.120	0.071	0.71	0.17	0.10
							C	1.81	0.174	0.064	0.71	0.25	0.09
Cool Pond	Field Odour Survey - Offsite	27/02/05	1830-1855	Odour	0.45	5.2	E-D	1.64	0.078	0.030	0.71	0.11	0.04
											Mean, (SD)	0.18, (0.07)	0.077, (0.032)
RDAs	TO-11A	4/01/05	1100-1200	Acetone	0.428	4.1	B	3.0	0.056	0.018	0.0092	6.1	1.93
			1400-1500		0.192	5.9	C	4.3	0.021	0.006	0.0092	2.3	0.65
			2300-2400		0.176	5.9	D	4.0	0.023	0.007	0.0092	2.5	0.80
											Mean, (SD)	3.32, (1.85)	1.1, (0.70)
RDAs	Field Odour Survey - Onsite	27/02/05		Odour	0.024	2.6	E-F	0.33	0.0094	0.006	0.017 composite (17^oC)	0.56	0.33
RDAs	Field Odour Survey - Onsite	26-27/02/05	NA	Odour	<0.023	3.0	E	0.6	<0.007	<0.003	0.021 composite (20^oC)	<0.32	<0.16
											Mean, (SD)	0.44, (0.17)	0.24, (0.12)

The back calculated flux rates were based on the following:

- The back calculations were all performed using the model Windtrax, either by Geordie Galvin of the Queensland DPI or David Pitt of Environmental Alliances;
- Cooling pond emissions that were determined from samples immediately down wind of the pond were estimated for two stability classes. One, assuming the stability class was as determined for over land, which for the night, clear sky conditions resulted in Pasquill Gifford classes of E or F. The other, assuming C Class stability as the air over the pond is unstable due to the heated water as shown in the CFD modelling (PAE, 2005). In the Windtrax emission estimates, the use of the C class stability resulted in a greater flux rate as the plume was predicted to have dispersed more. Emissions for C class conditions were found to be 3.5 times greater than that if F class conditions were assumed (Environmental Alliances, 2005). However, though the flux rate increased, the wind speed just above the surface also increases for the more unstable conditions resulting in an overall normalised emission flux which was only slightly above that found using the land based stability estimate;
- Odour estimates from the cooling pond were estimated from only the samples collected at the highest wind speeds on and offsite, as it is considered that the plume from the cooling pond is rising and is not fully captured by sampling down wind for lower wind speeds (see PAE, 2005). As the plume rise will be less at the higher wind speeds, the average of the onsite high wind speed and off site high wind speeds was used;
- Emissions of odour from the dry stacked areas were determined from one representative value from the line of best fit in Figure 15 of Environmental Alliances, (2005) to summarise their 9 data points. This measurement is an upper limit as no odours were detected, with the emission derived from half the detection limit of 0.6 ou for a 10 minute sample (Environmental Alliances, 2005).

For comparison to the flux chamber results, the back-calculated flux rates were reduced or normalised to a wind speed of 0.05m/s, measured at 0.1m, which is considered by some (eg Pollock, 2005) to be the approximate wind speed above the surface in the flux chamber. Normalised emission fluxes at 0.05 m/s were estimated based on **Equation 6.2** and a wind exponent of 0.5 (as used throughout Australia for odour studies) and 0.78 (used in chemical engineering).

Flux rates for the flux chamber were obtained from **Table 6.1** with the residue surfaces emissions given as the weighted value of three typical surfaces (wet residue, dry residue 1, dry residue 2) based on the time of year and temperature according to **Table 6.2**and **Equations 6-3** to **6-6**.

The summarised results in **Table 6.9** indicate the following:

- The ratio of the back calculated fluxes (normalised to a wind speed at 0.05 m/s at 0.1m using an exponent of 0.5) to the flux chamber tests using the TO-11 or GCMS measurements are 2.36 for the cooling pond and 3.32 for the RDA areas. These ratios

above are in general agreement with that recorded by others, when the results are normalised to 0.05 m/s. For example, the ratios of Jiang and Kaye (1996) are 0.42 to 2.51, CH2M Beca (2000) are 5.3 and Lakmaker et al (2003) are 4.1, though these rations are based on comparisons between wind tunnels and flux chambers. As Galvin (2004) found a near one to one correspondence between flux rates estimated by a flux chamber and back calculation methods, this relationship should be the same as between back calculated and flux chamber derived emission flux;

- Using a wind exponent of 0.78 to normalise the back calculated data to 0.05 m/s, the ratios are 0.8 and 1.1;
- Comparison of the back calculated odour flux rates from the field odour survey to the flux chamber data results in ratios of 0.18 to 0.44 when using the wind speed dependency of 0.5 and ratios of 0.077 and 0.24 when using an exponent of 0.78. These ratios are 4.6 to 13 times lower than that derived from comparison based on the TO-11 and GCMS results. This difference may be due to the different "analytical" methodologies used. The flux chamber odour results are obtained from a laboratory analysis using dynamic olfactometry, whilst the field odour survey estimates the odour intensity and then converts this to odour concentrations by an odour intensity/concentration relationship. Possible reasons for the difference between the ratios of VOCs and odours determined from the methods may be:
    - The assumed odour intensity/concentration relationship, based on slurry tank emissions may understate the actual odour intensity/concentration relationship; and
    - The odour intensity method under-predicts odour concentrations at locations where odour intensities are strong such as immediately down wind of the cooling pond (Environmental Alliances, 2005). This occurs as it is difficult to quantify the odour intensities for the strong odours due to nasal fatigue. As the odour intensities were less for the samples taken offsite and down wind of the RDAs, these estimated odour concentrations should be reliable, assuming the odour intensity/concentration is correct. For the down wind samples at stronger winds, the plume rise will be less and for the RDAs samples, will not be an issue. Therefore, these low ratios support the view that the difference is due to the concentration/intensity relationship or another difference between odour levels determined by dynamic olfactometry and odour surveys. It is noted that Galvin et al (2004) compared wind tunnel and down wind measurements immediately down wind of a pond using sampler bags and later dynamic olfactometry and found good correspondence between those two methods;

The above results therefore (neglecting the potential issues with the odour sampling), indicate that for the species sampled there is a reasonable agreement with results from other studies and supports the view that flux chamber results may measure fluxes lower by a factor of 2 to 5 times than that from actual emissions based on wind tunnels (and back calculation as found by Galvin et al, 2004) when normalised to a wind speed of 0.05 m/s using a wind speed dependence of 0.5. Using a wind speed dependence to the power of 0.78 however, the

emissions are very similar with the flux chamber results being generally slightly higher. These results support the view that emissions from liquid surfaces are wind speed dependent as varying the emissions using a wind speed dependence 0.5 or 0.78 provides better agreement with the back calculated data. More direct support for the wind speed dependence of the emissions from the cooling pond is found in the back calculated data reported in Environmental Alliances (2005) as presented in **Figure 6.1**.

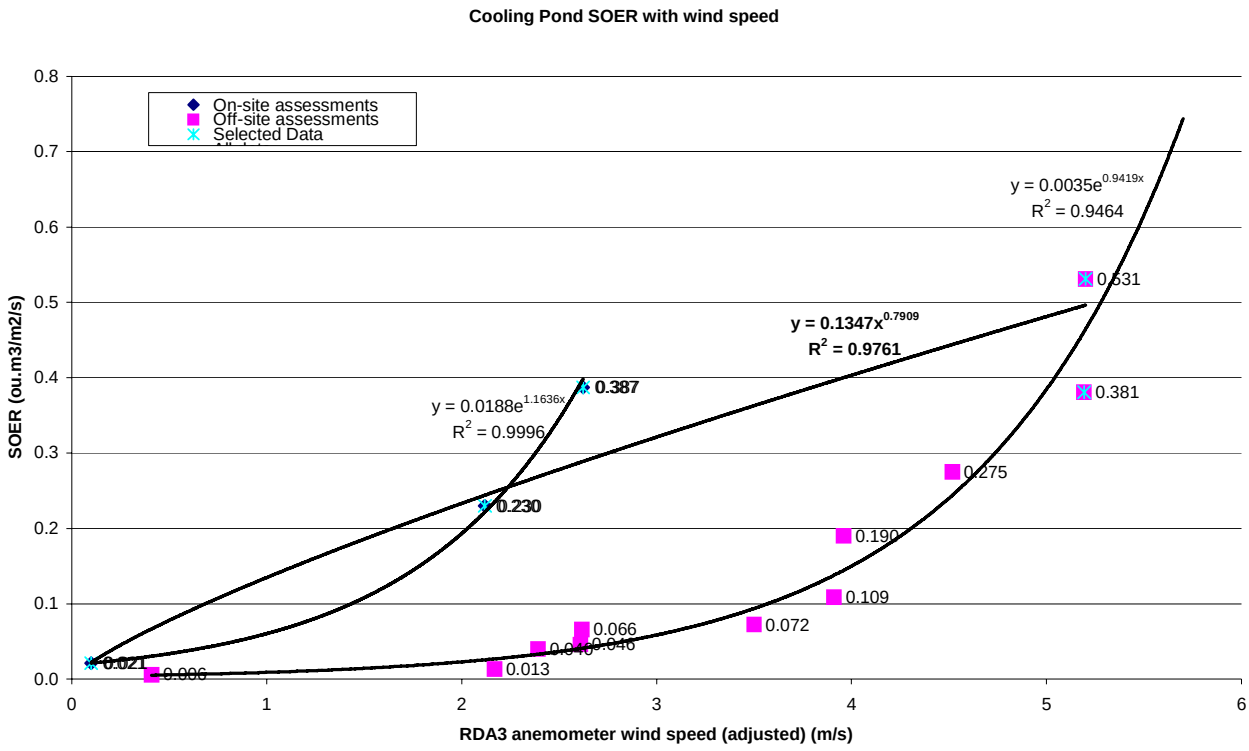


Figure 6.1 Cooling Pond Odour Emission Rates as a function of wind speed for night time conditions (from Environmental Alliances, 2005)

Figure 6.1 shows a very strong wind speed dependence on the flux rates from the off site measurements as indicated by the exponential curve. This strong wind speed dependence is considered to be due to both the decrease in flux rates (emissions) at low wind speeds, but also to the cooling pond plume lifting above the ground at the lower wind speeds. This was observed in the field at night under light winds, where the wind on the down wind side of the pond reversed and was also blowing into the pond, and where the air above the pond (as indicated by the steamy mist) was seen to be generally rising. This description is also supported by the CFD modeling for the along wind flows where the plume lifts off the pond (see PAE, 2005).

Environmental Alliances (2005) also suggest that actual emissions (without plume effects) may be better fitted by the wind speed to the power 0.78 curve, which was derived using the measurements which were at the time thought to be least influenced by plume rise influences. These were the highest measurements at the edge of the pond and the highest wind speed measurements off site, where the plume rise effect is much smaller as demonstrated in the

CFD modeling. The resultant best fit curve has a wind speed dependence to the power of 0.79 which is very close to that proposed by Sutton (1953) and used in chemical engineering. It is noted that in comparison to the flux chamber method, the points on this curve are a factor of 5 to 10 times lower than that derived from the flux chamber when they are converted to a wind speed of 0.05 m/s (the data on the exponential curve are even a greater factor lower). This much lower emission rates may be due to the factors discussed previously, including the problem with under estimating concentrations for a location with high odour intensity.

In the finalization of this report, a reviewer recommended that the TO-11a data also should be plotted as a function of wind speed. This is presented in **Appendix E** and is very supportive of a high wind speed dependence of the acetone and other volatile emissions from the cooling pond.

For the RDA data, no wind speed relationship can be proved or disproved as the offsite measurements could not detect odours from the RDAs and there was only one on site measurement. For the onsite measurements of acetone, only 3 data points exist, with the measurement suggesting increased emissions for the lowest wind speed, contrary to expectations. This is considered to occur as the emissions of acetone, as found from the flux chamber are very dependent on the state of the drying surface, varying by factor of 23 (2.52 $\mu g/m^2/min$ for wet residue to 0.11 $\mu g/m^2/min$ for dry residue 1, **Table 6.1**). Therefore, it is expected that any real relationship for acetone from down wind sampling will be hard to determine. As such, with no data to suggest otherwise, the recommendations of Eklund (1992) for a soil surface where used, with no wind speed dependence specified. It is suggested that further work is required to confirm the correct form of this relationship. In any case the validation presented in **Section 7.2** indicates that the residue drying areas are a minor source of the overall residue area emissions and that the residue area emissions already tend to over-predict concentrations offsite.

7 Model Validation

7.1 Total Suspended Particulate

A comparison of model predicted concentrations, against observations (minus background concentrations) is provided in **Table 7.1** and in **Figure 7.1** to **Figure 7.4**. These are provided using the winds predicted using TAPM. A comparison of the predicted and observed concentrations using observed winds from RDA3 and Bancell road is provided in **Appendix D**.

Table 7.1 Monitored and Predicted TSP Concentrations (µg/m^3) for 2003/2004

	RSE (1)	RS	RSW	RW	RNW	RE	RNE (1)	BRW (1)	RDA7 (1))
Monitored									
Mean	1.1	4.4	7.2	13.1	8.3	10.1	41.0	15.0	7.1
90th Percentile	3	8	12	34	17	19	86	29	17
95th Percentile	6	15	21	49	21	23	106	31	26
98th Percentile	15	37	76	57	26	27	152	36	34
99th Percentile	17	49	91	80	29	32	185	39	35
2nd Highest	18.4	116	211	87.6	32.5	38.0	184	38.2	35.1
Maximum	22	120	238	142	34	58	246	44	40
Modelled (TAPM Winds)									
Mean	2.0	4.5	9.9	7.1	1.5	3.7	24.0	0.5	7.4
90th Percentile	6	13	25	20	3	10	61	2	24
95th Percentile	7	17	56	53	6	15	90	2	35
98th Percentile	13	23	79	75	9	20	150	5	62
99th Percentile	12	29	113	106	15	29	177	6	90
2nd Highest	16.7	48.2	134	122	51.1	43.5	178	5.6	95.0
Maximum	32	60	149	140	124	50	205	6	128

Note: Monitoring and modelled results from RSE from 1/4/03 to 10/12/03, RDA7 from 1/12/03, RNE from 17/12/03 and BRW from 18/12/03

In comparing the model to monitored data it is important to note as discussed in **Section 3**, that a number of monitors have local sources nearby, such that the model should tend to under predict the concentrations at these locations. Some editing of the observed data has been undertaken as discussed in **Section 3** for the top 5 to 10 events. As such, model comparison will be most applicable for the highest 5 to 10 events (maximum, 2nd highest and 99th percentile), but for statistics such as the 95th, 90th percentile and the mean, some of the monitors will overstate the true contribution from the residue area. This is seen in particular for:

- BRW monitor. This is seen in that the BRW monitors mean, 90th and 95th percentile are higher than any of the monitors at the southern edge of the residue area, even though they are much closer to the residue area. This indicates that there is a reasonably frequent local source near the BRW monitor which typically adds 10 to 30 µg/m^3 to the 24-hour BRW concentrations;

- NW monitor. The mean for the period with overlapping data (17 December 2003 onwards) is higher than for the closer RDA7 site. Also, this is indicated in the number of high dust events in the raw data which were ascribed to other sources (see **Table 3.2**); and
- West monitor. As indicated by the number of local events that occurred under south westerlies (see **Table 3.2**). As such, it is considered that the mean contribution from Alcoa may be overstated.

Noting the contribution of other sources in the observations, **Table 7.1** and **Figure 7.1** to **Figure 7.7** indicate that the model using the TAPM winds:

- Predicts good agreement at the NE, E and SE monitors and generally good agreement at the west monitor, though over-predicting the 2nd highest to 98th percentile (approximately 7th highest). Note, that the high concentrations near the NE monitor are primarily due to earthworks and wind erosion associated from the borrow pit that was used with the construction of RDA7. Also, note that observations with an asterix are from part of the 12 months and are not directly comparable to the model predictions which are for the full period;
- Over-predicts at the RDA7 monitor for all statistics except the mean;
- Over-predicts the top two events at the NW monitors, whilst under-predicting the other statistics. The over prediction of the top events at the RDA7 and NW monitor indicates that the model is over-predicting the wind speeds and dust events for east/south east to south easterly winds;
- Slight under-prediction at the S and SW monitors for the top statistics, but good, if not slight over-prediction at the lower statistics and average concentrations; and
- For the BRW monitor, the model under-predicts by a large margin all concentrations. This is considered predominantly due to local sources as described previously, but will also reflect to some degree that TAPM under-predicted the frequency of northerly winds.

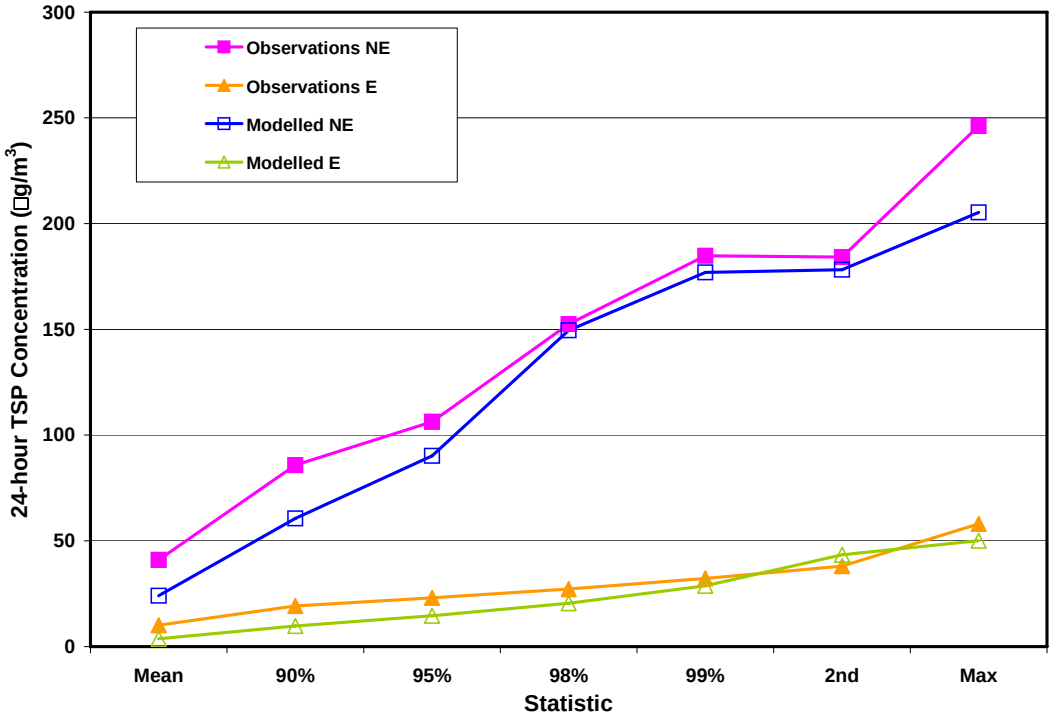


Figure 7.1 Monitored and Predicted TSP Concentrations at the NE and E Monitors

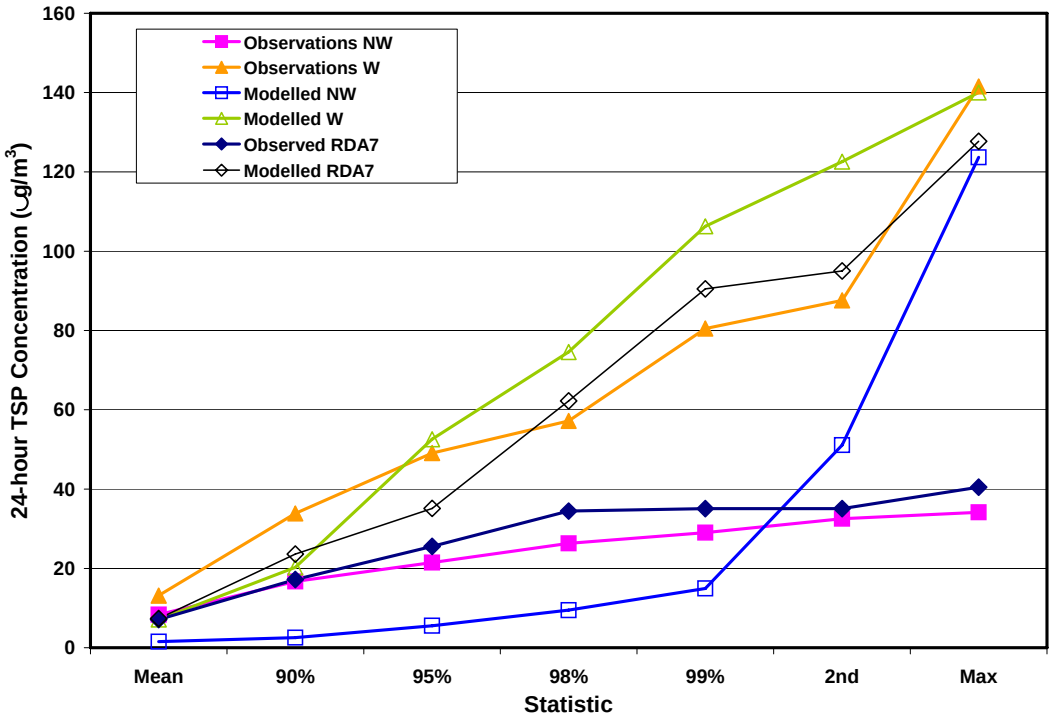


Figure 7.2 Monitored and Predicted TSP Concentrations at the W, NW and RDA7 Monitor

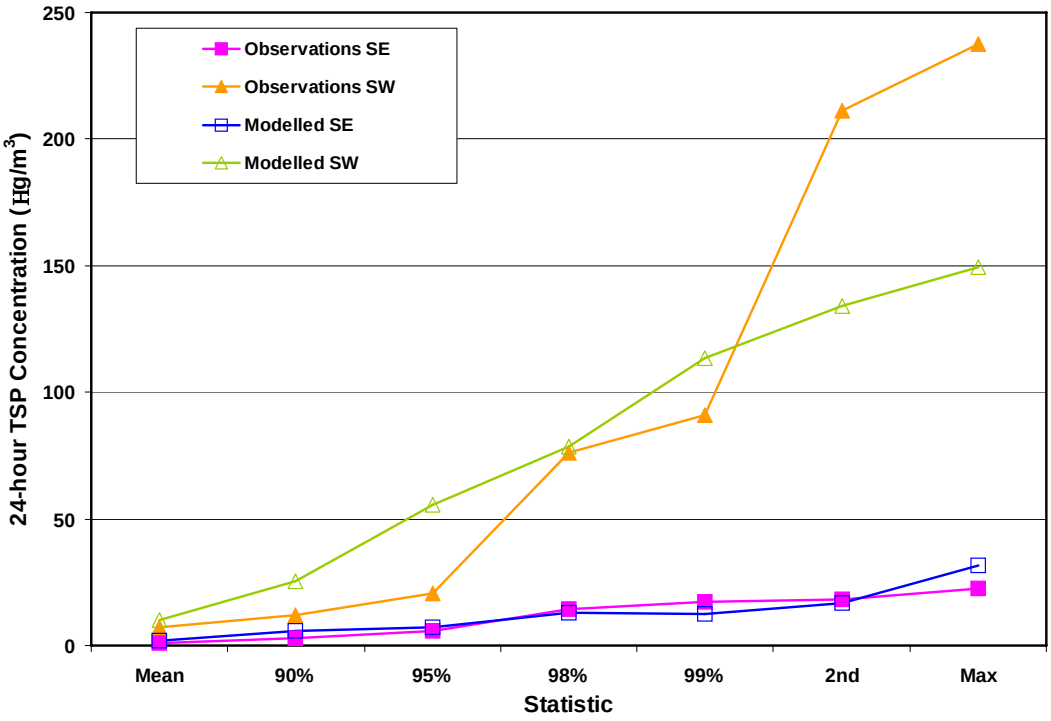


Figure 7.3 Monitored and Predicted TSP Concentrations at SE and SW Monitors

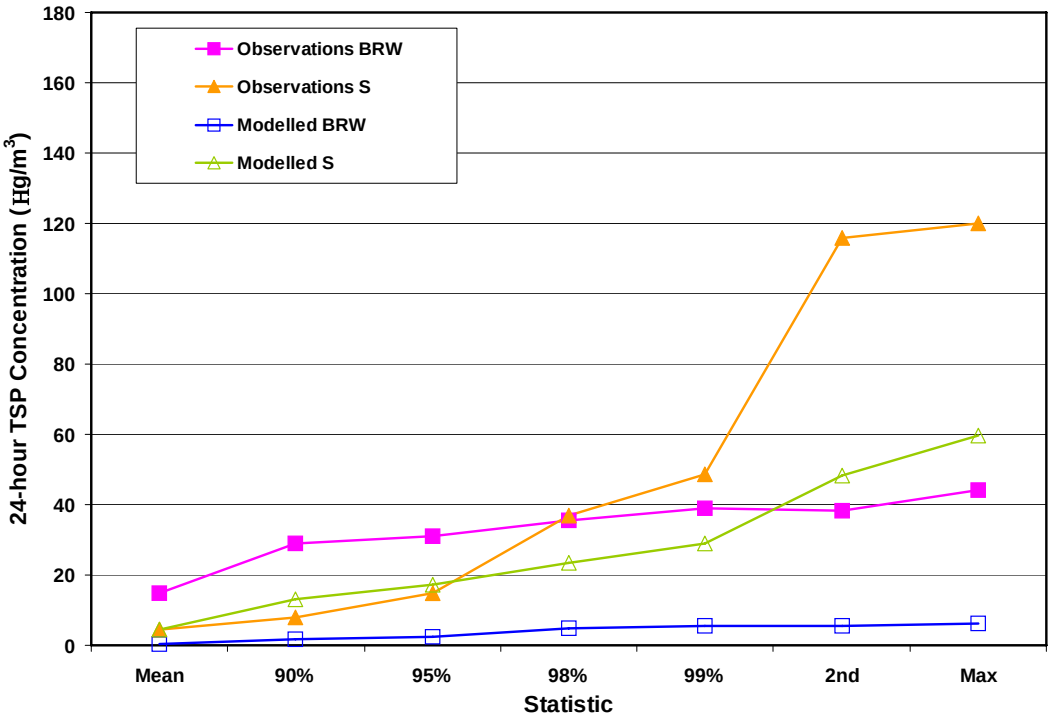


Figure 7.4 Monitored and Predicted TSP Concentrations at the BRW and South Monitors

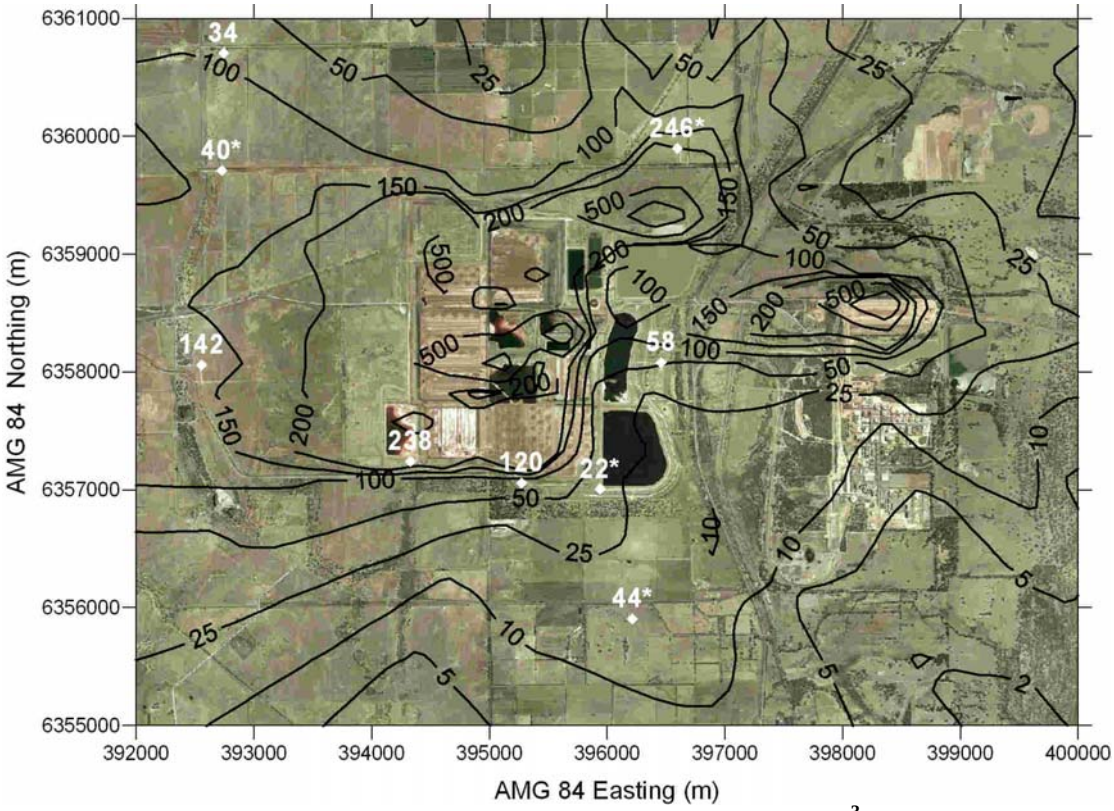


Figure 7.5 Predicted Maximum 24-hour TSP Concentrations (µg/m^3)

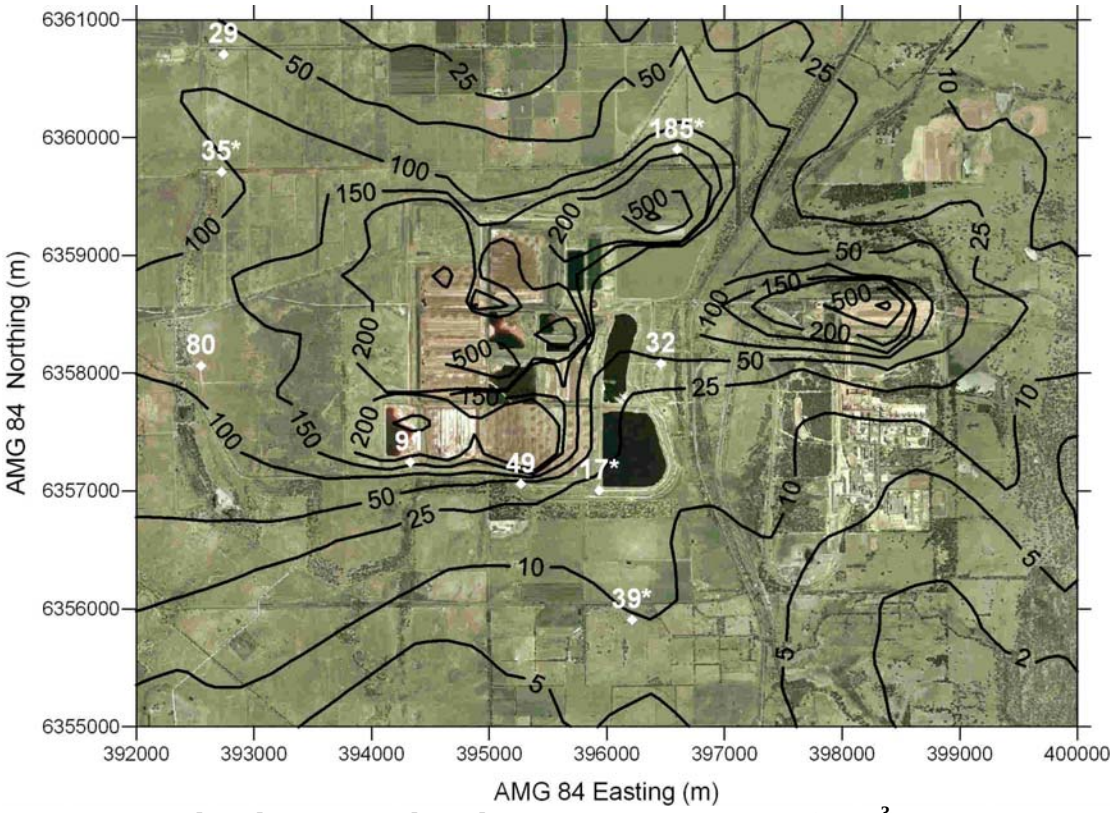


Figure 7.6 Predicted 99 percentile 24-hour TSP Concentrations (µg/m^3)

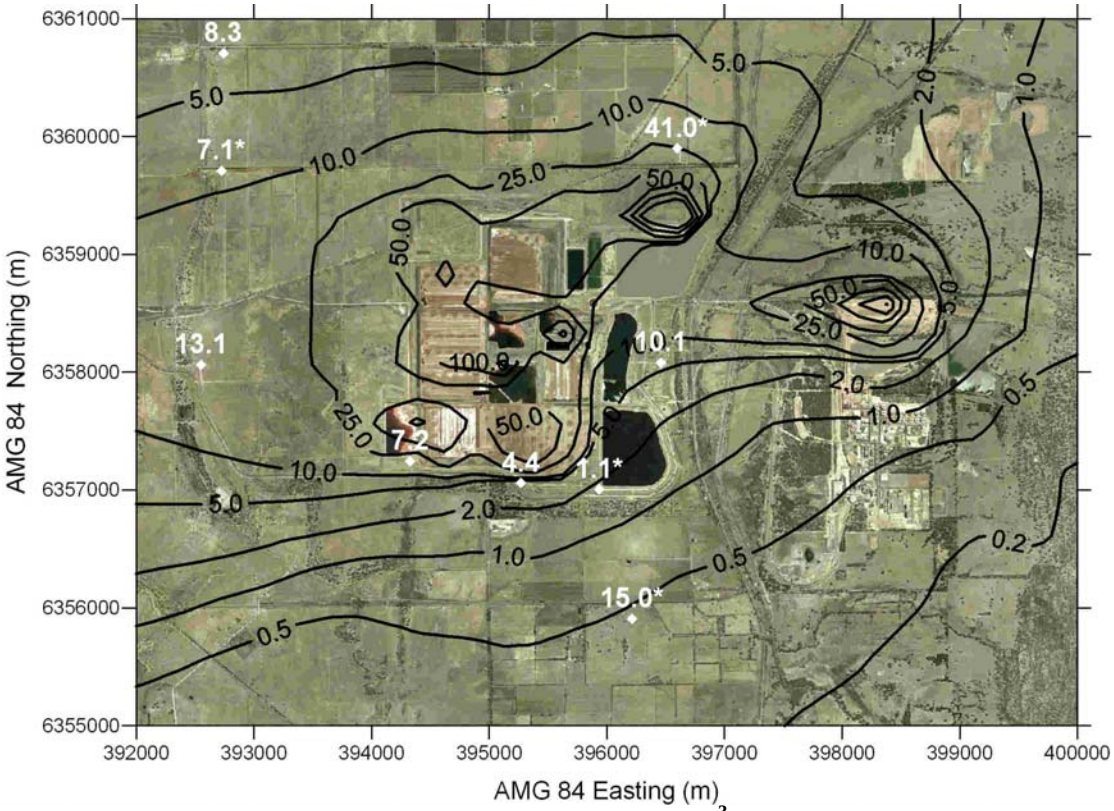


Figure 7.7 Predicted Average TSP Concentrations (µg/m^3)for 17 December 2003 to 31 March 2004

7.2 Gaseous Emissions

Data for the validation of the VOCs emitted from the fugitive sources comprise the ambient VOC sampling conducted by Alcoa in 2004 (see **Section 3**) and field odour surveys conducted immediately down wind of the residue area in December 2004 and February 2005 (Environmental Alliances, 2005).

7.2.1 VOC Validation

As a check on the model predictions, the average concentrations monitored over the 6 week period by the Radiello samplers in 2004 was compared against the modelled concentrations for the same 6 week period in the modelled year, 2003. Note, the Radiello samplers recorded the lower concentrations of the two samplers used for the ambient monitoring (see **Section 3.2**).

These results of the comparison are plotted in **Figure 7.8** and **Figure 7.9**. Noting that the use of a different year will introduce some differences between the two results, **Figure 7.8** and **Figure 7.9** still clearly indicate that the formaldehyde and acetaldehyde concentrations from the modelled fugitive sources are well below that measured. The only areas where the model predictions approach the measured concentrations are near the residue area for acetaldehyde. Here the concentrations at the site to the east of the residue area are slightly higher than the observed concentration. That the pattern of the observed concentrations do not show any

systematic increase towards the refinery or residue area indicate that the majority of the formaldehyde and acetaldehyde monitored are due to other sources. If the modelled concentrations are representative, this would indicate that the residue area except for close in to the refinery contributes only a small fraction to the overall concentrations. It is noted that if the higher TO11a measurements were used for the comparison, the model results would be even a smaller fraction of the observed concentrations.

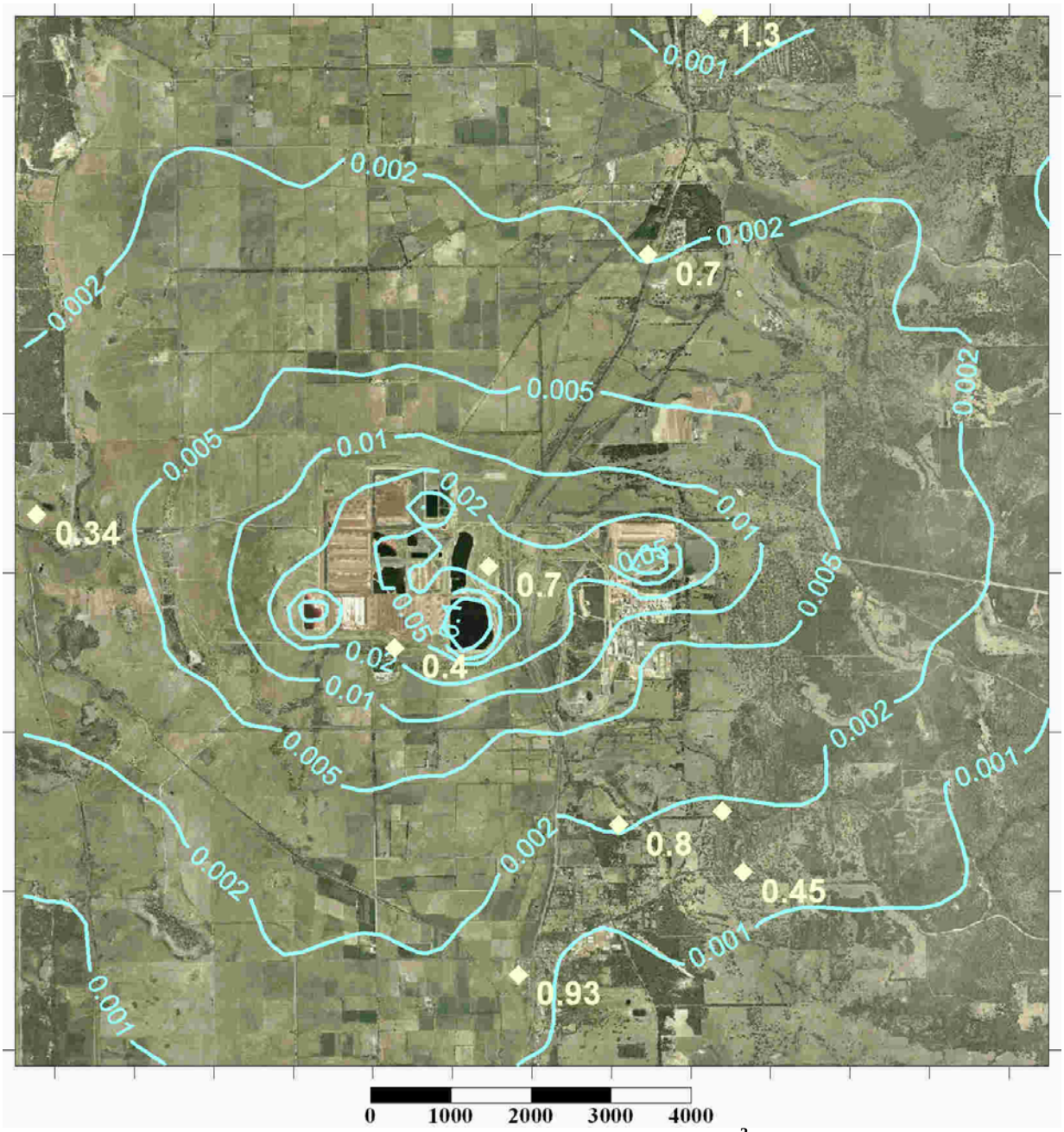


Figure 7.8 Predicted Average Formaldehyde Concentrations ((µg/m^3) for 23 August 2003 to 1 October 2004 with average Radiello monitored data for the period 23 August 2004 to 1 October 2004

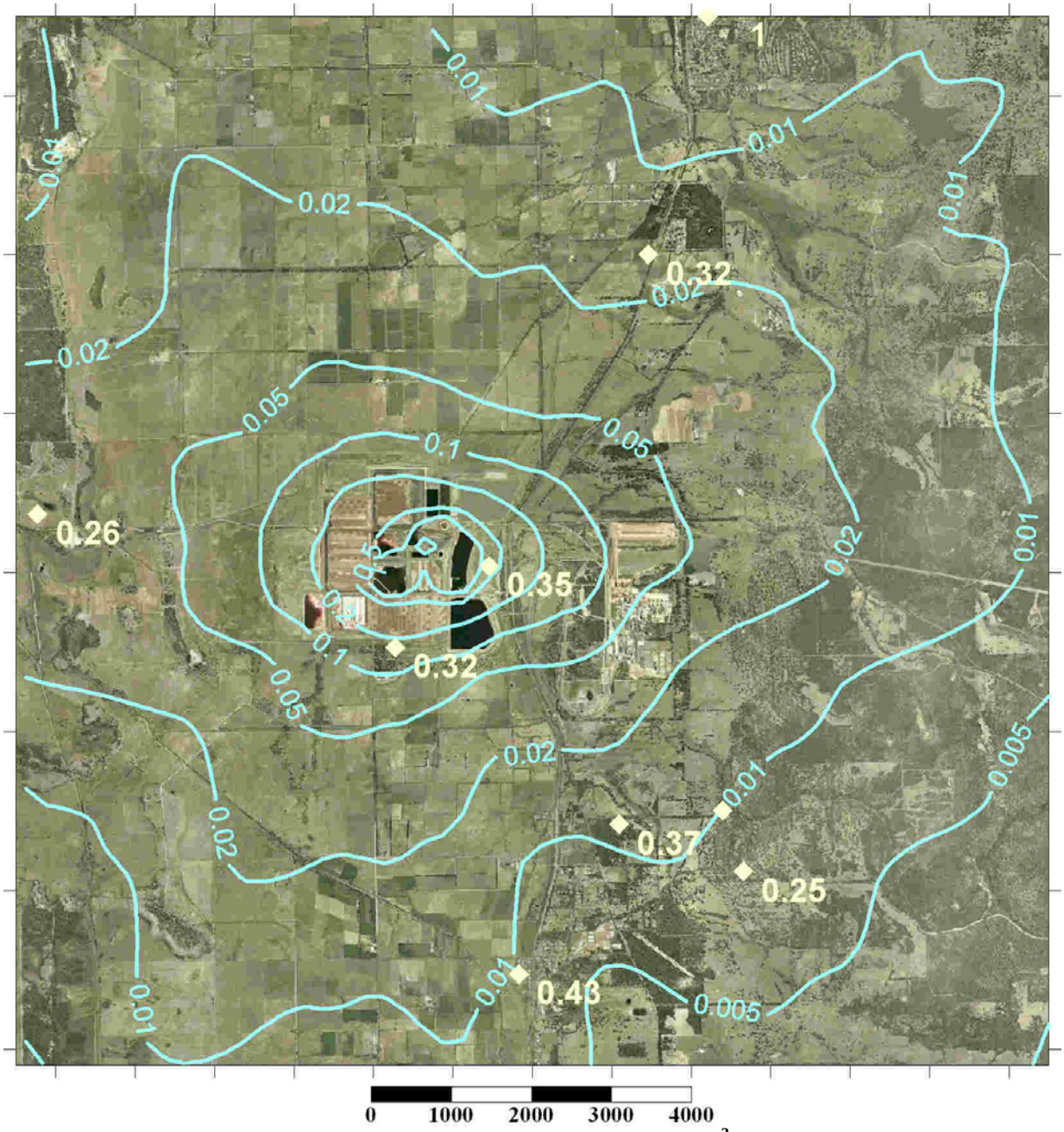


Figure 7.9 Predicted Average Acetaldehyde Concentrations (µg/m^3) for 23 August 2003 to 1 October 2004 with average Radiello monitored data for the period 23 August 2004 to 1 October 2004

7.2.2 Comparison of Predicted and Observed Odours

Odour concentrations around the Wagerup residue area were conducted on 6 days/nights in 2004 and 2005 as reported in Environmental Alliances (2005). The methodology for the field survey is similar to that used for previous field odour studies at the Wagerup refinery (Environmental Alliances, 2001 and Environmental Alliances, 2003), based on "VDI 3940.1 – Determination of Odourants in Ambient Air by Field Inspections" (VDI 1993).

The field surveys methodology can be summarised as:

- An olfactory test prior to the surveys for the assessors. Note all of the assessors had previous experience with alumina refinery odours;
- Assessors were sited downwind of the residue area as far as could be estimated at the time and within safety-related constraints, with a GPS used to determine the assessment locations. For the residue area the winds targeted were southerly to westerly to avoid the possibility of overlapping plumes from the refinery area;
- At each location the assessors recorded odour intensities every 10 seconds for each 10 minute assessment period. Recording odour intensities documents the fluctuations embodied in an odour "event", as well as allowing concentrations to be calculated using the relationship between intensity and concentration;
- Odour concentrations were later calculated for each intensity observed over the 10 minute assessment period, using the Weber-Fechner relationship for the odour. As no residue area odour intensity relationships have been derived, the intensity versus concentration relationship for odours emitted from the slurry vents at Alcoa's Kwinana refinery were used as this is considered to be the most applicable. For this source an odour intensity of 3 corresponds to 4.8 ou; and
- The 10-minute average odour concentration for the assessment period is then estimated as the arithmetic mean of the 60 calculated concentrations. In cases where odours from other sources are detected they can be omitted from the assessment by noting in the odour survey the probable source of the odour.

For comparison to the model predicted concentrations, 1-hour odour levels from the 10 minute surveys were constructed. For most sites, generally 2 to 4 samples were available in the hour, though this could range from only 1 sample to up to 6 samples. The data for each hour was then compared to the model predicted hourly average. Predictions were made for the days 15, 16 and 17 December 2004 and for the 26 February 2005. The 20 and 27 February were omitted due to time constraints and as 20 February only involved one assessor and the 27 February 2005 monitoring, conducted at night with very light winds, essentially detected no odours offsite.

Examples of hourly plume footprint and the corresponding hourly average odour observations are presented in **Figure 7.10** and **Figure 7.11**. **Figure 7.10** presents the observations and modelled results for an afternoon with moderate westerly winds of 4.3 m/s. This shows the main odour sources at the time being the southern area of RDA2, the sand lake and the cooling pond. Low odour levels are predicted from most other areas including the dry stacked areas (RDA 1, 3, 4, 5, 6 and 7, ROCP1 and 2, the ROWS pond, with the super thickener odour plume not being discernable. **Figure 7.11** presents the results for a night time, light wind speed (1.6 m/s), stable air flow. This indicates that the predicted concentrations are higher than in the day time case, though the observed concentrations are lower than in the day. That the model predictions are closer to the observations during the day and over-predicts at night is also shown in **Figure 7.12** and in **Table 7.2**.

Figure 7.10 Predicted and Observed 1-hour Odour Levels (ou) for the hour ending 1600 WST on 15 December 2004

Figure 7.11 Predicted and Observed 1-hour Odour Levels (ou) for the hour ending 2200 WST on 26 February 2005

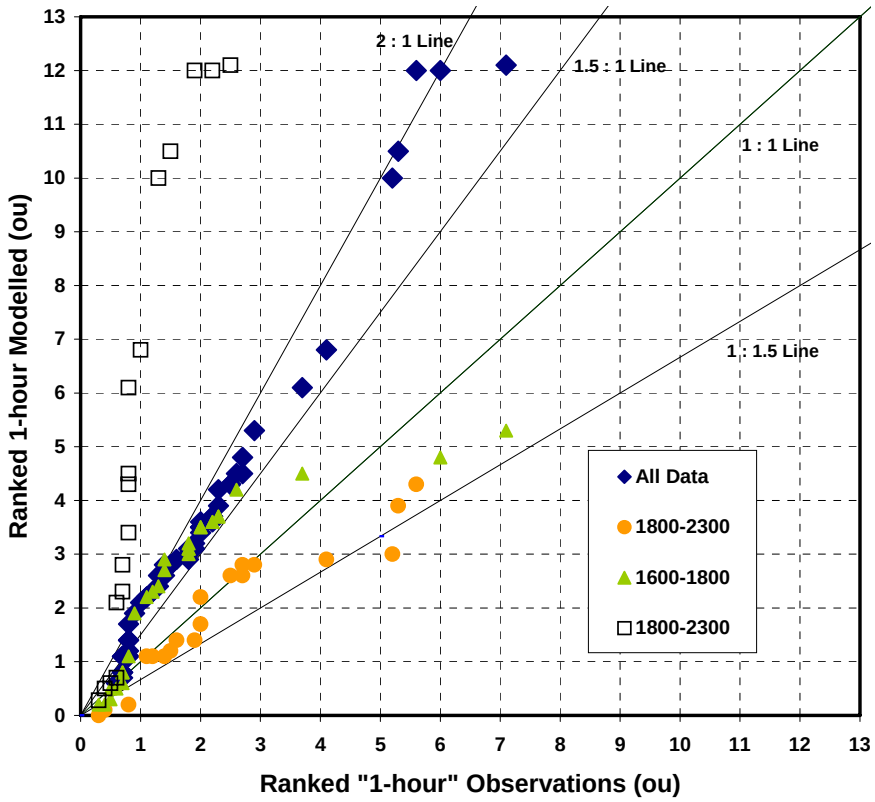


Figure 7.12 Predicted and Observed 1-hour Odour Levels (ou)

Table 7.2 Ratio of Selected Statistics by Time of Day for the Modelled and Observed Odour Levels

Statistic	All Data	1400-1600	1600-1800	1800-2300
Maximum 1-hour	1.70 (0.99)	0.77 (0.73)	0.75 (0.73)	4.84 (2.80)
RHC	1.96 (1.07)	0.59 (0.57)	0.77 (0.76)	4.83 (2.63)
2nd Highest	2.00 (1.15)	0.74 (0.64)	0.80 (0.75)	5.45 (3.14)
Average of top 5 1-hour events	1.94 (1.09)	0.73 (0.68)	1.04 (0.97)	6.02 (3.39)
Average all Data	1.81 (1.31)	0.81 (0.76)	1.39 (1.26)	3.82 (2.51)
Number of Data Pairs	65	19	29	17

Notes:

1) Values without brackets are as used in the modelling for the HRA. The figures in brackets are from predictions taking into account plume rise and using a revised wind speed dependency in the emissions.
2) RHC is the robust highest concentration (see CSIRO, 2005b), here evaluated with N =5 as there is only a small sample size.

Figure 7.12 and **Table 7.2** indicate that the model tends to under-predict the highest concentrations during the day, but significantly over-predicts the concentrations at night. Reasons for this may be;

- The model neglects plume rise from the heated liquid surfaces;
- The model neglects the increase in initial dispersion from the warm surfaces; and
- The emissions at the low wind speed, night time conditions are less than modelled.

7.3 Improved Dispersion Estimates for Odours and VOCs

During the study it became apparent that dispersion from the warm liquid surfaces was being affected by processes not included in the model, which lowered the concentrations at night. This was obvious from the comparison of the results from the first round of field odour surveys conducted in December 2004 to that predicted from the modelling. To investigate this, Environmental Alliances were contracted to undertake further odour surveys targeting night time conditions to provide additional data for model validation. Additionally, Pacific Air and Environment were contracted to undertake computational fluid dynamic (CFD) modelling of the cooling pond, RDA2 liquor-lake and the super-thickener, to confirm and quantify whether plume lift off from these surface was occurring. The data from these studies however was not available until the end of this project and could not be utilised for the prediction of VOC concentrations for the HRA.

The results from the CFD modelling by PAE (2005) indicate that:

- The vapour plume from the cooling pond is predicted to lift off the surface for winds parallel to the main pond axis, with this being most pronounced for neutral conditions and lighter wind speeds. For stable atmospheric conditions, the plume lift off was still significant, at typically 25 to 40m;
- For winds across the main axis of the cooling pond and for the RDA2 surface, no plume lift off was predicted. PAE ascribe this to the dimensions of the ponds, with elongated ponds favouring plume lift off, whilst large square ponds and air flow across a long pond being not conducive to plume lift off;
- For the super-thickener plume rise was predicted to occur for the one model run conducted; and
- For all surfaces at lower wind speeds, the dispersion of the plumes was increased by the increased turbulence over the warm water bodies and also by plume lift-off, if it occurred.

Further to the affects of the warm surfaces, the data collected by Environmental Alliances (2005) suggest that emissions increase with the power of around 0.78, as found by Sutton (1953) and not to the power of 0.5 as used generally for odour assessments in Australia and as used in the VOC modelling for the HRA. As such, emissions will increase/decrease faster with wind speed than was modelled. As well as supporting the CFD work in plume lift off, the field odour survey data also suggest that there are negligible odour emissions at low wind speeds. As the wind speed in the free atmosphere to which the flux chamber relates is not known (some unverified observations reported in **Section 6.3** suggest that it is approximately equivalent to 0.05 m/s at 0.1m), it is considered a higher wind speed than the 0.05 m/s at 0.1m assumed in the VOC modelling may be more appropriate. Therefore, as an attempt to improve the model predictions of odour, modelling was conducted with the following:

- All emissions were specified with a wind speed dependence to the power of 0.78, with the flux chamber emissions taken to be representative of emissions in the free

atmosphere at a wind speed of 0.25 m/s at 0.1m. This results in approximately equivalent emissions to that used previously at a wind speed of 6 m/s at 10m, but reduces the emissions at lower wind speeds;

- Use of an averaging time adjustment factor within Calpuff with the variable "tpg" set to 10 minutes instead of 60 minutes. This will increase the horizontal dispersion of the plumes in line with generally accepted practice within Australia and as implemented in Ausplume; and
- The cooling pond and super thickener plumes were both modelled to lift off the surface. In the modelling these have been parameterised by the following equations:

H_{CP} = max (1, 189.1 exp(-0.324 x WS)), A to D Class stability **Equation 7-1**

H_{CP} = max (1, 79 exp(-0.214 x WS)), E Class stability **Equation 7-2**

H_{CP} = max (1, 47.9 exp(-0.150 x WS)), F Class stability **Equation 7-3**

H_{ST} = 16.405 exp(-0.127 x WS)), All stabilities **Equation 7-4**

Where:

H_{CP} and H_{ST} are the final plume heights above the ground for the cooling pond and super thickener respectively. Note, that the top of the super thickener is at 5m such that the plume height reduces to this for a wind speed of 9.4m/s and is half this (2.5m) for wind speeds around 15 m/s. This therefore will approximate plume downwash which may occur for the higher wind speeds; and
WS is the wind speed at 10m.

These equations are based on the data presented in **Figure 7.13** for plume rise for winds along the main axis of the cooling pond and for the super thickener. These indicate that for neutral temperature profiles, that the plume rise exponentially increases with decreasing wind speed. For increasing stability, the data indicate that the plume rise decreases. To parameterise this, the E class and F class stability curves were selected to fit the available data following the same exponential pattern as for the neutral case, with E and F class fitted to the 0.04 and 0.07 ^{o}C/m potential temperature lapse rate data respectively. It is noted for comparison, that Ausplume and Calpuff uses potential temperature lapse rates of 0.02 and 0.035 deg ^{o}C/m for E and F class stability plume rise calculations. The Ausplume/Calpuff defaults are lower than modelled here, as they are approximations for lapse rates over greater heights above the ground than those determined here in the CFD modelling which are for the lowest 50m.

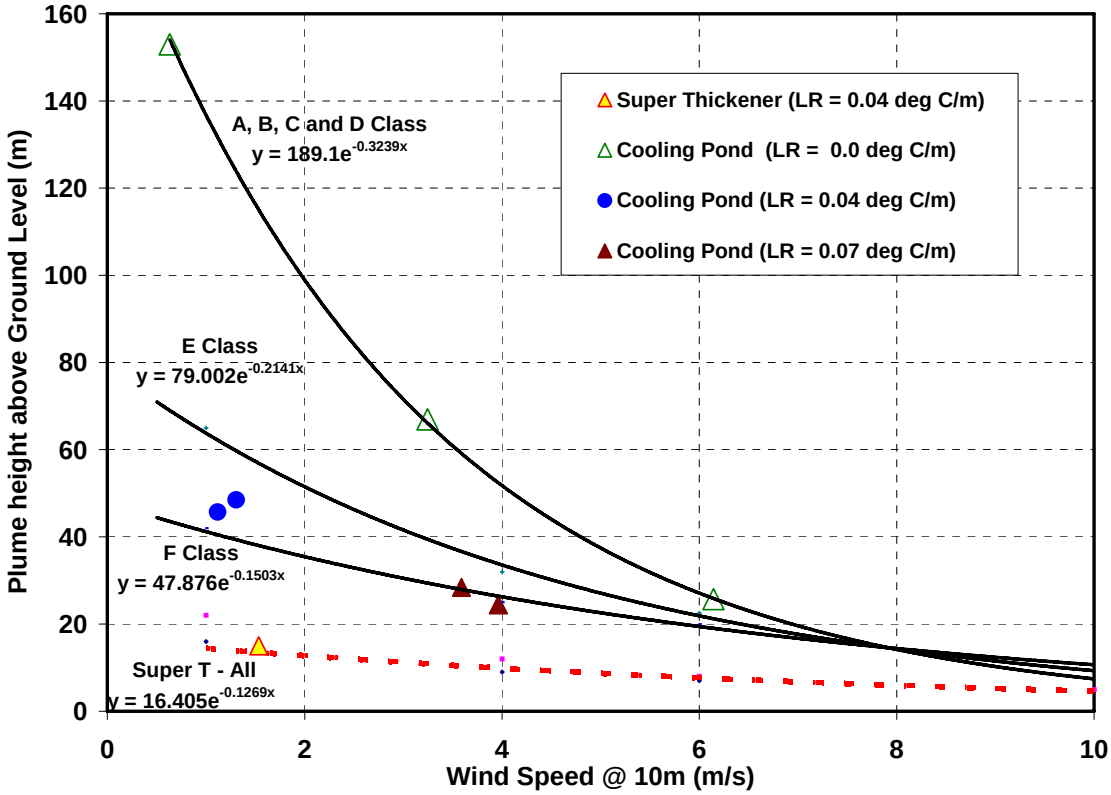


Figure 7.13 Final Plume Height as a Function of Wind Speed for Different Potential Temperature Lapse Rates (LR)

For the super thickener a similar exponential equation was selected which was lower than the data point to account for the possibilities of higher stabilities. The super thickener plume rise was specified independent of the wind direction, whilst the cooling pond final plume height was assumed to linearly decrease from that in **Equation 7-1** to**7-4,** to a height of 1m for winds 90 degrees from the main axis;

- The initial vertical dispersion for the plumes, modelled as area sources, were parameterised as:

$$Sigz = Sigz1 \times (1+0.4 \times 1/6 \times (6- WS)) \qquad \textbf{Equation 7-5}$$

Where:
Sigz1 is the initial standard deviation in the plume;
Sigz is the final adjusted standard deviation; and
WS is the wind speed.

This was based on the CFD modelling data as presented in **Figure 7.14** showing the vertical dispersion of the plume at the end of the ponds. This therefore represents the composite plume, consisting of material that will be emitted at the leading edge of the pond through to material just emitted before the end of the pond. **Figure 7.14** shows that at the higher wind

speeds the vertical dispersion is similar to that which would be estimated using D Class stability and a distance of half the pond. At lower wind speeds, the dispersion increases.

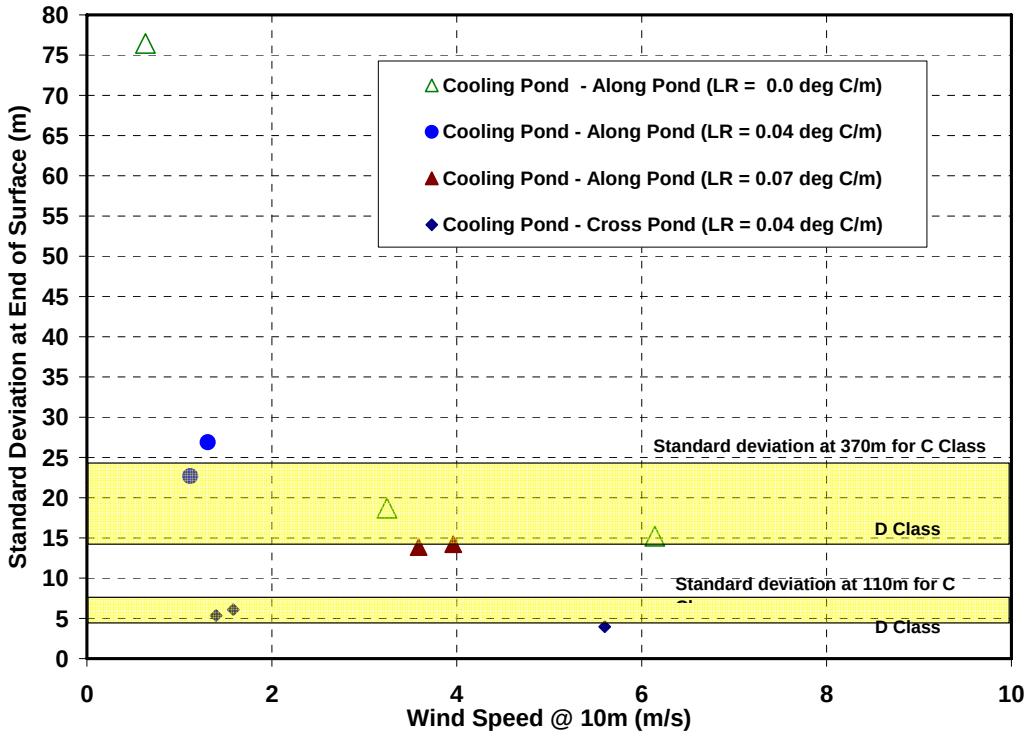


Figure 7.14 Standard deviation of plume spread as a Function of Wind Speed for Different Temperature Lapse Rates (LR) for the along pond and cross pond dispersion

Therefore, to parameterise this increase in dispersion, the initial dispersion of the plume was set to that estimated for D class stability for a distance equal to half the length of the pond, with the dispersion increasing for wind speeds below 6 m/s.

The resultant odour concentrations predicted using the above parameterisations are presented in **Figure 7.15** to **Figure 7.17** and in **Table 7.2**. These indicate slightly lower concentrations during the day time, but significantly lower concentrations at night, though the concentrations are still above that observed by the field odour surveys. Overall, for the limited data, the agreement is much better, though probably still being conservative. A preliminary analysis of the various changes made, indicates that the primary reason for the decrease in predicted concentrations arises from the new assumed flux chamber wind speed relationship. To a lesser extent, the reduction in the concentrations are due to the plume rise assumed from the cooling pond and super-thickener, with less of an effect from the increase in initial dispersion and change in the averaging time.

Figure 7.15 Predicted and Observed 1-hour Odour Levels (ou) for the hour ending 1600 WST on 15 December 2004 (Improved model Parameterisation)

Figure 7.16 Predicted and Observed 1-hour Odour Levels (ou) for the hour ending 2200 WST on 26 February 2005 (Improved model Parameterisation)

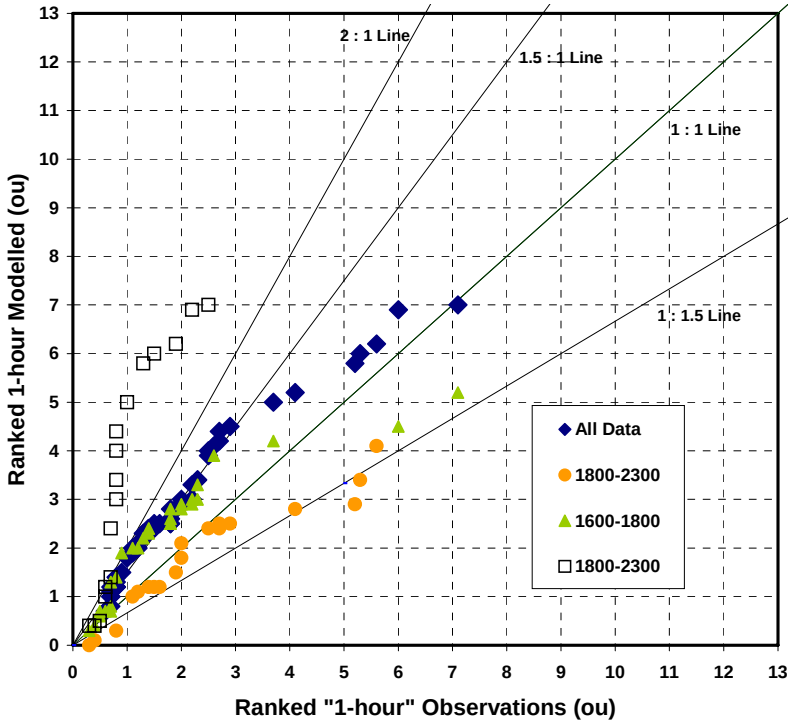


Figure 7.17 Predicted and Observed 1-hour Odour Levels (ou) (Improved model Parameterisation)

Apart from the implementation of the previous plume rise method, an attempt was made to use the plume rise formula within Calpuff, by using the buoyancy flux of the plume from the pond. This buoyancy flux was calculated using the sensible heat flux calculations using similarity theory as in **Section 4.3**. However, use of this method over predicted the plume rise, with a plume rise of around 100m predicted for stable conditions, unlike the observations of 25 to 40m. This over-prediction is considered to occur as the plume rise equations are not applicable for these large areas.

8 Predicted Concentrations

Predicted concentrations from the base case and expanded case from the Wagerup refinery fugitive sources are presented in **Sections 8.1** and **8.2**. It is noted that these do not include other sources in the area or include a general background level. Background levels of PM_{10}, VOC and metals have been estimated in **Section 3.1.4** and if required can be added to the predicted levels.

8.1 Base Case

The results of the model predictions of fugitive concentrations from the 16 substances (PM_{10}, 5 metals and 6 VOCs) have been summarised for 16 discrete receptors, identified as representative locations around the refinery. These sites are listed in **Table 8.1** with their AMG 84 coordinates. It is noted that the receptors used are indicative only, with ENVIRON et al (2005) using a greater number of locations in the health risk assessment which combines the concentrations from the fugitive and stack and vent sources from the refinery. Data from the refinery modelling (CSIRO, 2005a and b) and from this study has been supplied to ENVIRON in electronic format to enable the cumulative concentrations to be estimated. It is noted that this report does not interpret the implications of the predicted concentrations with this under-taken in the Health Risk Assessment by ENVIRON et al (2005).

Table 8.1 Location of Sites used as Representative receptors

Site Number	Easting (m) AMG84	Northing (m) AMG84
1	398,091	6,354,834
2	399,393	6,355,006
3	396,830	6,352,949
4	397,138	6,354,827
5	395,721	6,352,503
6	399,650	6,354,240
7	390,775	6,358,733
8	392360	6,362,131
9	396,099	6,362,024
10	398,460	6,362,000
11	398,207	6,360,331
12	399,210	6,364,535
13	400,52	6,364,215
14	400,727	6,360,830
15	402,726	6,356,435
16	397,365	6,359,285

Predicted 99.9 percentile 1-hour average concentrations (the 9th highest) in a year, 99.5 percentile 24-hour concentrations (2nd highest 24-hour in a year) and the annual average concentration for the base case are presented in **Table 8.2** to **Table 8.4**.

Table 8.2 Wagerup Refinery Base Case - 99.9 Percentile 1-hour Concentrations (µg/m^3)

Substance	Receptor Number																Highest at all Receptors
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
PM_{10}	10.4	5.4	9.0	18.3	10.0	4.0	128.6	17.0	11.6	15.0	23.5	6.9	7.9	13.3	2.2	34.3	128.6
Arsenic	4.94E-04	2.02E-04	4.13E-04	8.02E-04	4.47E-04	1.77E-04	5.95E-03	7.92E-04	5.40E-04	6.00E-04	7.42E-04	3.16E-04	3.02E-04	3.26E-04	9.35E-05	1.05E-03	5.95E-03
Selenium	3.13E-05	1.61E-05	2.69E-05	5.50E-05	3.00E-05	1.19E-05	3.86E-04	5.10E-05	3.48E-05	4.51E-05	7.04E-05	2.07E-05	2.36E-05	3.99E-05	6.71E-06	1.03E-04	3.86E-04
Manganese	2.39E-03	1.02E-03	2.03E-03	4.10E-03	2.24E-03	8.75E-04	2.92E-02	3.83E-03	2.62E-03	3.15E-03	4.04E-03	1.54E-03	1.49E-03	2.16E-03	4.61E-04	5.72E-03	2.92E-02
Cadmium	3.13E-07	1.61E-07	2.69E-07	5.50E-07	3.00E-07	1.19E-07	3.86E-06	5.10E-07	3.48E-07	4.51E-07	7.04E-07	2.07E-07	2.36E-07	3.99E-07	6.71E-08	1.03E-06	3.86E-06
Nickel	5.22E-05	2.69E-05	4.48E-05	9.16E-05	4.99E-05	1.98E-05	6.43E-04	8.49E-05	5.79E-05	7.52E-05	1.17E-04	3.45E-05	3.93E-05	6.65E-05	1.12E-05	1.72E-04	6.43E-04
Mercury	1.74E-03	1.20E-03	1.81E-03	2.51E-03	1.74E-03	7.75E-04	1.86E-03	1.42E-03	2.25E-03	2.44E-03	4.16E-03	1.37E-03	1.42E-03	1.70E-03	5.12E-04	7.33E-03	7.33E-03
Benzo(a)pyrene (BaP)	5.28E-07	4.47E-07	3.89E-07	6.83E-07	5.34E-07	3.23E-07	5.50E-07	5.38E-07	9.24E-07	8.53E-07	1.32E-06	4.88E-07	4.60E-07	6.89E-07	1.98E-07	2.30E-06	2.30E-06
Acetone	1.10E+00	8.35E-01	9.48E-01	1.37E+00	1.01E+00	7.26E-01	1.18E+00	9.91E-01	1.34E+00	1.59E+00	2.44E+00	8.41E-01	8.92E-01	1.32E+00	3.47E-01	4.01E+00	4.01E+00
Acetaldehyde	8.13E-01	6.22E-01	7.22E-01	1.00E+00	7.89E-01	5.47E-01	8.96E-01	7.43E-01	9.93E-01	1.17E+00	1.84E+00	6.41E-01	6.77E-01	9.84E-01	2.62E-01	2.96E+00	2.96E+00
Formaldehyde	1.13E-01	7.09E-02	1.45E-01	1.70E-01	1.36E-01	5.39E-02	9.40E-02	7.45E-02	1.06E-01	1.46E-01	2.40E-01	6.32E-02	8.18E-02	1.86E-01	3.15E-02	2.91E-01	2.91E-01
2-Butanone	1.34E-01	1.12E-01	1.20E-01	1.75E-01	1.25E-01	9.85E-02	1.53E-01	1.28E-01	1.68E-01	2.00E-01	3.27E-01	1.12E-01	1.15E-01	1.74E-01	4.89E-02	5.35E-01	5.35E-01
Benzene	1.51E-02	1.07E-02	1.30E-02	1.83E-02	1.41E-02	9.45E-03	1.52E-02	1.28E-02	1.74E-02	1.97E-02	3.38E-02	1.15E-02	1.15E-02	1.69E-02	4.91E-03	5.17E-02	5.17E-02
Toluene	2.58E-02	1.93E-02	2.24E-02	3.20E-02	2.53E-02	1.63E-02	2.75E-02	2.32E-02	3.38E-02	3.87E-02	5.96E-02	2.01E-02	2.11E-02	3.16E-02	8.02E-03	9.70E-02	9.70E-02
Xylene	3.76E-03	3.23E-03	2.73E-03	4.71E-03	3.72E-03	2.50E-03	3.98E-03	3.66E-03	6.03E-03	6.07E-03	9.92E-03	3.46E-03	3.27E-03	4.87E-03	1.42E-03	1.55E-02	1.55E-02

Table 8.3 Wagerup Refinery Base Case - 99.5 Percentile 24-hour Concentrations (µg/m^3)

Substance	Receptor Number																Highest at all Receptors
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
PM_{10}	2.0	0.9	1.6	4.4	1.1	0.9	33.2	4.9	3.5	5.3	6.4	2.6	1.5	3.3	0.6	7.1	33.2
Arsenic	9.32E-05	3.36E-05	7.50E-05	1.74E-04	4.73E-05	3.42E-05	1.49E-03	2.02E-04	1.68E-04	2.02E-04	2.09E-04	1.16E-04	7.02E-05	9.07E-05	2.73E-05	2.40E-04	1.49E-03
Selenium	5.98E-06	2.66E-06	4.80E-06	1.31E-05	3.25E-06	2.84E-06	9.97E-05	1.47E-05	1.05E-05	1.59E-05	1.91E-05	7.87E-06	4.64E-06	9.78E-06	1.85E-06	2.14E-05	9.97E-05
Manganese	4.55E-04	1.72E-04	3.66E-04	9.11E-04	2.48E-04	1.67E-04	7.40E-03	1.04E-03	8.11E-04	1.08E-03	1.19E-03	5.80E-04	3.47E-04	5.62E-04	1.36E-04	1.25E-03	7.40E-03
Cadmium	5.98E-08	2.66E-08	4.80E-08	1.31E-07	3.25E-08	2.84E-08	9.97E-07	1.47E-07	1.05E-07	1.59E-07	1.91E-07	7.87E-08	4.64E-08	9.78E-08	1.85E-08	2.14E-07	9.97E-07
Nickel	9.97E-06	4.43E-06	7.99E-06	2.18E-05	5.42E-06	4.73E-06	1.66E-04	2.45E-05	1.75E-05	2.66E-05	3.18E-05	1.31E-05	7.74E-06	1.63E-05	3.08E-06	3.57E-05	1.66E-04
Mercury	3.20E-04	2.23E-04	3.06E-04	4.26E-04	3.22E-04	1.75E-04	2.38E-04	1.93E-04	4.30E-04	4.58E-04	8.11E-04	2.72E-04	1.99E-04	5.02E-04	7.91E-05	1.35E-03	1.35E-03
Benzo(a)pyrene (BaP)	8.89E-08	8.28E-08	6.24E-08	1.25E-07	7.08E-08	5.54E-08	1.15E-07	1.07E-07	2.24E-07	2.37E-07	2.77E-07	1.20E-07	8.48E-08	1.56E-07	3.82E-08	5.25E-07	5.25E-07
Acetone	2.03E-01	1.69E-01	1.35E-01	3.34E-01	1.20E-01	1.37E-01	2.28E-01	1.93E-01	3.17E-01	3.90E-01	5.31E-01	1.98E-01	1.45E-01	3.09E-01	7.03E-02	8.60E-01	8.60E-01
Acetaldehyde	1.49E-01	1.27E-01	1.02E-01	2.50E-01	8.82E-02	1.02E-01	1.68E-01	1.42E-01	2.34E-01	2.89E-01	3.85E-01	1.47E-01	1.06E-01	2.29E-01	5.14E-02	6.27E-01	6.27E-01
Formaldehyde	2.02E-02	1.59E-02	2.16E-02	4.05E-02	1.52E-02	1.11E-02	2.17E-02	1.68E-02	2.42E-02	3.65E-02	5.93E-02	1.95E-02	1.55E-02	4.02E-02	1.16E-02	6.42E-02	6.42E-02
2-Butanone	2.53E-02	2.22E-02	1.75E-02	4.26E-02	1.55E-02	1.79E-02	2.95E-02	2.46E-02	4.11E-02	5.21E-02	6.70E-02	2.67E-02	1.94E-02	3.89E-02	9.07E-03	1.11E-01	1.11E-01
Benzene	2.74E-03	2.17E-03	1.81E-03	3.72E-03	1.68E-03	1.69E-03	2.73E-03	2.33E-03	4.30E-03	5.09E-03	6.76E-03	2.73E-03	2.00E-03	3.78E-03	8.55E-04	1.05E-02	1.05E-02
Toluene	4.93E-03	3.74E-03	3.36E-03	6.63E-03	3.08E-03	2.95E-03	5.40E-03	4.84E-03	8.68E-03	9.62E-03	1.30E-02	4.72E-03	3.35E-03	6.72E-03	1.62E-03	2.29E-02	2.29E-02
Xylene	6.35E-04	6.01E-04	4.37E-04	9.01E-04	4.93E-04	4.20E-04	7.77E-04	7.26E-04	1.48E-03	1.64E-03	1.92E-03	8.57E-04	6.21E-04	1.16E-03	2.64E-04	3.16E-03	3.16E-03

Table 8.4 Wagerup Refinery Base Case -Annual Average Concentrations (µg/m^3)

Substance	Receptor Number																Highest at all Receptors
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
PM_{10}	0.11	0.07	0.09	0.17	0.09	0.06	1.67	0.33	0.36	0.35	0.70	0.13	0.13	0.19	0.04	1.18	1.67
Arsenic	4.58E-06	2.76E-06	3.60E-06	7.03E-06	3.61E-06	2.17E-06	7.36E-05	1.38E-05	1.37E-05	1.26E-05	2.15E-05	5.06E-06	5.29E-06	5.97E-06	1.41E-06	3.61E-05	7.36E-05
Selenium	3.29E-07	2.17E-07	2.68E-07	5.17E-07	2.68E-07	1.68E-07	5.02E-06	9.96E-07	1.08E-06	1.04E-06	2.09E-06	3.96E-07	4.05E-07	5.82E-07	1.23E-07	3.54E-06	5.02E-06
Manganese	2.34E-05	1.47E-05	1.87E-05	3.63E-05	1.87E-05	1.15E-05	3.68E-04	7.08E-05	7.29E-05	6.85E-05	1.26E-04	2.68E-05	2.78E-05	3.51E-05	7.84E-06	2.13E-04	3.68E-04
Cadmium	3.29E-09	2.17E-09	2.68E-09	5.17E-09	2.68E-09	1.68E-09	5.02E-08	9.96E-09	1.08E-08	1.04E-08	2.09E-08	3.96E-09	4.05E-09	5.82E-09	1.23E-09	3.54E-08	5.02E-08
Nickel	5.49E-07	3.61E-07	4.47E-07	8.62E-07	4.47E-07	2.80E-07	8.36E-06	1.66E-06	1.79E-06	1.73E-06	3.48E-06	6.60E-07	6.75E-07	9.70E-07	2.04E-07	5.90E-06	8.36E-06
Mercury	1.46E-05	9.07E-06	1.18E-05	1.99E-05	1.37E-05	6.60E-06	1.83E-05	2.05E-05	4.14E-05	2.66E-05	5.10E-05	1.15E-05	1.07E-05	1.73E-05	4.29E-06	1.15E-04	1.15E-04
Benzo(a)pyrene (BaP)	6.83E-09	4.63E-09	4.55E-09	7.97E-09	5.38E-09	3.73E-09	1.30E-08	1.13E-08	2.22E-08	1.36E-08	2.47E-08	5.94E-09	5.79E-09	8.86E-09	2.50E-09	6.03E-08	6.03E-08
Acetone	1.43E-02	9.85E-03	9.81E-03	1.76E-02	1.13E-02	7.76E-03	2.84E-02	2.60E-02	4.09E-02	2.61E-02	4.51E-02	1.18E-02	1.13E-02	1.69E-02	4.88E-03	1.03E-01	1.03E-01
Acetaldehyde	1.06E-02	7.27E-03	7.32E-03	1.30E-02	8.40E-03	5.75E-03	2.13E-02	1.96E-02	3.05E-02	1.92E-02	3.31E-02	8.74E-03	8.39E-03	1.24E-02	3.56E-03	7.55E-02	7.55E-02
Formaldehyde	1.81E-03	1.29E-03	1.35E-03	2.39E-03	1.46E-03	9.43E-04	3.08E-03	2.66E-03	3.97E-03	3.14E-03	5.82E-03	1.39E-03	1.38E-03	2.41E-03	7.51E-04	1.08E-02	1.08E-02
2-Butanone	1.81E-03	1.26E-03	1.24E-03	2.21E-03	1.43E-03	9.94E-04	3.59E-03	3.27E-03	5.23E-03	3.32E-03	5.76E-03	1.50E-03	1.45E-03	2.15E-03	6.15E-04	1.33E-02	1.33E-02
Benzene	1.78E-04	1.20E-04	1.25E-04	2.18E-04	1.45E-04	9.45E-05	3.44E-04	3.18E-04	5.25E-04	3.23E-04	5.63E-04	1.47E-04	1.40E-04	2.09E-04	5.88E-05	1.32E-03	1.32E-03
Toluene	3.22E-04	2.15E-04	2.26E-04	3.96E-04	2.60E-04	1.71E-04	6.53E-04	6.01E-04	9.97E-04	6.13E-04	1.06E-03	2.76E-04	2.63E-04	3.84E-04	1.09E-04	2.48E-03	2.48E-03
Xylene	4.82E-05	3.28E-05	3.20E-05	5.62E-05	3.78E-05	2.63E-05	8.93E-05	7.76E-05	1.51E-04	9.37E-05	1.70E-04	4.11E-05	4.01E-05	6.19E-05	1.74E-05	4.16E-04	4.16E-04

To illustrate the spatial distribution of the concentrations, **Figure 8.1** to **Figure 8.7** present the predicted:

- 99.9 percentile 1-hour, 99.5 percentile 24-hour and annual average concentrations of PM_{10};
- 99.9 percentile 1-hour, 99.5 percentile 24-hour and annual average concentrations of acetaldehyde; and
- Annual average concentrations of arsenic.

Figure 8.1 Predicted 1-hour 99.9 Percentile PM_{10} Concentrations (µg/m^3) from the Base Case Refinery

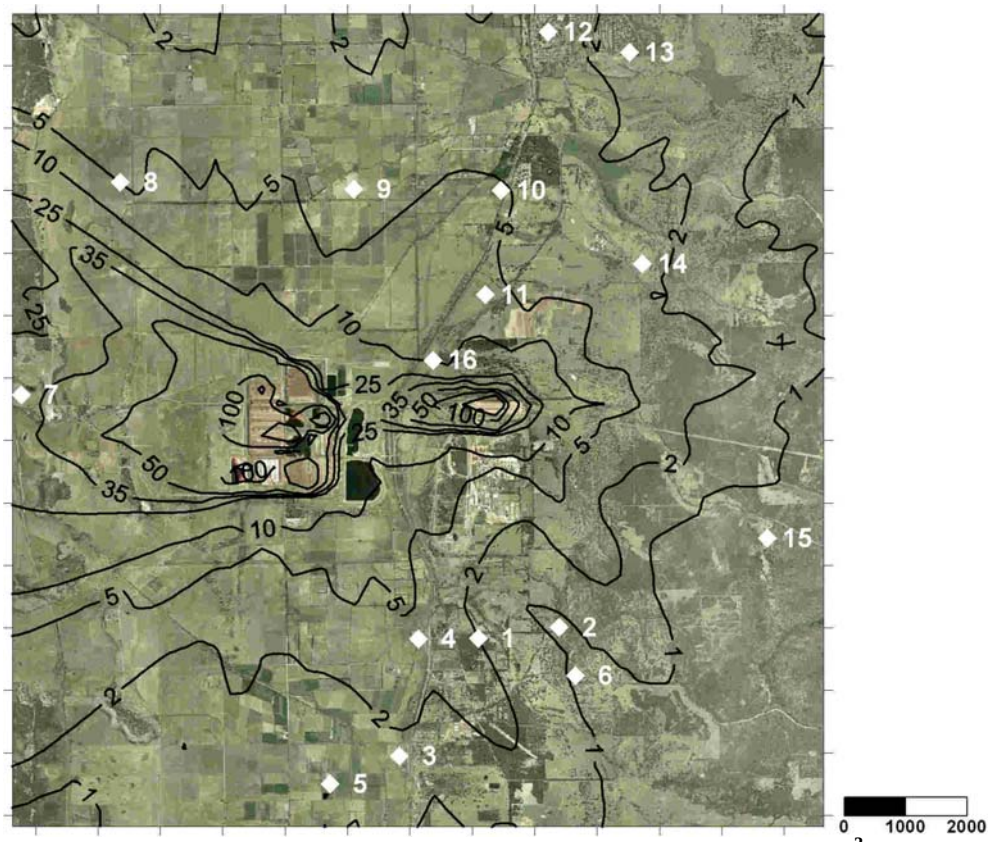


Figure 8.2 Predicted 24-hour 99.5 Percentile PM_{10} Concentrations (µg/m^3) from the Base Case Refinery

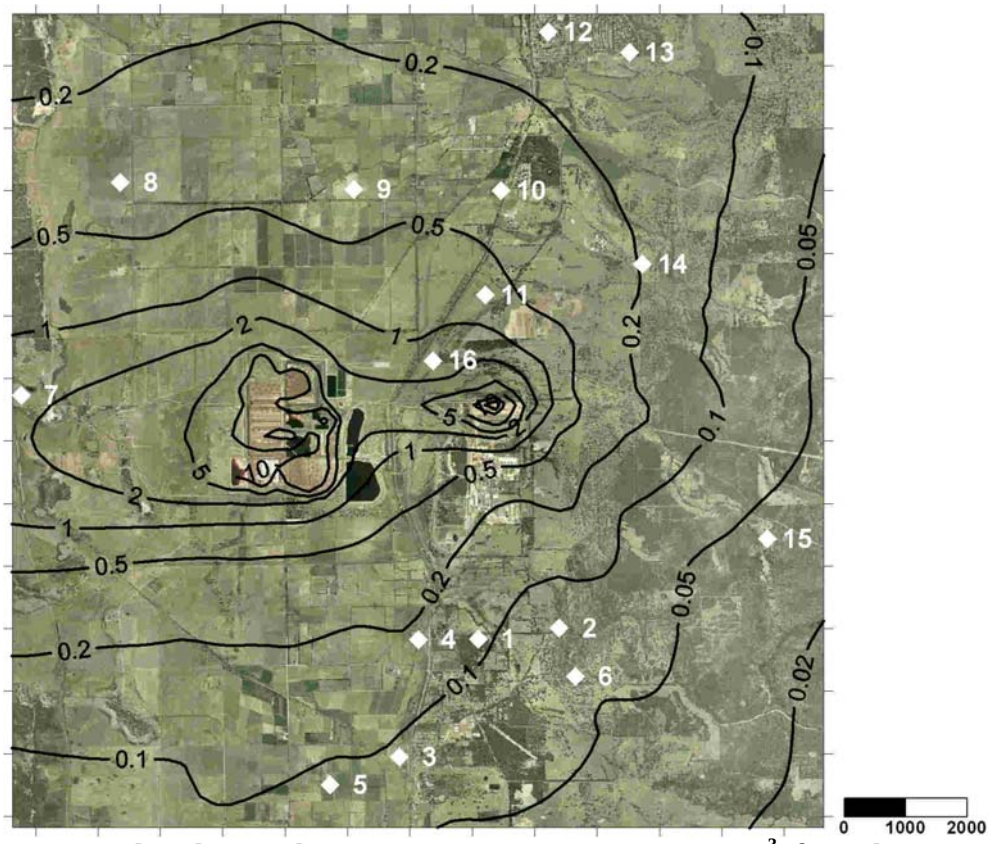


Figure 8.3 Predicted Annual Average PM_{10} Concentrations (µg/m^3) from the Base Case Refinery

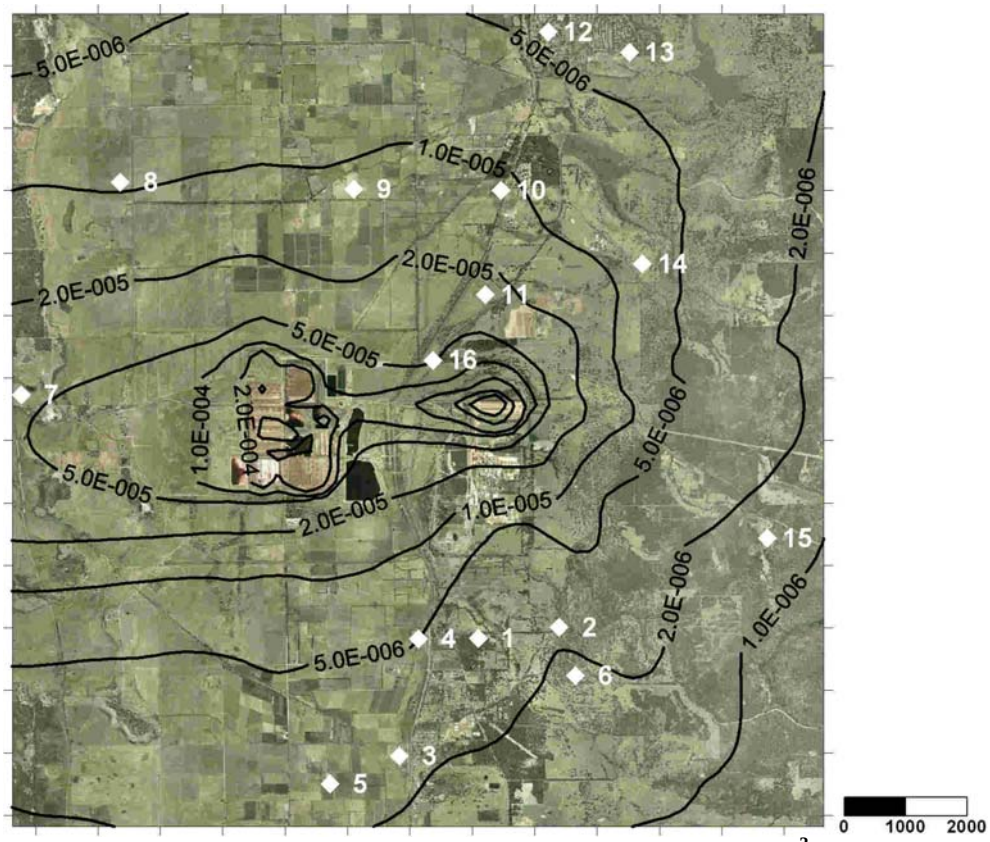


Figure 8.4 Predicted Annual Average Arsenic Concentrations (µg/m^3) from the Base Case Refinery

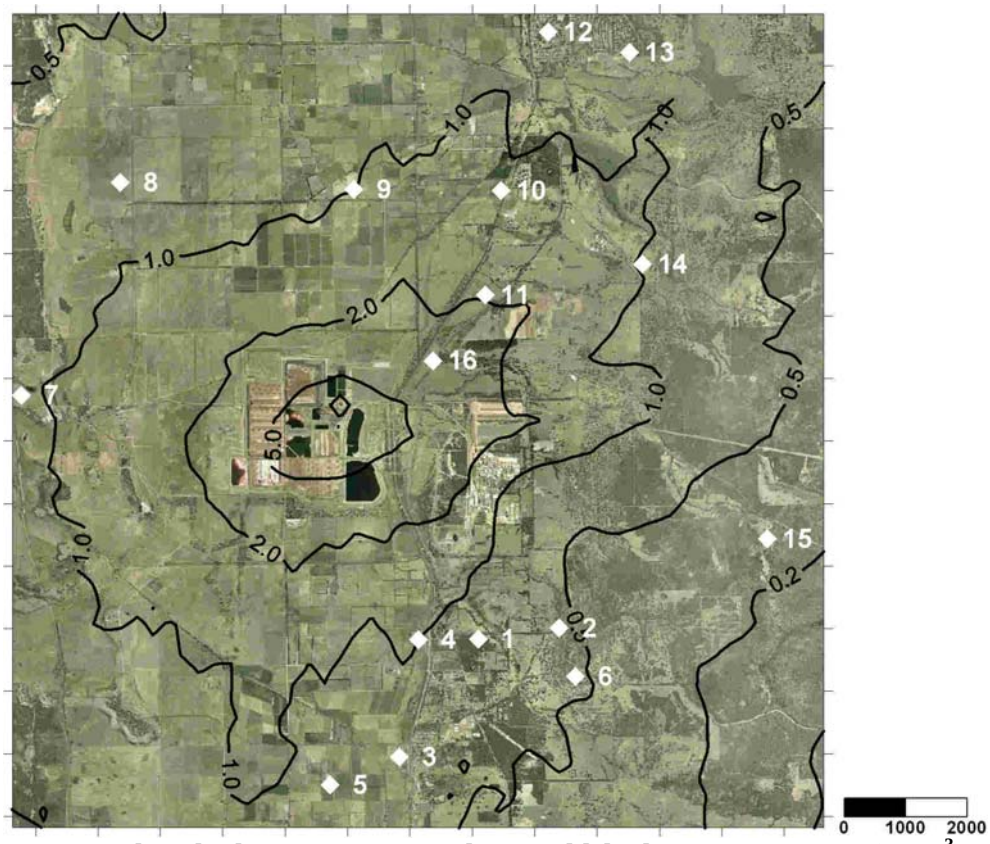


Figure 8.5 Predicted 1-hour 99.9 Percentile Acetaldehyde Concentrations (µg/m^3) from the Base Case Refinery

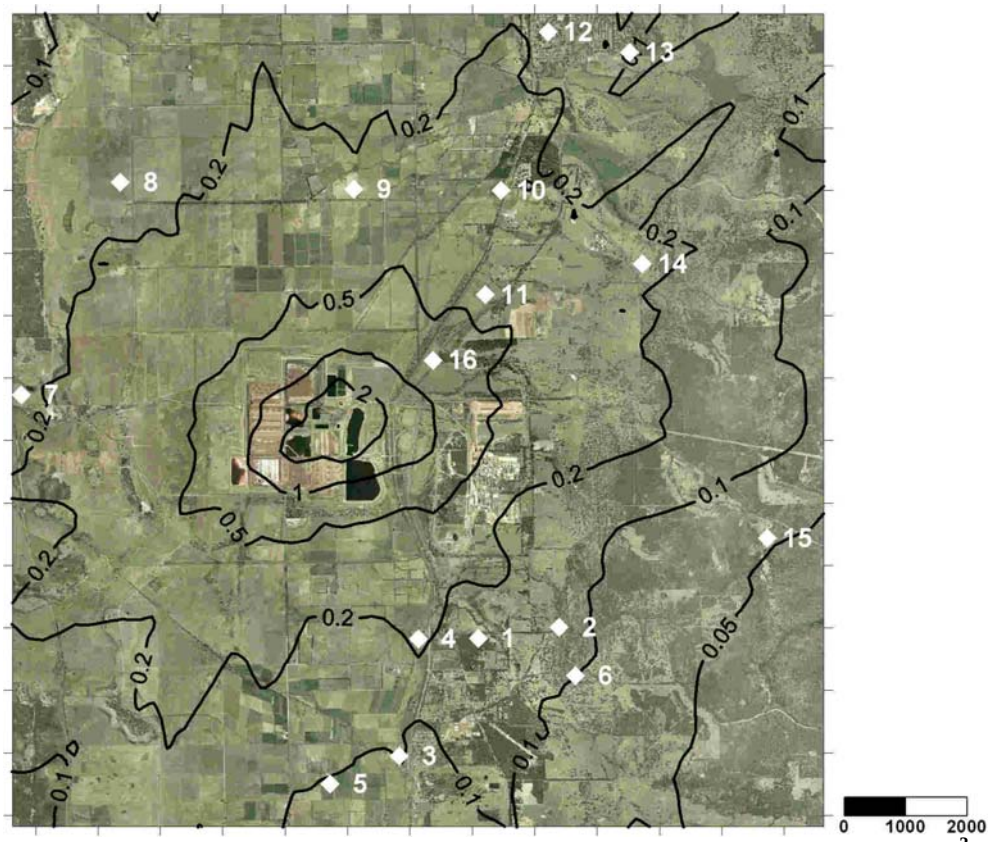


Figure 8.6 Predicted 24-hour 99.5 Percentile Acetaldehyde Concentrations (µg/m^3) from the Base Case Refinery

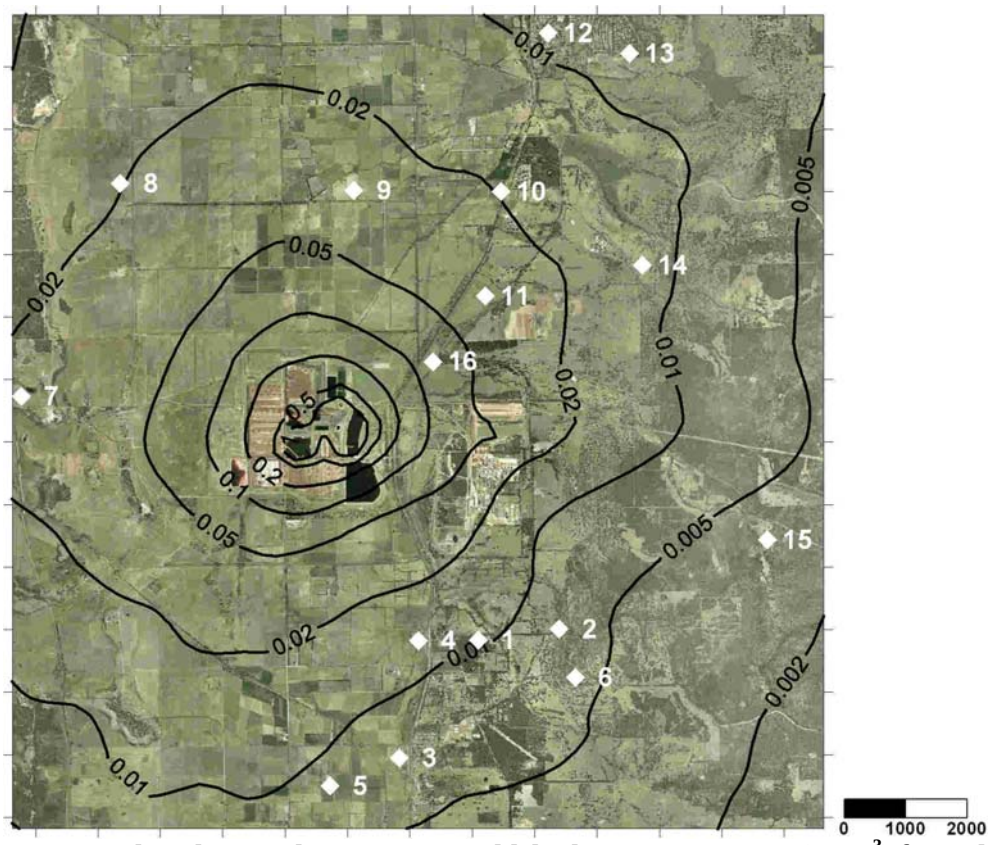


Figure 8.7 Predicted Annual Average Acetaldehyde Concentrations (µg/m^3) from the Base Case Refinery

8.2 Expansion Case

Predicted 99.9 percentile 1-hour average concentrations (the 9th highest) in a year, 99.5 percentile 24-hour concentrations (2nd highest 24-hour in a year) and the annual average concentration for the base case are presented in **Table 8.5** to **Table 8.7**. **Figure 8.8** to **Figure 8.14** present the predicted:

- 99.9 percentile 1-hour, 99.5 percentile 24-hour and annual average concentrations of PM_{10};
- 99.9 percentile 1-hour, 99.5 percentile 24-hour and annual average concentrations of acetaldehyde; and
- Annual average concentrations of arsenic.

A comparison of the predicted change of concentrations from the base case to expansion case is presented in **Table 8.8** to **Table 8.10**. These indicate that with the expansion:

- The highest 1 hour (99.9 percentile) and 24-hour (99.5 percentile) PM_{10} and metal concentrations that is predicted at a receptor location (receptor 7) will decrease. This is due to the proposed better dust control from the residue area, which contributes the majority of dust to this location. At other locations, with lower concentrations, the concentrations are predicted to increase, particularly for those closer to the bauxite stockpiles, with the concentrations predicted to increase by between 1.6 to 1.8 times at receptor 16. This increase at receptor 16 is due to the predicted increase in dust emissions from the bauxite stockpiles. This increase however, is considered to be overstated due to conservative assumptions used, such as assuming the new emergency stockpile and associated area will result in an increase of 33 % (**Table 5.4**) in dust emissions from wind erosion. This is thought to be overstated as the emergency stockpile should form a crust and be less erodible than the active stockpiles.
- Annual average metal concentrations are predicted to increase by between 8 and 13% at receptor 7 (the receptor in the base case with the highest concentrations), with an increase of between 46 to 60% for receptor 16 (which now becomes the receptor for highest concentrations of 3 of the 5 modelled metals);
- Mercury concentrations are predicted to substantially decrease with concentrations 4 to 20% of the existing concentrations; and
- VOC concentrations are predicted to generally increase, with a few exceptions at one or two receptors. In general, the concentrations are predicted to increase between 11% for acetone and acetaldehyde to 57% for formaldehyde.

The above comparison it is noted is only for the fugitive area source emissions and should be placed in the context that they may only be a small fraction of the total concentrations from the refinery and/or a small percentage of any health based criteria. A more detailed comparison of the relative change between the base case and expansion case and the implications for health impacts is presented in ENVIRON et al (2005).

Table 8.5 Wagerup Refinery Expansion Case - 99.9 Percentile 1-hour Concentrations (µg/m^3)

Substance	Receptor Number																Highest at all Receptors
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
PM_{10}	11.1	8.6	11.3	17.8	10.9	6.5	111.3	22.0	16.6	19.0	41.8	9.2	9.7	20.8	3.6	60.0	111.3
Arsenic	5.00E-04	2.69E-04	5.20E-04	7.85E-04	5.25E-04	1.96E-04	4.59E-03	8.22E-04	6.41E-04	5.95E-04	1.02E-03	3.20E-04	3.40E-04	5.44E-04	1.10E-04	1.72E-03	4.59E-03
Selenium	3.32E-05	2.58E-05	3.38E-05	5.35E-05	3.28E-05	1.96E-05	3.34E-04	6.61E-05	4.97E-05	5.70E-05	1.25E-04	2.77E-05	2.92E-05	6.23E-05	1.08E-05	1.80E-04	3.34E-04
Manganese	2.55E-03	1.44E-03	2.51E-03	4.00E-03	2.54E-03	1.16E-03	2.39E-02	4.12E-03	3.18E-03	3.07E-03	6.51E-03	1.74E-03	2.02E-03	3.55E-03	6.64E-04	1.03E-02	2.39E-02
Cadmium	3.32E-07	2.58E-07	3.38E-07	5.35E-07	3.28E-07	1.96E-07	3.34E-06	6.61E-07	4.97E-07	5.70E-07	1.25E-06	2.77E-07	2.92E-07	6.23E-07	1.08E-07	1.80E-06	3.34E-06
Nickel	5.53E-05	4.29E-05	5.64E-05	8.92E-05	5.47E-05	3.27E-05	5.57E-04	1.10E-04	8.29E-05	9.51E-05	2.09E-04	4.62E-05	4.87E-05	1.04E-04	1.80E-05	3.00E-04	5.57E-04
Mercury	1.08E-04	1.18E-04	1.64E-04	2.66E-04	1.05E-04	8.82E-05	9.71E-05	1.51E-04	1.88E-04	2.35E-04	4.05E-04	9.68E-05	1.60E-04	3.45E-04	5.49E-05	6.25E-04	6.25E-04
Benzo(a)pyrene (BaP)	7.29E-07	6.22E-07	5.28E-07	9.11E-07	7.20E-07	4.83E-07	7.68E-07	7.07E-07	1.16E-06	1.17E-06	1.91E-06	6.61E-07	6.32E-07	9.37E-07	2.76E-07	2.99E-06	2.99E-06
Acetone	1.21E+00	9.77E-01	9.99E-01	1.67E+00	1.12E+00	7.58E-01	1.22E+00	1.14E+00	1.55E+00	1.71E+00	2.83E+00	9.72E-01	1.00E+00	1.45E+00	4.30E-01	4.40E+00	4.40E+00
Acetaldehyde	9.47E-01	7.44E-01	7.42E-01	1.21E+00	8.35E-01	5.73E-01	9.77E-01	8.66E-01	1.13E+00	1.31E+00	2.12E+00	7.24E-01	7.26E-01	1.08E+00	3.21E-01	3.23E+00	3.23E+00
Formaldehyde	1.98E-01	1.15E-01	2.30E-01	2.92E-01	2.09E-01	9.67E-02	1.48E-01	1.31E-01	1.89E-01	2.00E-01	3.56E-01	1.05E-01	1.26E-01	2.58E-01	4.51E-02	4.58E-01	4.58E-01
2-Butanone	1.59E-01	1.34E-01	1.21E-01	2.12E-01	1.50E-01	1.06E-01	1.65E-01	1.52E-01	1.98E-01	2.39E-01	3.94E-01	1.31E-01	1.31E-01	1.95E-01	5.73E-02	5.94E-01	5.94E-01
Benzene	1.94E-02	1.45E-02	1.59E-02	2.46E-02	1.81E-02	1.13E-02	1.92E-02	1.68E-02	2.24E-02	2.58E-02	4.38E-02	1.47E-02	1.44E-02	2.17E-02	6.23E-03	6.62E-02	6.62E-02
Toluene	3.03E-02	2.43E-02	2.58E-02	4.21E-02	3.02E-02	1.87E-02	3.23E-02	2.76E-02	4.20E-02	4.20E-02	6.82E-02	2.40E-02	2.56E-02	3.38E-02	1.03E-02	1.06E-01	1.06E-01
Xylene	5.42E-03	4.59E-03	3.81E-03	6.71E-03	5.19E-03	3.53E-03	5.53E-03	4.74E-03	7.89E-03	8.60E-03	1.40E-02	4.81E-03	4.62E-03	6.87E-03	1.98E-03	2.10E-02	2.10E-02

Table 8.6 Wagerup Refinery Expansion Case - 99.5 Percentile 24-hour Concentrations (µg/m^3)

Substance	Receptor Number																Highest at all Receptors
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
PM_{10}	2.1	1.3	1.6	4.3	1.5	1.2	28.9	5.8	3.7	5.5	9.0	2.8	1.9	5.4	1.2	11.4	28.9
Arsenic	9.64E-05	5.06E-05	6.28E-05	1.36E-04	6.50E-05	4.30E-05	1.21E-03	2.61E-04	1.70E-04	1.95E-04	2.50E-04	1.15E-04	5.99E-05	1.34E-04	3.44E-05	3.58E-04	1.21E-03
Selenium	6.44E-06	3.80E-06	4.85E-06	1.29E-05	4.42E-06	3.51E-06	8.67E-05	1.75E-05	1.12E-05	1.65E-05	2.70E-05	8.31E-06	5.63E-06	1.62E-05	3.49E-06	3.42E-05	8.67E-05
Manganese	4.78E-04	2.64E-04	3.31E-04	7.87E-04	3.24E-04	2.32E-04	6.18E-03	1.26E-03	8.22E-04	1.07E-03	1.55E-03	5.92E-04	3.74E-04	8.81E-04	1.97E-04	2.10E-03	6.18E-03
Cadmium	6.44E-08	3.80E-08	4.85E-08	1.29E-07	4.42E-08	3.51E-08	8.67E-07	1.75E-07	1.12E-07	1.65E-07	2.70E-07	8.31E-08	5.63E-08	1.62E-07	3.49E-08	3.42E-07	8.67E-07
Nickel	1.07E-05	6.33E-06	8.09E-06	2.15E-05	7.37E-06	5.85E-06	1.44E-04	2.92E-05	1.87E-05	2.75E-05	4.50E-05	1.38E-05	9.38E-06	2.70E-05	5.81E-06	5.69E-05	1.44E-04
Mercury	1.40E-05	2.53E-05	2.83E-05	4.01E-05	1.61E-05	2.03E-05	1.21E-05	2.04E-05	2.48E-05	3.87E-05	6.88E-05	1.39E-05	2.82E-05	8.35E-05	1.12E-05	1.16E-04	1.16E-04
Benzo(a)pyrene (BaP)	1.23E-07	1.16E-07	8.45E-08	1.74E-07	9.56E-08	8.09E-08	1.50E-07	1.40E-07	2.86E-07	3.17E-07	3.69E-07	1.65E-07	1.20E-07	2.23E-07	5.10E-08	6.12E-07	6.12E-07
Acetone	2.16E-01	1.91E-01	1.39E-01	3.12E-01	1.47E-01	1.44E-01	2.33E-01	2.18E-01	3.94E-01	4.52E-01	5.69E-01	2.48E-01	1.85E-01	3.27E-01	7.80E-02	9.05E-01	9.05E-01
Acetaldehyde	1.59E-01	1.42E-01	1.04E-01	2.31E-01	1.07E-01	1.08E-01	1.72E-01	1.59E-01	2.90E-01	3.32E-01	4.11E-01	1.82E-01	1.33E-01	2.48E-01	5.70E-02	6.69E-01	6.69E-01
Formaldehyde	3.51E-02	2.85E-02	3.05E-02	6.53E-02	2.40E-02	1.96E-02	3.13E-02	2.58E-02	4.26E-02	5.34E-02	8.83E-02	2.83E-02	2.42E-02	5.81E-02	1.70E-02	1.18E-01	1.18E-01
2-Butanone	2.69E-02	2.58E-02	1.81E-02	3.96E-02	1.91E-02	1.98E-02	3.05E-02	2.84E-02	5.17E-02	6.17E-02	7.32E-02	3.36E-02	2.47E-02	4.17E-02	1.03E-02	1.22E-01	1.22E-01
Benzene	3.35E-03	2.85E-03	2.24E-03	4.45E-03	2.21E-03	2.18E-03	3.48E-03	3.09E-03	5.72E-03	6.62E-03	8.06E-03	3.56E-03	2.71E-03	4.62E-03	1.10E-03	1.36E-02	1.36E-02
Toluene	5.68E-03	4.59E-03	3.92E-03	6.84E-03	3.75E-03	3.41E-03	5.94E-03	5.55E-03	1.05E-02	1.13E-02	1.42E-02	5.87E-03	4.22E-03	7.82E-03	1.89E-03	2.32E-02	2.32E-02
Xylene	9.00E-04	8.35E-04	6.10E-04	1.28E-03	6.85E-04	6.21E-04	1.04E-03	9.89E-04	1.97E-03	2.27E-03	2.62E-03	1.19E-03	8.47E-04	1.50E-03	3.65E-04	4.44E-03	4.44E-03

Table 8.7 Wagerup Refinery Expansion Case -Annual Average Concentrations (µg/m^3)

Substance	Receptor Number																Highest at all Receptors
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
PM_{10}	0.14	0.10	0.13	0.22	0.12	0.08	1.86	0.53	0.62	0.52	1.08	0.20	0.19	0.31	0.07	1.89	1.89
Arsenic	5.40E-06	3.66E-06	4.75E-06	8.20E-06	4.68E-06	2.84E-06	7.95E-05	2.18E-05	2.31E-05	1.72E-05	3.01E-05	7.32E-06	6.93E-06	8.77E-06	2.09E-06	5.29E-05	7.95E-05
Selenium	4.22E-07	3.15E-07	3.80E-07	6.68E-07	3.75E-07	2.40E-07	5.59E-06	1.59E-06	1.86E-06	1.55E-06	3.25E-06	6.11E-07	5.76E-07	9.33E-07	1.97E-07	5.68E-06	5.68E-06
Manganese	2.86E-05	2.03E-05	2.54E-05	4.43E-05	2.51E-05	1.56E-05	4.03E-04	1.12E-04	1.24E-04	9.73E-05	1.87E-04	4.00E-05	3.78E-05	5.39E-05	1.21E-05	3.27E-04	4.03E-04
Cadmium	4.22E-09	3.15E-09	3.80E-09	6.69E-09	3.75E-09	2.40E-09	5.59E-08	1.59E-08	1.86E-08	1.55E-08	3.25E-08	6.11E-09	5.76E-09	9.33E-09	1.97E-09	5.68E-08	5.68E-08
Nickel	7.03E-07	5.24E-07	6.33E-07	1.11E-06	6.25E-07	4.00E-07	9.31E-06	2.66E-06	3.10E-06	2.58E-06	5.42E-06	1.02E-06	9.59E-07	1.56E-06	3.29E-07	9.46E-06	9.46E-06
Mercury	9.87E-07	8.23E-07	9.02E-07	1.58E-06	7.91E-07	5.94E-07	8.85E-07	1.30E-06	2.72E-06	2.87E-06	7.14E-06	1.03E-06	1.15E-06	2.36E-06	6.04E-07	1.33E-05	1.33E-05
Benzo(a)pyrene (BaP)	9.31E-09	6.34E-09	6.17E-09	1.08E-08	7.30E-09	5.07E-09	1.73E-08	1.50E-08	2.92E-08	1.81E-08	3.28E-08	7.93E-09	7.74E-09	1.20E-08	3.35E-09	8.04E-08	8.04E-08
Acetone	1.54E-02	1.05E-02	1.04E-02	1.83E-02	1.21E-02	8.24E-03	2.88E-02	2.59E-02	4.57E-02	2.86E-02	5.07E-02	1.27E-02	1.23E-02	1.89E-02	5.33E-03	1.20E-01	1.20E-01
Acetaldehyde	1.13E-02	7.68E-03	7.75E-03	1.35E-02	9.01E-03	6.07E-03	2.20E-02	2.00E-02	3.45E-02	2.12E-02	3.72E-02	9.44E-03	9.16E-03	1.38E-02	3.89E-03	8.87E-02	8.87E-02
Formaldehyde	2.89E-03	1.99E-03	2.09E-03	3.80E-03	2.29E-03	1.44E-03	4.82E-03	4.21E-03	6.37E-03	4.60E-03	8.19E-03	2.10E-03	2.05E-03	3.45E-03	1.04E-03	1.59E-02	1.59E-02
2-Butanone	1.97E-03	1.35E-03	1.31E-03	2.31E-03	1.54E-03	1.07E-03	3.63E-03	3.23E-03	5.88E-03	3.68E-03	6.57E-03	1.63E-03	1.59E-03	2.44E-03	6.81E-04	1.59E-02	1.59E-02
Benzene	2.25E-04	1.51E-04	1.57E-04	2.70E-04	1.83E-04	1.20E-04	4.44E-04	4.13E-04	6.95E-04	4.19E-04	7.29E-04	1.88E-04	1.82E-04	2.72E-04	7.60E-05	1.75E-03	1.75E-03
Toluene	3.67E-04	2.44E-04	2.58E-04	4.42E-04	2.98E-04	1.94E-04	7.39E-04	6.89E-04	1.19E-03	7.12E-04	1.24E-03	3.19E-04	3.05E-04	4.51E-04	1.26E-04	2.99E-03	2.99E-03
Xylene	6.76E-05	4.62E-05	4.47E-05	7.86E-05	5.28E-05	3.68E-05	1.23E-04	1.07E-04	2.07E-04	1.29E-04	2.34E-04	5.67E-05	5.54E-05	8.61E-05	2.41E-05	5.74E-04	5.74E-04

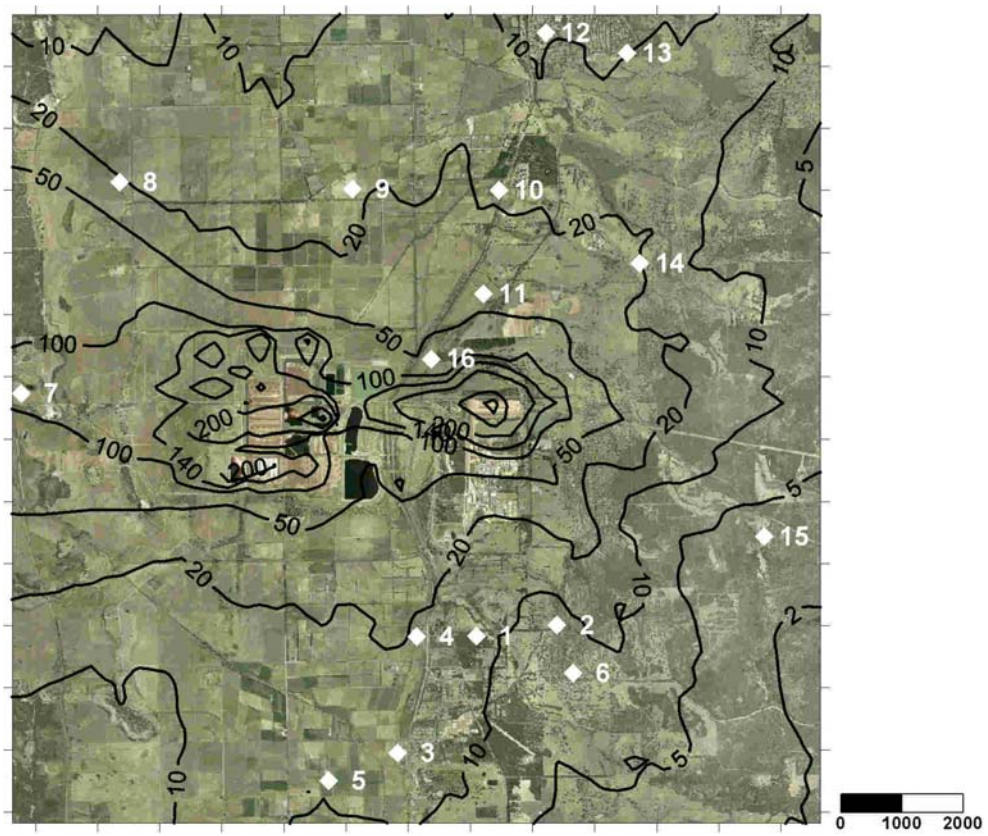


Figure 8.8 Predicted 1-hour 99.9 Percentile PM_{10} Concentrations (µg/m^3) from the Expanded Refinery

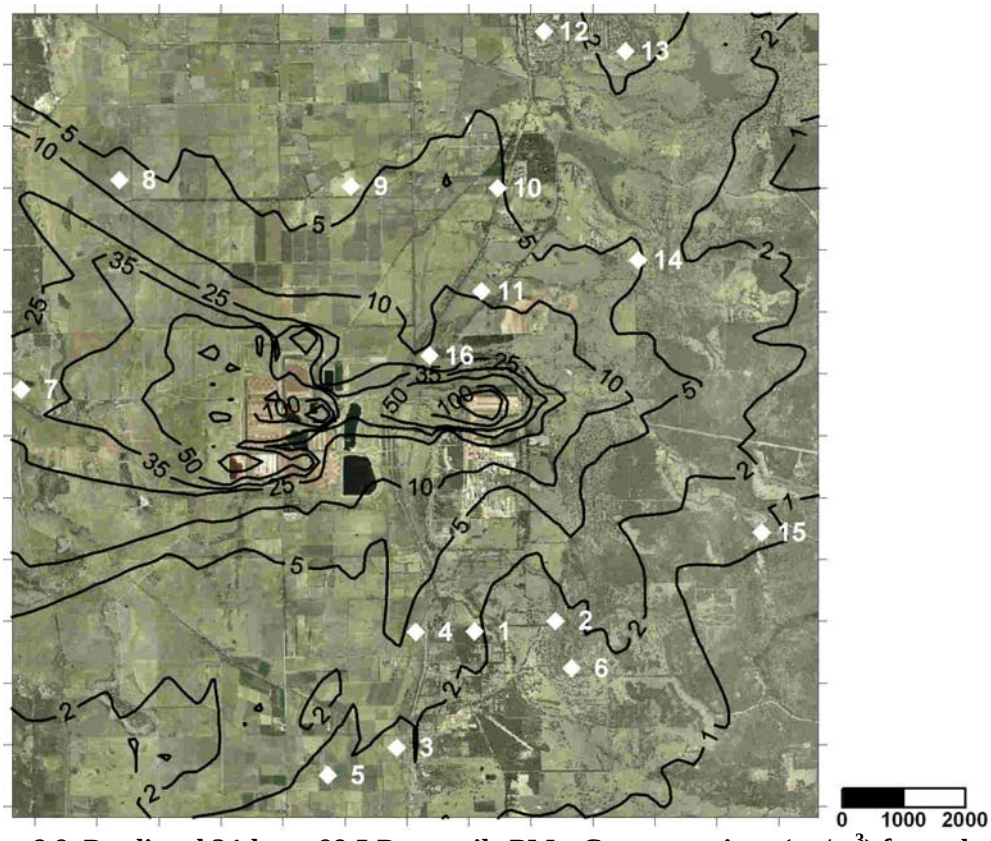


Figure 8.9 Predicted 24-hour 99.5 Percentile PM_{10} Concentrations (µg/m^3) from the Expanded Refinery

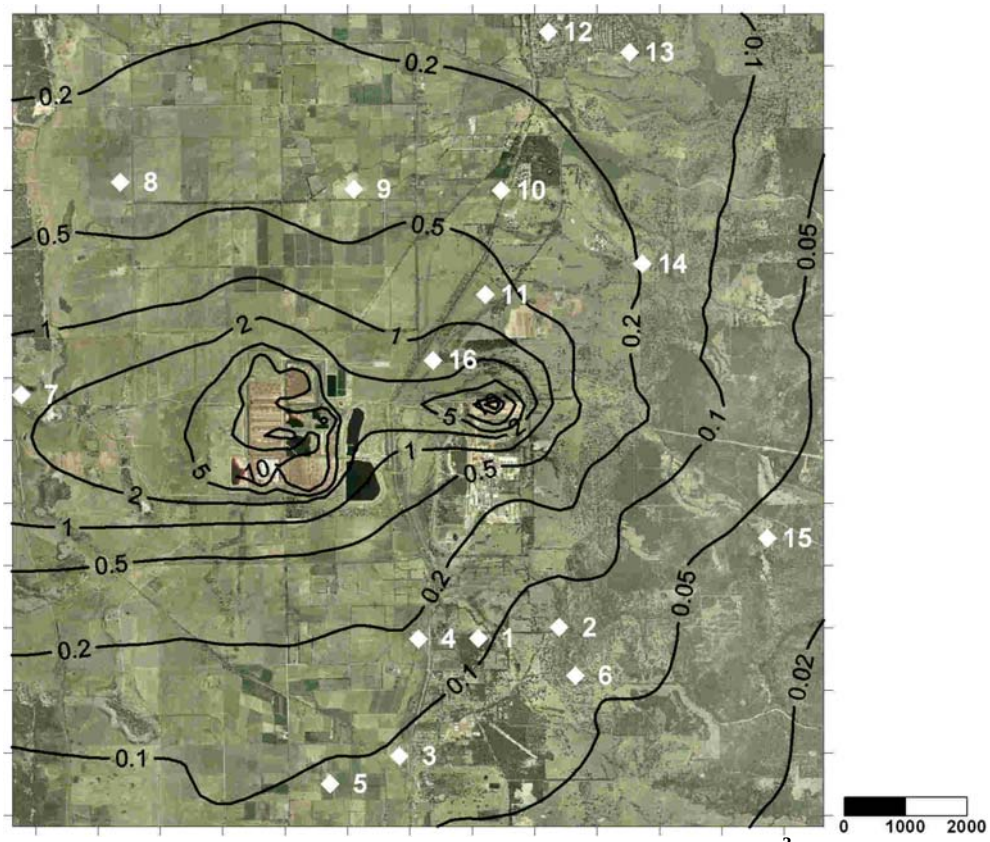


Figure 8.10 Predicted Annual Average PM_{10} Concentrations (µg/m^3) from the Expanded Refinery

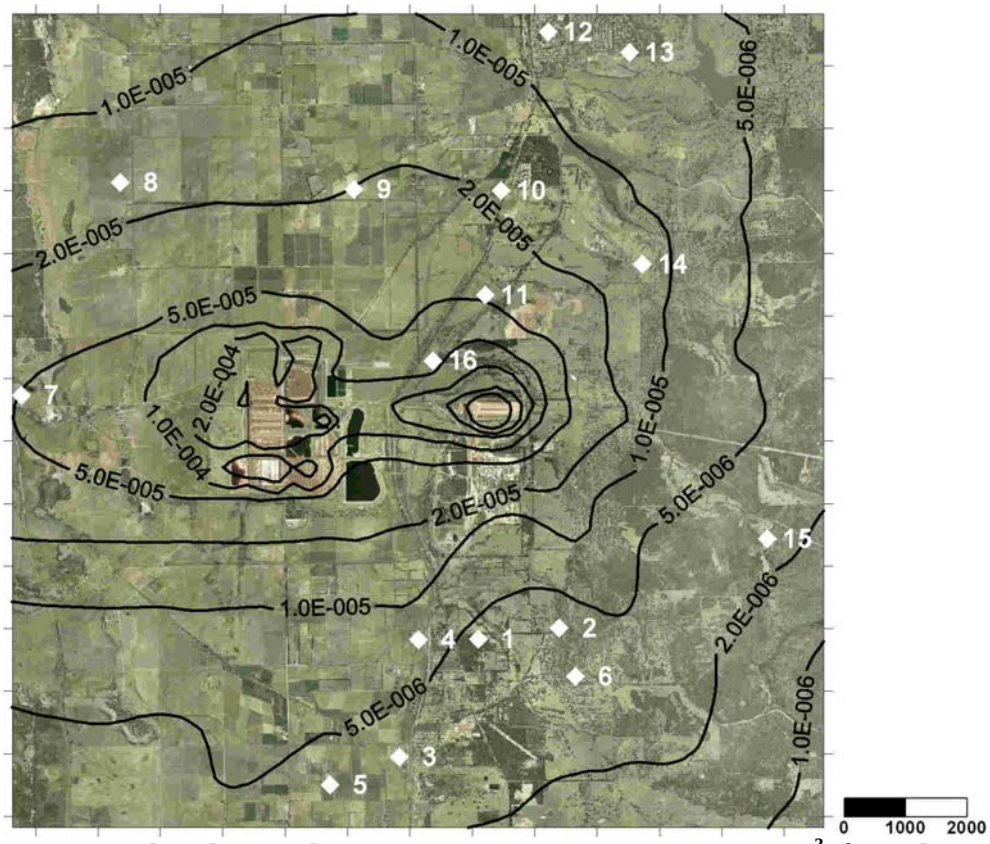


Figure 8.11 Predicted Annual Average Arsenic Concentrations (µg/m^3) from the Expanded Refinery

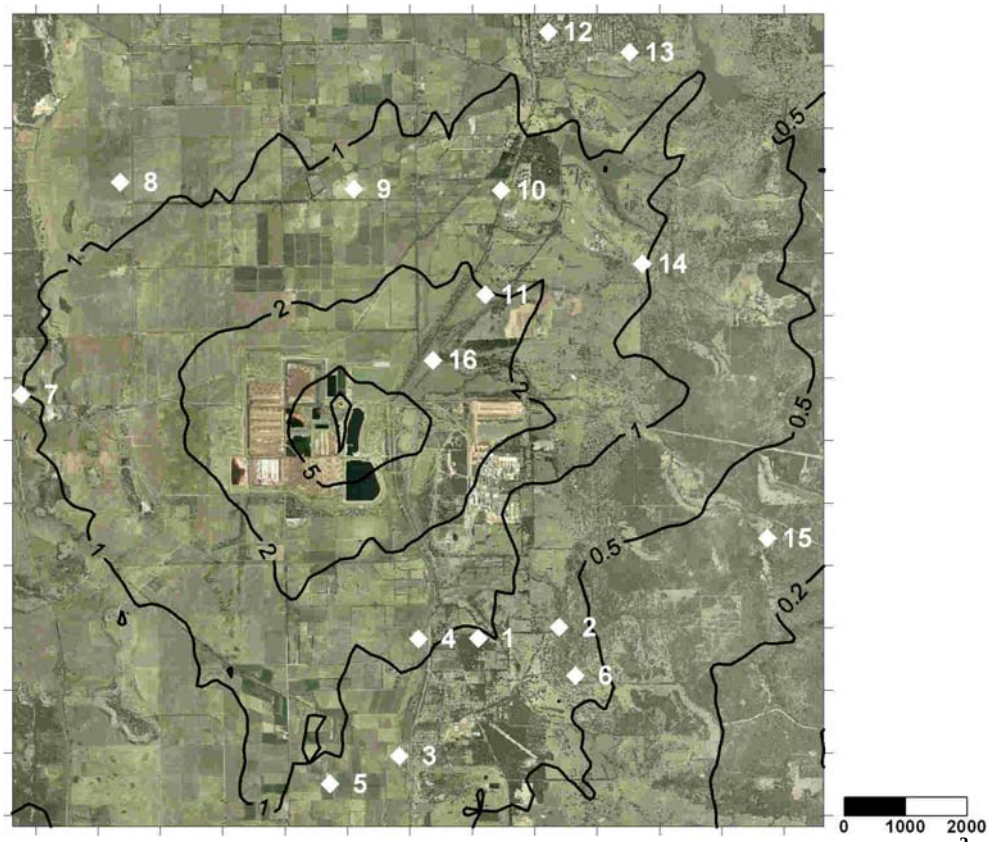


Figure 8.12 Predicted 1-hour 99.9 Percentile Acetaldehyde Concentrations (µg/m^3) from the Expanded Refinery

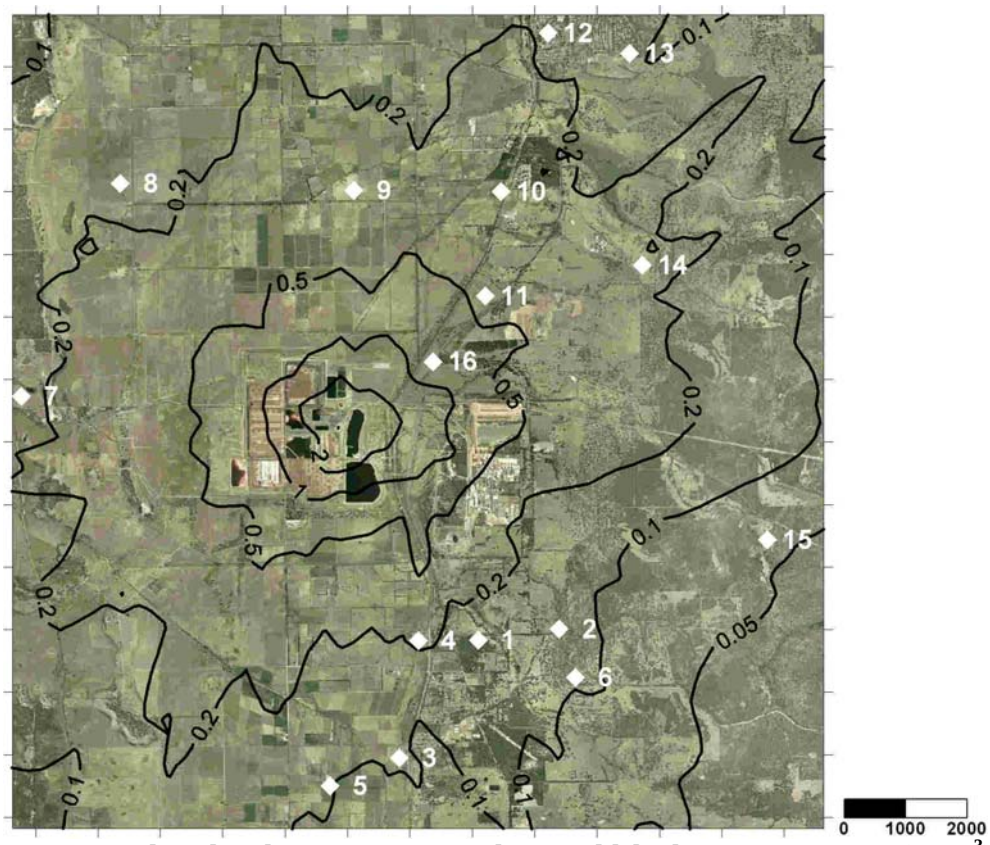


Figure 8.13 Predicted 24-hour 99.5 Percentile Acetaldehyde Concentrations (µg/m^3) from the Expanded Refinery

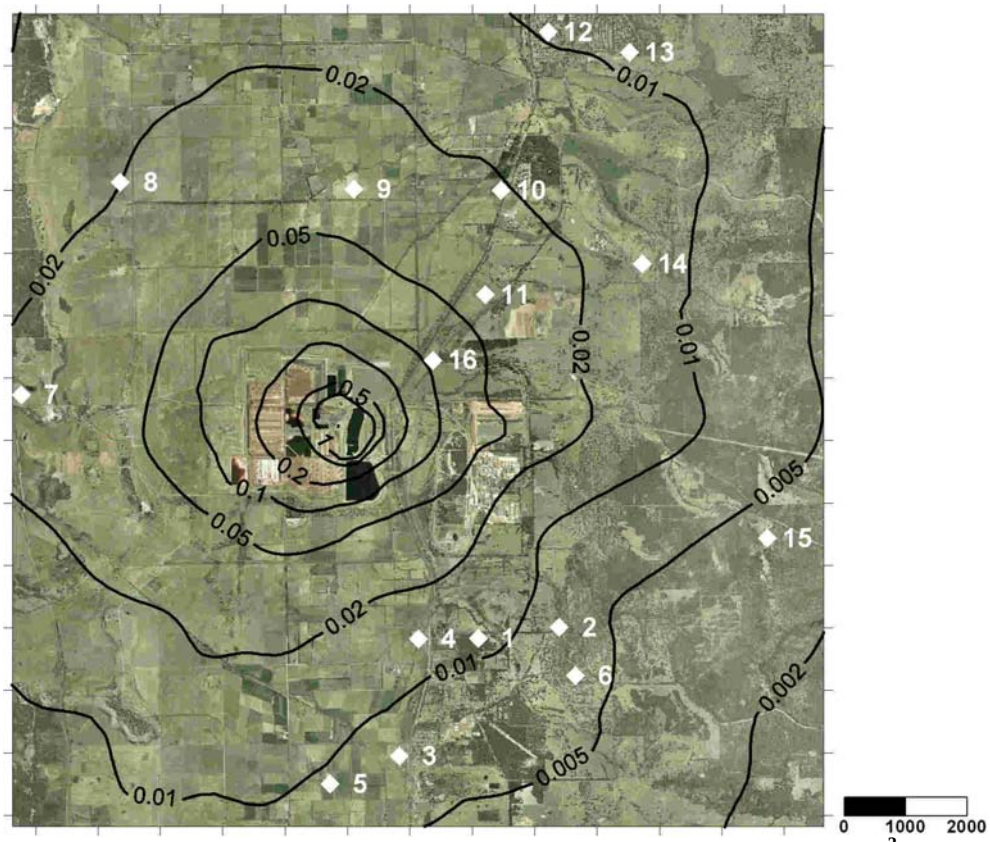


Figure 8.14 Predicted Annual Average Acetaldehyde Concentrations (µg/m^3) from the Expanded Refinery

Table 8.8 Wagerup Refinery - Relative Change in Concentrations from the Base Case to Expansion Case. 1-hour 99.9 Percentile

Substance	Receptor Number																Ratio of Highest in Expansion to Base Case
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
PM_{10}	1.06	1.59	1.26	0.97	1.10	1.65	0.87	1.30	1.43	1.26	1.78	1.34	1.24	1.56	1.61	1.75	0.87
Arsenic	1.01	1.34	1.26	0.98	1.17	1.10	0.77	1.04	1.19	0.99	1.37	1.01	1.12	1.67	1.18	1.63	0.77
Selenium	1.06	1.59	1.26	0.97	1.10	1.65	0.87	1.30	1.43	1.26	1.78	1.34	1.24	1.56	1.61	1.75	0.87
Manganese	1.07	1.41	1.24	0.97	1.13	1.32	0.82	1.08	1.22	0.97	1.61	1.13	1.36	1.64	1.44	1.80	0.82
Cadmium	1.06	1.59	1.26	0.97	1.10	1.65	0.87	1.30	1.43	1.26	1.78	1.34	1.24	1.56	1.61	1.75	0.87
Nickel	1.06	1.59	1.26	0.97	1.10	1.65	0.87	1.30	1.43	1.26	1.78	1.34	1.24	1.56	1.61	1.75	0.87
Mercury	0.06	0.10	0.09	0.11	0.06	0.11	0.05	0.11	0.08	0.10	0.10	0.07	0.11	0.20	0.11	0.09	0.09
Benzo(a)pyrene (BaP)	1.38	1.39	1.36	1.33	1.35	1.50	1.40	1.31	1.25	1.37	1.44	1.36	1.37	1.36	1.39	1.30	1.30
Acetone	1.11	1.17	1.05	1.22	1.11	1.04	1.03	1.15	1.16	1.08	1.16	1.16	1.13	1.10	1.24	1.10	1.10
Acetaldehyde	1.17	1.20	1.03	1.21	1.06	1.05	1.09	1.17	1.14	1.12	1.15	1.13	1.07	1.10	1.22	1.09	1.09
Formaldehyde	1.76	1.62	1.58	1.72	1.54	1.79	1.58	1.76	1.78	1.37	1.48	1.66	1.54	1.39	1.43	1.58	1.58
2-Butanone	1.18	1.20	1.01	1.21	1.20	1.07	1.08	1.19	1.18	1.20	1.21	1.17	1.14	1.12	1.17	1.11	1.11
Benzene	1.28	1.35	1.23	1.34	1.29	1.19	1.26	1.32	1.28	1.31	1.30	1.29	1.26	1.28	1.27	1.28	1.28
Toluene	1.17	1.26	1.15	1.32	1.19	1.15	1.18	1.19	1.24	1.09	1.14	1.19	1.22	1.07	1.28	1.09	1.09
Xylene	1.44	1.42	1.39	1.42	1.39	1.41	1.39	1.29	1.31	1.42	1.41	1.39	1.41	1.41	1.39	1.35	1.35

Table 8.9 Wagerup Refinery -Relative Change in Concentrations from the Base Case to Expansion Case. 24-hour 99.5 Percentile

Substance	Receptor Number																Ratio of Highest in Expansion to Base Case
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
PM_{10}	1.08	1.43	1.01	0.98	1.36	1.24	0.87	1.19	1.07	1.03	1.41	1.06	1.21	1.66	1.88	1.59	0.87
Arsenic	1.03	1.50	0.84	0.78	1.38	1.26	0.81	1.29	1.01	0.97	1.19	0.99	0.85	1.47	1.26	1.49	0.81
Selenium	1.08	1.43	1.01	0.98	1.36	1.24	0.87	1.19	1.07	1.03	1.41	1.06	1.21	1.66	1.88	1.59	0.87
Manganese	1.05	1.54	0.91	0.86	1.31	1.39	0.84	1.22	1.01	1.00	1.30	1.02	1.08	1.57	1.44	1.68	0.84
Cadmium	1.08	1.43	1.01	0.98	1.36	1.24	0.87	1.19	1.07	1.03	1.41	1.06	1.21	1.66	1.88	1.59	0.87
Nickel	1.08	1.43	1.01	0.98	1.36	1.24	0.87	1.19	1.07	1.03	1.41	1.06	1.21	1.66	1.88	1.59	0.87
Mercury	0.04	0.11	0.09	0.09	0.05	0.12	0.05	0.11	0.06	0.08	0.08	0.05	0.14	0.17	0.14	0.09	0.09
Benzo(a)pyrene (BaP)	1.38	1.40	1.35	1.39	1.35	1.46	1.30	1.31	1.28	1.34	1.33	1.38	1.41	1.43	1.34	1.17	1.17
Acetone	1.07	1.13	1.03	0.93	1.23	1.05	1.02	1.13	1.24	1.16	1.07	1.25	1.27	1.06	1.11	1.05	1.05
Acetaldehyde	1.07	1.12	1.02	0.93	1.22	1.06	1.02	1.12	1.24	1.15	1.07	1.23	1.26	1.09	1.11	1.07	1.07
Formaldehyde	1.74	1.80	1.42	1.61	1.58	1.77	1.44	1.54	1.76	1.46	1.49	1.45	1.56	1.45	1.47	1.84	1.84
2-Butanone	1.07	1.16	1.03	0.93	1.23	1.10	1.03	1.15	1.26	1.18	1.09	1.26	1.27	1.07	1.13	1.10	1.10
Benzene	1.22	1.32	1.23	1.19	1.32	1.29	1.28	1.33	1.33	1.30	1.19	1.30	1.36	1.22	1.29	1.30	1.30
Toluene	1.15	1.23	1.17	1.03	1.22	1.15	1.10	1.15	1.21	1.18	1.10	1.24	1.26	1.16	1.17	1.01	1.01
Xylene	1.42	1.39	1.40	1.43	1.39	1.48	1.35	1.36	1.33	1.38	1.37	1.39	1.36	1.30	1.38	1.40	1.40

Table 8.10 Wagerup Refinery - Relative Change in Concentrations from the Base Case to Expansion Case. Annual Average

Substance	Receptor Number																Ratio of Highest in Expansion to Base Case
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
PM_{10}	1.28	1.45	1.42	1.29	1.40	1.43	1.11	1.60	1.73	1.49	1.56	1.54	1.42	1.60	1.61	1.60	1.13
Arsenic	1.18	1.33	1.32	1.17	1.30	1.31	1.08	1.58	1.68	1.36	1.40	1.45	1.31	1.47	1.48	1.46	1.08
Selenium	1.28	1.45	1.42	1.29	1.40	1.43	1.11	1.60	1.73	1.49	1.56	1.54	1.42	1.60	1.61	1.60	1.13
Manganese	1.22	1.38	1.36	1.22	1.34	1.36	1.09	1.59	1.70	1.42	1.48	1.49	1.36	1.54	1.54	1.53	1.09
Cadmium	1.28	1.45	1.42	1.29	1.40	1.43	1.11	1.60	1.73	1.49	1.56	1.54	1.42	1.60	1.61	1.60	1.13
Nickel	1.28	1.45	1.42	1.29	1.40	1.43	1.11	1.60	1.73	1.49	1.56	1.54	1.42	1.60	1.61	1.60	1.13
Mercury	0.07	0.09	0.08	0.08	0.06	0.09	0.05	0.06	0.07	0.11	0.14	0.09	0.11	0.14	0.14	0.12	0.12
Benzo(a)pyrene (BaP)	1.36	1.37	1.36	1.36	1.36	1.36	1.32	1.33	1.32	1.33	1.33	1.33	1.34	1.35	1.34	1.33	1.33
Acetone	1.08	1.06	1.06	1.04	1.07	1.06	1.01	1.00	1.12	1.10	1.12	1.08	1.09	1.12	1.09	1.17	1.17
Acetaldehyde	1.07	1.06	1.06	1.03	1.07	1.06	1.03	1.02	1.13	1.10	1.12	1.08	1.09	1.12	1.09	1.17	1.17
Formaldehyde	1.60	1.54	1.55	1.59	1.57	1.53	1.57	1.58	1.60	1.47	1.41	1.51	1.49	1.43	1.39	1.47	1.47
2-Butanone	1.08	1.07	1.06	1.04	1.08	1.07	1.01	0.99	1.12	1.11	1.14	1.09	1.10	1.13	1.11	1.19	1.19
Benzene	1.26	1.26	1.26	1.24	1.26	1.27	1.29	1.30	1.32	1.29	1.29	1.28	1.30	1.30	1.29	1.33	1.33
Toluene	1.14	1.13	1.14	1.12	1.14	1.13	1.13	1.15	1.19	1.16	1.17	1.16	1.16	1.17	1.16	1.21	1.21
Xylene	1.40	1.41	1.40	1.40	1.40	1.40	1.37	1.38	1.36	1.37	1.37	1.38	1.38	1.39	1.39	1.38	1.38

8.3 Conditions Leading to Maximum Offsite Concentrations

An analysis of the highest hourly VOC concentrations that are predicted to result from the residue area sources, indicate that these generally occur under wind speeds from 1 to 4 m/s and stable to neutral stabilities. These are higher wind speeds than would occur for a surface release with a constant emission rate, where very low wind speed, class F conditions typically lead to the highest concentrations offsite as they result in the lowest amount of dilution and dispersion of the plumes. For emissions which are wind speed dependent, the increase in emissions with wind speed partially counteracts the increase in dilution and dispersion with the higher wind speeds. That the lower incidence of stable class F conditions in the TAPM derived winds compared to the observed winds is not the reason for the lack of higher concentrations from these conditions (see **Appendix C**), can be seen in the good comparison with the model predictions using the observed wind data as presented in **Appendix D**.

8.4 Odour Levels

Figure 8.15 and **Figure 8.16** present the predicted 99.9 and 99.5 percentile 3-minute odour concentrations from the base case using the modified model and emission setup as described in **Section 7.3**. Maximum 3 minute concentrations were estimated from the 1-hour concentrations using a simple power law formula as commonly used in odour assessments where:

$$C_1 = C_2 (Tave_1/Tave_2)^{pa} \qquad \textbf{Equation 8-1}$$

Where $Tave_1$ and $Tave_2$ are the averaging times for 1 and 2
C_1 and C_2 are the concentrations for averaging times 1 and 2; and
pa is an exponent

For the exponents a value of 0.1 for the stable conditions and 0.15 for the neutral and unstable conditions was used based on that recommended by Katestone Scientific (1998) for area sources and as incorporated within the NSW modelling guidelines (NSW EPA, 2004). This results in multipliers of 1.35 and 1.57 to convert 1-hour concentrations to 3-minute concentrations.

Figure 8.15 and **Figure 8.16** indicate that the high odour concentrations are predicted to extend furtherest in the east west direction, with relatively lower concentrations in the north and south directions. The lower concentrations in the north south directions are due partially to the effect of plume rise over the cooling pond when the wind "blows" along the near north south, main axis. For winds across the cooling pond (easterlies and westerlies), there is minimal plume lift off and therefore higher concentrations down wind.

Figure 8.17 and **Figure 8.18** present the 99.9 and 99.5 percentile 3-minute odour concentrations from the expanded case. This shows a small increase in concentrations from the base case, which is in line with the small (7% overall) increase in the emissions as detailed in **Table 6.4**.

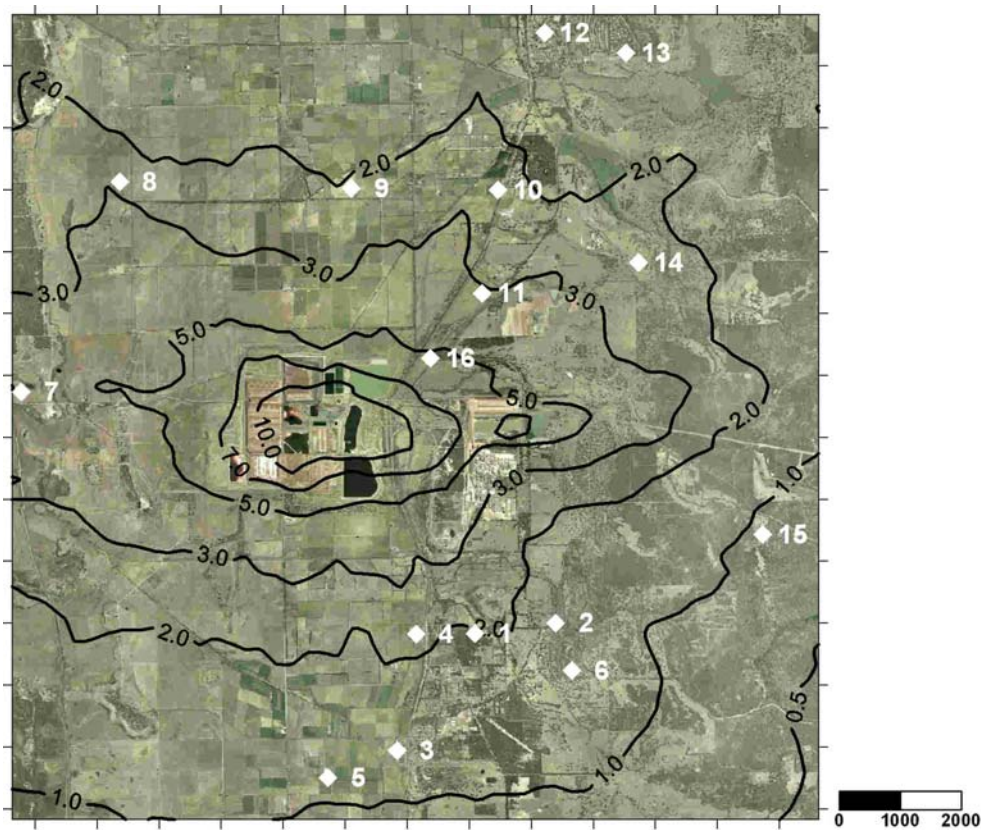


Figure 8.15 Predicted 99.9 Percentile 3-Minute Odour Concentrations (ou) from the Base Case Refinery

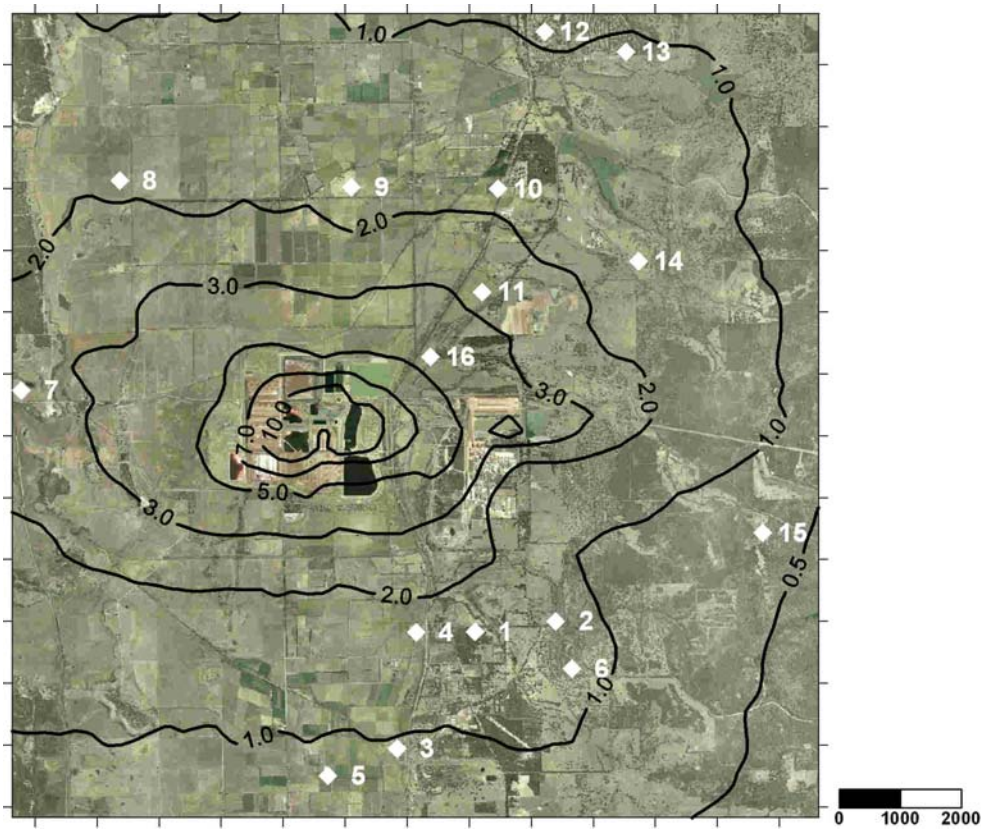


Figure 8.16 Predicted 99.5 Percentile 3-Minute Odour Concentrations (ou) from the Base Case Refinery

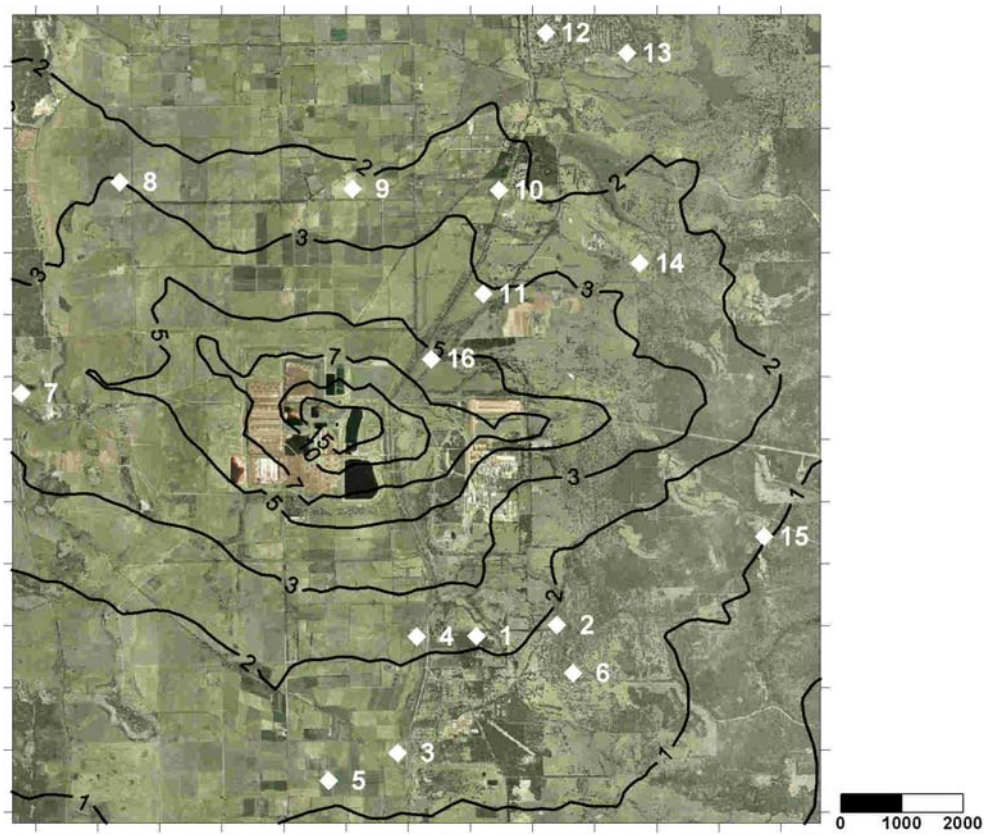


Figure 8.17 Predicted 99.9 Percentile 3-Minute Odour Concentrations (ou) from the Expanded Refinery

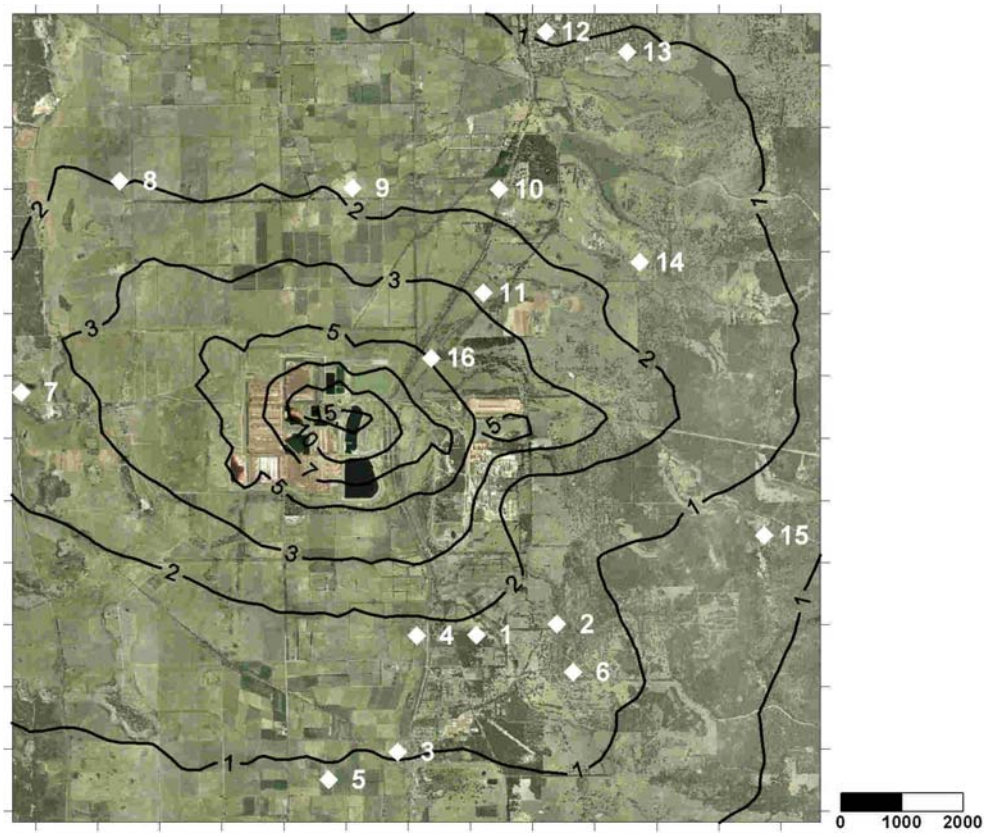


Figure 8.18 Predicted 99.5 Percentile 3-Minute Odour Concentrations (ou) from the Expanded Refinery

8.5 Uncertainty in the Predictions

The following section presents a qualitative overview of the uncertainty in the predictions that has also been covered in the various sections of the report. This analysis is based on comparison of model predictions to observations where available. A quantitative assessment is not considered possible due to the many factors which are not precisely known.

The main areas of uncertainty in this study arise from the:

1. Representativeness of the meteorological data for the task of modeling;
2. Representativeness of the meteorological period for modeling;
3. Accuracy of the emission estimates;
4. Accuracy of the modelling system; and
5. Accuracy in modeling chemical transformation, loss and deposition.

Point 1 has been covered in **Section 2 2** where it is noted that the winds in the region are complex with on occasions large changes in wind speeds and directions over a few kilometres. In the fugitive modelling, TAPM winds have been used to be consistent with the winds used in the refinery modelling in order to enable the merging of the results from the fugitive and refinery studies. The TAPM winds also provide a grided wind field for the region. It is noted that TAPM winds (without data assimilation) in general: do not correctly predict the frequency of light near-calm winds; tend to over predict the strength of the easterly foothill winds; and under-predict the frequency of northerly winds, particularly close to the scarp. It is argued that to more accurately model the emissions and dispersion of substances from the residue area, a local residue wind site is required. This data is available from the RDA3 wind sensor, though its use was not intended for air quality studies and there are some issues with its siting and the stalling of the sensor.

An attempt has been made to correct the RDA3 wind data as discussed in **Appendix A**. A comparison of predictions using the TAPM winds and the RDA3 corrected winds showed reasonable agreement with the predictions generally being within 50%, though for some statistics and some areas the observed winds predicted higher concentrations by a factor of 2 than predicted by TAPM winds. Conversely the TAPM winds in some areas predicted concentrations around a factor of 2 higher than the observed winds. As such, it is considered that the TAPM winds are reasonably representative for the task of modelling the dispersion from the residue area. If more accurate predictions are required an air quality grade meteorological station is however required sited adjacent to or on the residue area.

Point 2 has been covered in **Section 2.1.6** where it is considered that 2003/2004 had

- 7% less easterlies and 17% less strong easterlies (greater than 10 m/s) than the on average;
- Had a low percentage of strong northerlies; and
- Slightly above average frequency of light winds.

As such, it should be reasonably representative for predicting VOCs from surface releases where highest concentrations occur under low wind speeds, but it may under-predict the PM_{10} and metal concentrations to the east and south of the residue area which are dependent primarily on wind erosion.

Point 3 regarding the accuracy of the emissions estimates is very difficult to quantify for VOC emissions. For PM_{10} it is considered that predictions will be more accurate as the model emissions of TSP were calibrated against observations to provide a reasonable match to the observations. Predictions of PM_{10} are then based on fairly standard PM_{10}/TSP fraction from similar studies at Pinjarra and supported by Alcoa's ambient measurements at Pinjarra and Wagerup. The metal predictions will be less certain, as there is some uncertainty to whether some metals will have higher percentages in the dust than in the bulk residue samples. In this study the speciation from the fine residue which is already less than 150 µm was used, such that it should be reasonable close to PM_{10} fraction. The metal speciation also will tend to be lower than the bulk sample as sodium carbonate tends to be "enriched" in the surface dust from the drying areas. Therefore, PM_{10} and metals are considered to be reasonable well predicted for the year modelled.

The VOC predictions are considered to have greater uncertainty, but are expected to be high or conservative. The uncertainty arises from difficulties and uncertainty in the flux chamber measurements as noted in the GHD report, and the difficulty in equating flux chamber measurements in a controlled environment to that of the real world. In particular - as to what wind speed conditions the flux chamber measurements represent and how the emissions vary with wind speed and temperature in the free atmosphere. Further the relationship with wind speed may be different for the individual VOCs that are emitted, as noted by Jiang and Kaye (1996). The conservatism considered is a result of the VOC modelling not accounting for plume rise from the heated water surfaces where most of the VOC emissions originate (the cooling pond, RDA2 surface and sand lake) and also for the increased dispersion from these surfaces as demonstrated in the CFD modelling (PAE, 2005). Data from the field odour surveys also indicate that the wind speed conditions that the flux chamber represents may be higher than that assumed, with the emissions increasing to a higher power of wind speed than 0.5, such that concentrations at the lower wind speeds are reduced. This may result in an over prediction by 3 to 5 times (as found for modelling odours) with the assumptions used in the VOC set up compared to that used in the revised odour modelling set up in **Section 7.3**.

For the odour predictions, the areas of conservatism that were noted in the VOC modelling were addressed somewhat, such that predictions should be more realistic than the VOC predictions. The greatest uncertainties in the modelling again are in the uncertainty in the emission rates used, and how they relate to ambient wind speed and temperature. Additionally, there are uncertainties in the model changes for increased plume rise and increased dispersion which are not well defined as yet, with these requiring further work to refine them.

Point 4. The modelling system is based on a standard model used throughout the world with, which has been verified on numerous occasions and used previously at Wagerup to predict the NO_X concentrations from the refinery reasonably well (SKM, 2002a). Further in the modelling of PM_{10} and metals in fugitive dust it has been calibrated to match the observations. However, as stated above, the modelling approach for VOCs is considered conservative as plume rise from the warm water surfaces were not

taken into account and because there has been much less continuous data available for model calibration.

Point 5. Chemical transformation of VOCs was neglected such that model predictions of species with a short half life, such as formaldehyde will be over predicted. Simple calculations suggest that this may lead to an over prediction by 20 to 50% for formaldehyde and between 3 to 6 % for acetaldehyde (see **Section 4.4**). Deposition of dust and its depletion with distance were considered using the standard methodology within Calpuff. Wet deposition due to rain events was neglected as this will be a small effect, with dust events occurring primarily in dry weather. As such, these effects are considered to have been appropriately modelled and if not a conservative assumption made.

Therefore overall, it is considered that uncertainties in the assessment primarily arise in the VOC predictions through uncertainties in the emissions. Any underestimation in the emissions is likely countered however, in that cooling pond plume rise and consequent increased dispersion and increased wind speed dependence have been neglected in the VOC modelling, resulting in conservative estimates. For PM_{10} and metals the major uncertainty is considered to be in the representativeness of the 12 months modelled, with the predictions for this period probably being lower than an average year and certainly a year with above average strong winds. Additionally, the use of TAPM winds (non assimilated) is shown to lead to under-predictions to the south, whilst over-predicting to the west north west of the residue area.

9 Conclusions

This report presents an assessment of likely ground level concentrations from substances emitted from fugitive sources at the Wagerup refinery for both the existing base case and a future expansion case. These results, along with predicted ground level concentrations from stack and vent sources at the refinery CSIRO (2005a and b) are required as inputs into the health risk assessment (HRA) of the refinery (ENVIRON et al, 2005).

Fugitive sources that are covered in this study include, particulate matter emitted from the residue area and bauxite stockpile area and VOC emissions from the residue area and the lower dam. Minor sources such as vehicular generated dust and wind erosion at the refinery have been omitted as small compared to these modelled sources.

Emissions of particulate matter from the residue and bauxite stockpile area were based on emissions estimates developed from the Pinjarra and Kwinana refineries, expressed as a function of the wind speed. These were initially adjusted to the Wagerup refinery by the relative area of exposed ground and relative throughputs of bauxite. These emissions were then used within a model, Calpuff to estimate ground level concentrations, with the emission factors adjusted to better match the observed dust levels at Wagerup. This process of adjustment, or calibration is necessary as the operations and controls at the various sites are different, and as the emission method is sensitive to wind speed. Further there are siting and exposures issues for the wind measurements at each site which need to be corrected for.

The resultant particulate estimates, indicate that on an annual basis, the major sources of dust are wind erosion from the residue area and then the bauxite stockpiles, followed by dust generated from operational activities on the residue area and stockpiles. On a short term, hourly basis, wind erosion from the residue area and the bauxite stockpiles are by far the largest sources.

Emissions of VOCs were obtained from flux chamber measurements conducted by GHD (2005). The flux chamber was selected for measurement as it has the lowest detection limits of any of the methods available. A preliminary comparison of the emissions determined from the flux chamber with that from down wind sampling and back-calculation was conducted for acetone, 2-butanone and odour for the cooling pond and for acetone and odour for the drying areas. These indicate good agreement assuming a wind speed dependence of the liquid surface emissions and assuming that the flux chamber emissions are representative of very low wind speed conditions. In developing an emission data base for modelling, the emissions from the liquid surfaces where specified to vary with the wind speed to the power of 0.5, whilst emissions from the dry stacked areas were assumed constant, except for two species whose emissions were dependent on temperature.

The resultant annual emission file indicated that the major sources of VOCs for the existing refinery diffuse sources in order of decreasing ranking are the:

- Cooling pond (accounts for at least 50% of 7 of the 8 modelled VOCs);
- Super thickener;

- RDA2 liquor areas;
- Sand Lake; and
- The ROWS pond, lower dam, dry stacked RDAs and ROCPs were all minor emitters - except for formaldehyde where they contributed 38.4, 20.4, 15.6 and 14.8% of the fugitive emissions respectively.

Predictions of ground level concentrations were conducted using the Calpuff modelling system, an annual meteorological file and the emission estimates derived emissions on an hourly basis. The meteorological file was derived using winds predicted by TAPM as used in the refinery modelling by CSIRO. This was selected as the predictions from the TAPM refinery emissions modelling are to be added with these predictions on an hourly basis and consistent wind fields between the two models are required. An alternative meteorological file was also derived using observed winds. Comparisons of the winds indicate that there are significant differences with TAPM tending to predict higher frequency of high wind speed easterlies than observed and a lower than observed amount of low wind speeds. Comparison of the model outputs for the VOCs however indicate relatively small differences, which are considered to be due to the highest concentrations occurring for wind speeds in the range of 1 to 3 m/s, where TAPM performs best at predicting the observed wind conditions.

Modelling of fugitive particulate and metal concentrations from the base case, indicate that the highest concentrations will occur to the west of the residue area and bauxite stockpile area, due to strong easterly winds that develop during the summer months. For the VOC emissions the predicted concentrations are more circular and are due to the more even frequency distribution of lighter winds.

Estimates of the emissions for the expansion case were derived based on engineering advice from Alcoa. These changes included: locations of new RDAs and changes in the drying areas; changes to the bauxite stockpile area; increase in tonnages, improvement in dust control, such as a new water cannon layout to be installed on all new and old RDAs; and the expected changes in the VOC content and flows of the various liquid streams. Based on the above changes, fugitive PM_{10} emissions were predicted to decrease by 7% at the residue area, whilst increasing by 57% at the stockpile area, with an overall increase of 9%. Metals emissions were estimated to increase by between 1 to 13%. Emissions of VOCs for the upgrade were predicted to increase between 4% (acetaldehyde) to 49% for formaldehyde with odours estimated to increase by up to 7%

Utilising these estimates within Calpuff, it is predicted that:

- At the receptor with the highest 1 hour (99.9 percentile) and 24-hour (99.5 percentile), PM_{10} and metal concentrations (receptor 7), the concentrations will decrease. This is due to the predicted better control of dust at the residue area, being the largest source of dust at this monitor. At other locations, with lower dust concentrations, the concentrations are predicted to increase, particularly for those closer to the bauxite stockpiles with the concentrations predicted to increase by between 1.6 to 1.8 times (receptor 16). This increase at receptor 16 is due to a predicted increase in dust emissions from the bauxite stockpiles.
- Annual average metal concentrations are predicted to increase by between 8 and 13% at receptor 7 (the receptor in the base case with highest concentrations), with an increase of

between 46 to 60% for receptor 16 (which now becomes the receptor for highest concentrations of 3 of the 5 metals modelled).

- Mercury concentrations are predicted to substantially decrease, with concentrations only 4 to 20% of the existing concentrations.
- VOC concentrations are predicted to generally increase with a few exceptions for one or two receptors. In general, the concentrations are predicted to increase between 11% for acetone and acetaldehyde to 57% for formaldehyde.

An assessment of the likely odour concentrations from the fugitive sources is also presented. This was conducted utilizing results from field odour surveys and computational fluid dynamics (CFD) modelling, that was not available at the time of the VOC modelling. The CFD modeling results indicate that substantial plume lofting from the cooling pond occurs when the wind is along the main pond axis, especially for light winds and neutral conditions. Under stable, night time conditions, the CFD modeling still predicted that the plume rise would be around 25 to 40m. Plume lofting was also predicted for the super thickener. The CFD modeling also predicted that the initial dispersion from the warm pond surfaces was greater than would be predicted otherwise.

Using the CFD modeling results, simple parameterisations were incorporated into the odour modelling to account for the plume rise from the cooling pond and super thickener, the increased dispersion from the warm ponds and with a revised odour emission, wind speed relationship. The resultant odour concentrations predicted were 3 to 5 times lower than predicted using the VOC model setup and were in much better agreement with those observed in the field odour surveys, though still tending to over-predict the overall odour concentrations. Therefore, it is expected that the modeling for the VOCs in the HRA is likely to be over-predicted by a similar amount.

10 Recommendations

To improve the model estimates, if required, the following are recommended:

Meteorology and Modelling

- Wind flow in the Wagerup area is noted as being complex compared to other areas with the development of strong easterly foothill winds, wind reversals, rotors and channelling of the wind by the scarp. As such, any weather station will only be representative of a limited area. Therefore to improve model predictions, it is recommended that at least three meteorological stations are required. These are at the base of the scarp (where the new scarp monitor is being sited), at Bancell road and near the residue area. Additionally, a site near Yarloop would be advantageous. Though not required specifically for modelling fugitive sources, wind profile data up to several hundred metres or possibly a taller meteorological station would assist predictions especially for the refinery plumes.
- To improve the modelling of dispersion from the heated liquid surfaces, more realistic approximations should be used. It is considered that the ponds could be approximated as a stack source to achieve the correct plume rise as predicted using the CFD modelling. CFD modelling of other conditions, including the wind at 45 degrees from the long axis are recommended to determine the plume rise as a function of wind direction. Additionally, further tests for cross wind flows at low wind speeds are required, as well as tests to determine the possible effects of the terrain in the first hundred metres around the site.
- The predictions in this assessment are only for one 12 month period from 1 April 2003 to 31 March 2004. This is considered to be a year with slightly above average light wind conditions, but with a lower than average frequency of strong easterly and northerly winds. Therefore, it is considered that the VOC concentrations will be reasonably predicted though the TSP and metals may be understated. As such, if a more accurate assessment of PM_{10} and metal concentrations is required and to a lesser degree VOC concentrations, at least one or more other years of meteorological data are required. For PM_{10}, these should capture the infrequent northerly "gales" that can occur.

Monitoring

- Consideration should be given to shifting some of the dust monitoring sites or reducing the local sources of dust near them. This should occur in particular for the BRW and NW monitors site and to a lesser degree the West monitor. Sources of dust at these sites may include livestock and general farming practises, which could be limited by fencing off a larger area near the monitors.

Emissions

- It is considered that emissions of PM_{10} are reasonably well quantified through the calibration of the model with the ambient monitoring data. Emissions of VOCs and odour are less well defined. To improve these, more emission measurements are required, preferably using down wind sampling with back-calculation of emissions. Though this can only be achieved for several species, it is considered more appropriate in that it provides representative emissions of

a large source area and do not interfere with the emission processes. Such methods should provide emission rates for several species and odour and be used to determine the wind speed and temperature dependence. Flux chamber data can then be used to extrapolate these data to other species if required. Alternatively, use of the flux chamber could be continued if its relationship to actual atmospheric conditions could be better determined.

- It is recommended that for estimating odour from back calculation of field odour survey data, odour intensity/concentration data is required for the major sources, the cooling pond, RDA2 liquor surface and the sand lake liquor. This is required to provide a more accurate estimate of the odours as the current concentrations are based on using the odour intensity/concentration relationship from slurry tank odour. Additionally, the field odour methodology should be validated against the Australian Standard method of sampling by bag and sending to laboratory for dynamic olfactometry analysis. This will need to be undertaken at a location of reasonably high concentrations, such as immediately down wind of the cooling pond, but would provide more confidence in the field odour survey methods
- As the relative change in concentrations between the base and expansion case are dependent on a range of assumptions, it is considered that a further review of assumptions in the emissions should be undertaken. For example, it is considered that the assumption of the change in dust emissions from the bauxite stockpiles, based purely on the increase in bare area may overstate the emissions as the additional emergency stockpile should be less susceptible to wind erosion than an active stockpile. Additionally, the modelling did not account for changes in the coarse/fine residue split. This may have the affect of making the coarse residue stockpile areas prone to generate more dust than they currently do.
- As the recent validation of the model with field odour survey data indicates that the VOC concentrations could be significantly overstated it is recommended that these be remodelled with the new model and emission set-up.
- In calibrating the model, the mineral sand mines should be included as advice now indicates that it can be a significant source of dust concentrations to the NE monitor.
- To further refine the metal speciation in the dust, metal speciation of dust from a range of dust events due to Alcoa operations for the critical species are required. Such data could be obtained from analysis of filter paters at Wagerup and also should be available from the Pinjarra fine particle study currently in progress.

11 References

Alcoa, (2004a). Email from Patrick Coffey of Alcoa Australia on November 11, 2004.

Alcoa, (2004b). Email from Hannah Struckman of Alcoa Australia on November 11, 2004.

Alcoa, (2005a). Email from Ian Yull (seconded to Alcoa Australia) of March 10, 2005 on existing and future lateral failures titled "Lateral 03/04 summer"

Alcoa, (2005b). Email from Hannah Struckman of Alcoa Australia on March 22, 2005 regards sources of dust at the NE monitor.

Alcoa, (2005c). WG residue composition.doc (from TDG group) via email from P Coffey of Alcoa Australia on November 11, 2004

Alcoa, (2005d). Email from P Coffey of Alcoa Australia on January 28, 2005 titled "Metal Speciation"

Alcoa, (2005e). *Derivation of Diffuse Source Emission Rates for HRA Modelling - VOCs and Odour from Wagerup Refinery RDA Source.* Report by Patrick Coffey, Alcoa. Emailed 4 April, 2005

Alcoa, (2005f). Email from Ian Yull (seconded to Alcoa Australia) on March 14, 2005 titled "RDA Areas for modelling 14 Mar 05.xls"

Alcoa, (2005g). Email from P Coffey of Alcoa Australia on March 15, 2005, titled "Changes to RDA Emission Concentrations with Expansion"

Alcoa, (2005h). Spreadsheet WGCombinedEmissionsRev9a.xls as emailed from P Coffey of Alcoa Australia on March 30, 2005.

Aust-Environ (Patrick Coffey Engineering) (1984). *Report on a residue disposal dust study. Internal Alcoa Kwinana Document*.

Air Water Noise (AWN), (2003). *Environmental Audit: Alcoa World Alumina Australia Wagerup refinery, April 2002 - May 2003.* Final report for Department of Environmental Water and Catchment Protection, Perth, Western Australia.

Bagnold R.A. (1941). *The Physics of Blown Sand and Desert Dunes*. Methuen, London 265 pp.

Bell, P. (1984). *Micrometeorological and statistical analysis of wind blown dust.* Honours thesis Murdoch University

Blockley, J. A. and Lyons T. J. (1994). *Airflow over a two dimensional escarpment. III: Nonhydrostatic Flow.* Q. J. R. Meteorol. Soc. 120, 79-109.

Bliss, P.J. Kiang, K. Schulz, T.J. (1995). *The development of a sampling system for the determination of odor emission rates from areal surfaces II. Mathematical Model.* J. Air Waste Management Assoc.

Cavanaugh, T.A. Siegell, H. J. H. and Steinberg, K.W. 1994. *Simulation of vapour emissions from liquid spills.* J. Hazardous Materials, 38-41.

Cmemfate, (1994). Syracuse Research Corporation's Environmental Fate Data Bases. Syracuse Research Corporation, Syracuse, NY. Available online at http://www.syrres.com/esc/chemfate.htm

Coffey, P. and Evans, N. (2000). *Estimation of fugitive PM_{10} dust emissions from exposed tailings by monitoring & modelling*. In Conference Proceedings of the 15th International Clean Air & Environmental Conference. Sydney Australia, 26-30 November 2000.

Coffey, P.S., Scott, W.D., and Summers, K.J., (1986). *The effects of tailing dam profiles on relative wind erosion rates*. J. Env. Quality 15, 168-172.

Countess, R.W. Barbard C, Claiborn, C. Gillette, D. Pace, T. Vimont, J. and Watson, J. (2002). *A review and update of fugitive dust emission estimation methods*. Final Report prepared for Western Governor's Association, Electronically published at http://www.wrapair.org/reports/Dust%20Expert%20Panel%20Follow-Up-Report.pdf. November 2002

CSIRO (2004a). *Meteorological and Dispersion modelling using TAPM for Wagerup. Phase 1: Meteorology*. November 2004.

CSIRO (2004b). *Wagerup Air Quality Review.* May 2004. Prepared for Alcoa World Alumina Australia, Western Australia. Report C/0936

CSIRO (2005a). *Meteorological and Dispersion modelling using TAPM for Wagerup. Phase 3A: HRA (Health Risk Assessment) Concentration Modelling - Current Refinery Scenario.* 14 February 2005.

CSIRO (2005b). *Meteorological and Dispersion modelling using TAPM for Wagerup. Phase 3B: HRA (Health Risk Assessment) Concentration Modelling - Expanded Refinery Scenario*. 11 February 2005.

CSIRO (2005c). *Meteorological and dispersion modelling using TAPM for Wagerup. Phase 1 Meteorology. Appendix A.* Additional modelling details 14February 2005.

Dames & Moore, (1977). *Atmospheric Dispersion and Recommended Chimney Heights. Pinjarra, WA.* September 1977. Report to Alcoa of Australia (WA) Limited.

Dear, S.J., Bell, M.J.and Lyons, T.J. (1990). *Western Australian Wind Atlas and Supplement - Atlas program.* Report No. 4. Minerals and Energy Research institute of Western Australia.. Report 64.

Department of Environmental Protection (DEP), (2002). *Odour Methodology Guideline*, March 2002.

Eklund, B. (1992). *Practical guidance for Flux Chamber Measurements of Fugitive Volatile Organic Emission Rates.* J. Air Waste Management Assoc, 42, 1583-1591.

ENVIRON (2005). *Residue Disposal Area Wagerup.* Sprinkler Deposition Modelling

ENVIRON and Benchmark Toxicology Services Pty Ltd (2005). *Health Risk Assessment of Atmospheric Emissions. Expansion of Wagerup Refinery to 4.7 Mtpa*.

Environment Australia, (2001). *National Pollutant Inventory, Emission Estimation Techniques Manual for Mining*. Version 2.3, Commonwealth of Australia, December 2001.

Environmental Alliances (2001). *Field odour surveys around Alcoa Alumina Refinery, Wagerup – August to September 2001*, November 2001.

Environmental Alliances (2003). *Field odour surveys around Alcoa Wagerup Refinery 2003*, November 2003.

Environmental Alliances (2005). *Wagerup refinery residue disposal areas Field Odour Surveys December 2004 and February 2005.* Prepared for Alcoa World Alumina Australia, April 2005.

Environmental Protection Authority (EPA), 2002, *Guidance for the Assessment of Environmental Factors – Assessment of Odour Impacts from New Proposals No. 47,* March 2002.

EPA (1999). *Revised Draft Environmental Protection (Kwinana)(Atmospheric Wastes) Policy. Report to the Minister for the Environment.* EPA, Perth, WA.

Fryrear, D.W., Bilbro, J.D., Saleh, A., Schomberg, H., Stout, J., and Zobeck, T.M. (1998). *RWEQ: Improved with erosion technology.* J. Soil Water Conserv. 55, 183-189.

FSA Environmental (2000). *Development of a Pig Effluent Emissions Database and Analysis of promising control strategies. Final Report - Part A - Database on odour research and emission rates.* December 2000. Report to the Pig Research & Development Corporation.

Galvin, G. Casey, K.D. Lowe, S. A. Hudson, N.A. Atzeni, M. A. McGahan, E.J. (2003). *Spatial variability of odor emissions from anaerobic piggery lagoons in Queensland*. In Air Pollution from Agricultural Operations III, Proceedings of the 12-15 October 2003 Conference ASAE Publication Number 701P1403, ed H keener.

Galvin, G. Lowe, S. and Smith, R. (2004). *The validation of a simple Gaussian dispersion model for determining odour emission rates from area sources*. Dev. Chem. Eng. Mineral Process. 12(5/6), 1-14.

Galvin, G. (2004). *Back Calculations of OERs*, Wasteline, Queensland DPI, Vol 11, Nov2004, page 5.

GHD (2005). *Emissions to Air from Residue Disposal Area. Assessment of Emissions from Diffuse Area Sources.* Report to Alcoa World Alumina

Hagen, L. (1995). *USDA wind erosion predictions system: Technical description: Introduction.* Proceedings, WEPP/WEPS Symposium, Des Moines, IA.

Halpern Glick Maunsell., (1996). *Residue Area Dust Suppression Cannon Testing*. Report to Alcoa.

Hartman, B. 2003. *How to collect reliable soil-gas data for upward risk assessments. Part 2: Surface flux-chamber method*. LUSTline Bulletin 44, August 2003.

Jiang, K. and Kaye, R. (1996) *Comparison study on portable wind tunnel system and isolation chamber for determination of VOCs from areal sources.* Water Sci. Tech. 34 No 3-4 1996.

Jiang, J. and Sands, J (1998) *Report on odour emissions from Poultry Farms in Western Australia - Principal Technical Report,* Centre for Water and Waste Technology, University of NSW, Sydney.

Jiang, K.J. and Sands, J.R. (2000). *Odour and Ammonia Emission from Broiler Farms. A report for the Rural Industries Research and development Corporation.* February 2000. RIRDC Publication No 00/2.

Katestone Scientific, (1998). *Peak-to-Mean Concentration Ratios for odour Assessments*. Katestone Scientific Pty Ltd, Brisbane.

Lakmaker, S. Holmes, K. Lott, S and Patricks, R. (2003). *Accounting for feedlot management practices in odour dispersion modelling.* In proceedings of the CASANZ National Clean Air conference,, 23-27 November 2003. Newcastle, Australia

Lees, F.P., (1996). *Loss Prevention in the Process Industries*. Butterworths, London.

Lee, S. Cope, M. and Hess, D. (2003). *Forecasting wind-blown dust events with the Australian Air Quality Forecasting System.* In National Clean Air Conference, Newcastle, Australia, 23-27 November.

Lee, S. Cope, M. Hess, D. and Burgers, M. (2004). *Forecasting wind blown dust events with the Australian Air Quality Forecasting System (AAQFS*). Wind-blown Dust Workshop - the emission, transport and impacts of wind-blown dust from soil erosion: modelling and observation 8-10 November 2004 at CSIRO Atmospheric Research, Aspendale, Victoria, Australia.

Midwest Research Institute (MRI), (1998). Emission *factor documentation for AP-42. Section 13.2.2. Unpaved Roads. Final Report*. Report prepared for U.S. Environmental Protection Agency. September 1998.

National Pollutant Inventory (NPI). (2001). *Emission Estimation Technique Manual for Mining, Version 2.3, (5 December 2001) (part of the Mining Handbook)*. Available by download from the NPI website at: http://www.npi.gov.au/handbooks/approved_handbooks/pubs/mining.pdf

Ng, Y.L., (2004). *Estimating annual average windblown dust emissions from agricultural lands and unpaved roads*. Wind-blown Dust Workshop - the emission, transport and impacts of wind-blown dust from soil erosion: modelling and observation 8-10 November 2004 at CSIRO Atmospheric Research, Aspendale, Victoria, Australia.

NSW EPA (2001). *Approved methods for the sampling and analysis of air pollutants in New South Wales.* July 2001

NSW EPA (2004). *Approved methods for the modelling and assessment of air pollutants in New South Wales.* December 2004

Pacific Air & Environment (PAE), (2005). *Cooling Pond Plume Growth. CFD Modelling.* Report prepared for Alcoa World Alumina Australia

Pitts O. (2000). *Fugitive PM_{10} Emission Factors*. In Conference Proceedings of the 15th International Clean Air & Environmental Conference. Sydney Australia, 26-30 November 2000.

Pitts, R.O. and Lyons T.J. (1988). *The influence of topography on Perth radiosonde Observations.* Aust. Meteorol. Mag., 36,17-23.

Pitts, R.O. and Lyons T.J. (1989). *Airflow over a two dimensional escarpment. I: Observations.* Q. J. R. Meteorol. Soc. 115,965-981.

Pitts, R.O. and Lyons T.J. (1990). *Airflow over a two dimensional escarpment. II: Hydrostatic Flow.* Q. J. R. Meteorol. Soc. 116, 363-378.

Pollock, T.J. (1997). *Dispersion Modelling to Predict Off-site Impact of Odour Sources*. National Workshop on Odour Measurement Standardisation, Sydney, 20-22 August 1997.

Pollock, T.J. (2005). Personnel communication with Tim Pollock of Gutteridge, Haskins and Davey (GHD), Melbourne of February2005.

Ray. D.K. Nair, U.S. Welch, R.M. Han, Q. Zeng, J. Su, W. Kikuchi, T. and Lyons, T.J. (2003). *Effects of land use in Southwest Australia: 1. Observations of cumulus cloudiness and energy fluxes.* J. Geophys. Res. 108, D14, 4414

Scire, J, S, Robe, F, R. Fernau, M.E, Yamartino, R.J. (2000). A User's Guide for the CALMET Meteorological Model (version 5). Earth Tech, Inc, Concord, MA 01742, January 2000.

Scott, W.D. (1994). *Wind erosion of residue waste. Part 1. Using the wind profile to characterise wind erosion*. Catena, 21, 291-203.

Shao, Y., Raupach, M.R., and Leys J.F., (1994). *Practical Numerical Model for Estimation of Sand Drift and Dust Emission Caused by Wind Erosion*. Aust. J. Soils Res.

Shao, Y., Raupach, M.R., and Leys J.F., (1996). *A model for predicting aeolian sand drift and dust entrainment on scales from paddock to region*. Aust. J. Soils Res., 34, 309-342.

Sinclair Knight Merz (SKM), (1997). *Dust Assessment – Pinjarra Bauxite Stockpile Area*. Report prepared for Alcoa of Australia, Pinjarra.

Sinclair Knight Merz (SKM), (2001a). *Comparison of Wagerup RDA and Bancell Road winds.* Facsimile of 13 February 2001 from Owen Pitts (SKM) to Patrick Coffey (Alcoa).

Sinclair Knight Merz (SKM), (2001b). *Wind Erosion over Future Wagerup Residue Areas.* Report Prepared for Alcoa of Australia 15 March 2001.

Sinclair Knight Merz (SKM), (2001c). *Wagerup Area Wind Study.* Facsimile of Owen Pitts (SKM) to Patrick Coffey (Alcoa)

Sinclair Knight Merz (SKM), (2001d*). Alcoa World Alumina Australia. Alcoa Dust Management. Residue Area Dust Generation. March 2001*. Internal report prepared for Alcoa World Alumina Australia.

Sinclair Knight Merz (SKM), (2002a). *Wagerup Refinery Odour Assessment. Field odour Assessments and Odour Modelling.* Final, February 2002. Report prepared by Sinclair Knight Merz for Alcoa Australia.

Sinclair Knight Merz (SKM), (2003a). *Wagerup Refinery Atmospheric Tracer Modelling Study*. Final Report. 7 July 2003.

Sinclair Knight Merz (SKM), (2003b). *Pinjarra Refinery Upgrade - Air Dispersion Modelling*. Final Report. 3 December 2003.

Sinclair Knight Merz (SKM), (2004a). *Kwinana Residue Area - Dust Buffer Study*. Report prepared for Alcoa World Alumina Australia.

Sinclair Knight Merz (SKM), (2005a). *Collie Power Station Expansion. Air Quality Assessment. Air Quality modelling and screening air quality health risk assessment*. Report prepared for Western Power, Griffin Energy and collie Power Consortium and project managed by Sinclair Knight Merz. January 2005.

Sinclair Knight Merz (SKM), (2005b). *Improvement of NPI Fugitive Particulate Matter Emission Estimation Techniques.* Report prepared for WA Department of Environment.

Smith, R.J. (1995). *A Gaussian Model for estimating odour emissions from area sources.* Mathl. Comput. Modelling. Vol 21, no 9, 23-29.

Smith, R.J. and Watts, P.J. (1994). *Determination of Odour Emissions Rates from Cattle Feedlots: Part 1, A Review*, Journal of Agricultural Engineering Research, 57, 145-155.

Southern, R.L. and MacNicol. B.F. (1973). *The key role of meteorology in urban planning*. Proc. 45th ANZAAS Congress, Perth, 1973.

State Pollution Control Commission (SPCC), (1986). *Particle size distributions in dust from open cut coal mines in the Hunter Valley*. Report Number 10636-002-71, Prepared for the State Pollution Control Commission of NSW by Dames & Moore, Sydney.

Steedman Science & Engineering (SSE) (1994). *Dispersion Studies of Airborne dust from Alcoa's Kwinana Residue Disposal Areas.* Job No. E1641, Report No. R700. Prepared for Halpern Glick Maunsell.

Sutton, O. G. (1953). *Micrometeorology*. McGraw-Hill. New York.

U.S. Environmental Protection Agency, (2000*). Meteorological Monitoring Guidance For Regulatory Modeling Applications*, Research Triangle Park, North Carolina.

USEPA (1995). *Compilation of Air Pollution Emission Factors, AP-42*. United States Environmental Protection Agency.

Van Emden, B. and Power, G. (2005). *Wagerup Ambient Air Quality Monitoring Programme. Intensive Ambient Air Quality Study.* Phase 2: August to October 2004. February 2005.

Verein Deutscher Ingenieure (VDI), (1992). *VDI 3882.1 - Olfactometry – Determination of Odour Intensity*.

Verein Deutscher Ingenieure (VDI), (1993). *VDI 3940 – Determination of Odorants in Ambient Air by Field Inspection*s, October 1993.

Wills, S. Power, G. (2005). *Wagerup Ambient Air Quality Monitoring Programme Phase 1: May to September 2004*, In preparation.

12 Glossary

A brief summary of abbreviations and technical terms is provided below:

Ausplume	The Victorian EPA regulatory dispersion model
Calmet	The meteorological pre processor to the dispersion model Calpuff
Calpuff	The Californian puff model. A US regulatory dispersion model for the prediction of long range transport and the dispersion on a case by base basis in complex terrain
CSIRO	Commonwealth Industrial Research Organisation
Lapse Rate	The temperature change with height. A temperature decrease of 1 deg C per 100m increase in height has a lapse rate of 0.01 deg C/m
MDL	Method detection limit. The lower detection limit of the measurements technique
MW	Mega watts
ou	Odour unit. The number of dilutions required for a sample of air to be diluted until it can only be detected by 50% of odour panellists. A sample with 10 ou would need to be diluted ten times to be dilute enough such that half the panellists could not detect it.
RA	Residue Area. Area approximately 2 km to the west of the refinery used for the drying and storage of bauxite residue from the refining process
RDA	Residue Drying Area. Area within the residue area used for the drying and storage of residue fines. Presently there are 7 RDAs.
RHC	Robust Highest Concentration. A robust measure of the peak concentration. It is used as the actual maximum concentration can often contain unrepresentative or untypical values whereas the RHC provides a more "robust" value of the maximum. It is defined as: $RHC = C(R) + (Cm - C(R))\ln(3R-1)/2)$ Where C(R) is the Rth highest concentration and Cm is the mean of the top R-1 concentrations
STINK	A Gaussian plume model used for the back calculation of odours by the Queensland Department of Primary Industry
PM_{10}	Particulate matter below 10 µm
TSP	Total suspended particulate. Nominally particulate matter below 50 µm
TAPM	The Air Pollution Model. A meteorological and dispersion model developed by the CSIRO Division of Atmospheric Research. This model can be run without local wind observations, instead predicting the local winds and dispersion by solving the relevant equations.
TEOM	Tapered Element Oscillating Microbalance. A continuous dust monitor that can be used to sample PM_{10} or TSP
VOC	Volatile organic compounds
WAsP	The Wind Atlas and siting Program used to predict wind speed changes over terrain and used extensively in the wind turbine industry

Windtrax	A model used to model dispersion from area sources that can be used to back calculate the emission flux rate from areas using a down wind concentration measurement
$\mu g/m^3$	micro grams (one millionth of a gram) per cubic metre

Appendix A Adjustment of RDA3 Wind Data

A.1 Wind Speeds

Figure A.1 and **A.2** present scatter plots of the wind speeds at the Bancell road 10m sensor and the RDA3 site for two periods. **Figure A.1** presents the comparison in 2000/2001 when the stalling was less of an issue (see **Figure A.5**) and **Figure A.2** shows the comparison in 2003/2004 when the stalling was greater. This shows that for the lower wind speeds, the RDA3 site has a tendency to stall whilst at higher wind speeds the RDA3 winds are significantly higher than at Bancell road. That the RDA3 site winds are greater at high wind speeds is considered due to the open area in which the RDA3 wind sensor is situated and the elevated area there. To derive a relationships without this stalling affect, the relationship of RDA3 = BR_{10} +0.2m/s has been adopted. This does not follow the data for the low winds speeds as it is considered that this a function of the stalling of the anemometer

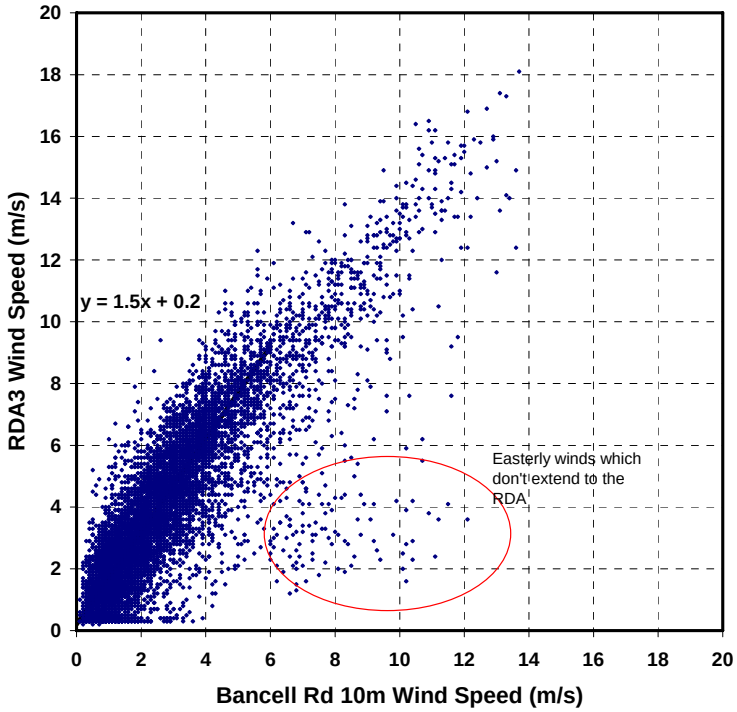


Figure A.1 Scatterplot of Bancell Rd 10m versus RDA3 site for 1/7//00 to 30/6/01

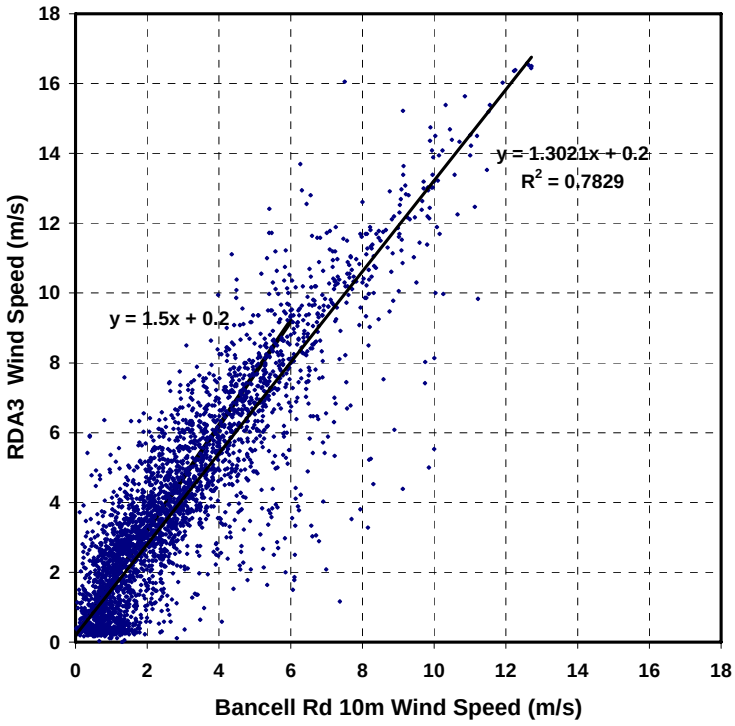


Figure A.2 Scatterplot of Bancell Rd 10m versus RDA3 site for 1/3/03 to 15/7/03

Figure A.3 shows a scatter plot between the 30m data and the RDA3 site in 2003/2004. This shows a more pronounced "stalling" effect, with the apparent line due to stalling (triangles) provided along with the line that is specified assuming the RDA3 does not have stalling issues.

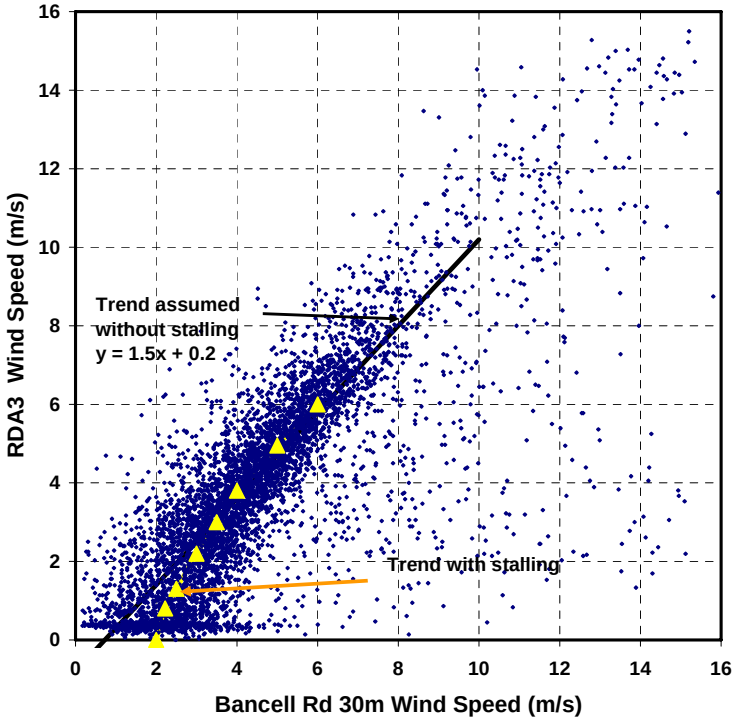


Figure A.3 Scatterplot of Bancell Rd 30m versus RDA3 site for 18/7//03 to 31/03/04

Figure A-4 presents the scatter plot of the TAPM derived RDA3 winds (without nudging) and against the RDA3 sensor for 2003/2004. This shows much more scatter. For this a relationship of RDA3 = 0.8

has been selected as appropriate for the low winds speeds (below 5 m/s) assuming that the RDA3 sensor did not have stalling problems.

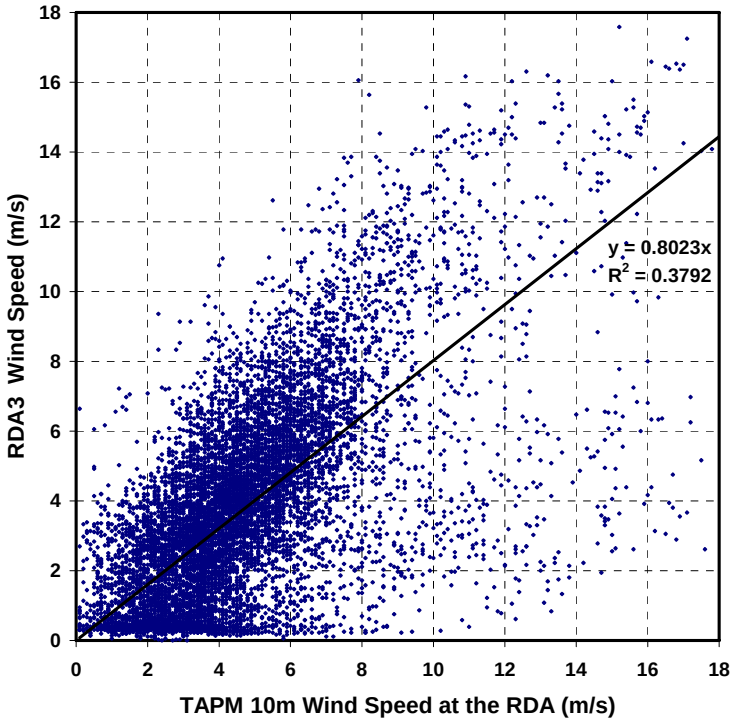


Figure A.4 Scatter plot of TAPM predicted 10m RDA3 winds (without nudging) versus RDA3 observations (7.2m) for 1/4//03 to 31/03/04

Using the above relationships the RDA3 data was corrected for stalling based on the following:

$RDA3_C$ = RDA3 (no change) RDA3 ≥ 2.5 m/s

$RDA3_C$ = max(RDA3, max ($RDA3_N$, RDA3+1.2)) RDA3 < 2.5 m/s

Where

RDA3 are the observed RDA3 winds;
$RDA3_C$ are the corrected RDA3 winds; and
$RDA3_N$ are the derived RDA3 winds from the alternative data sources.

That is, RDA 3 winds were replaced by the maximum of either the RDA3 winds or the alternative derived winds, with the change limited to being only 1.2 m/s above the RDA3 wind observations. That is, the winds must be at least equal to he RDA3 wind speed, but no more than 1.2 m/s above the RDA3 wind speed. This range is specified in that the stalling only reduces the RDA3 speed, with the wind speeds considered to be lowered by around a maximum of 1.2 m/s.

The alternative wind speed $RDA3_N$ was derived from:

For the period - 1 March 2003 to 15 July 2003 (with the old 10m Bancell road mast)

If valid Bancell 10m data, $RDA3_N = 1.5\ BR_{10} + 0.2$

Where BR_{10} is the Bancell road 10 m winds.

Otherwise $RDA3_N = 0.8\ RDA_T$

Where RDA_T are the RDA3 winds predicted by TAPM

For the period 18 July 2003 to 31 March 2004
If valid Bancell 10m data, (wind direction from 230 through north to 70 degrees, to eliminate the effect of the 30m mast).

$RDA3_N = 1.5\ BR_{10} + 0.2$,

else, if Bancell road 30m data is available

$RDA3_N = \max (0.1,\ 1.1\ BR_{30} - 0.8)$

If there are no valid Bancell Rd observations

$RDA3 = 0.8\ RDA_T$

Note. This only occurred for a few hours.

The resultant wind frequency distribution before and after the corrections along with other RDA3 winds from other years and the TAPM predicted RDA3 winds are presented in **Figure A-5**. This shows that the corrected winds have a comparable wind distribution to the years with no stalling problems (1998/1999 and 1999/2000), with 5% of winds below 1 m/s. **Figure A-5** also presents the original 2003/2004 data showing the large frequency of low wind speeds due to the stalling of the wind sensor and the TAPM predicted winds with low percentage of winds below 2 m/s.

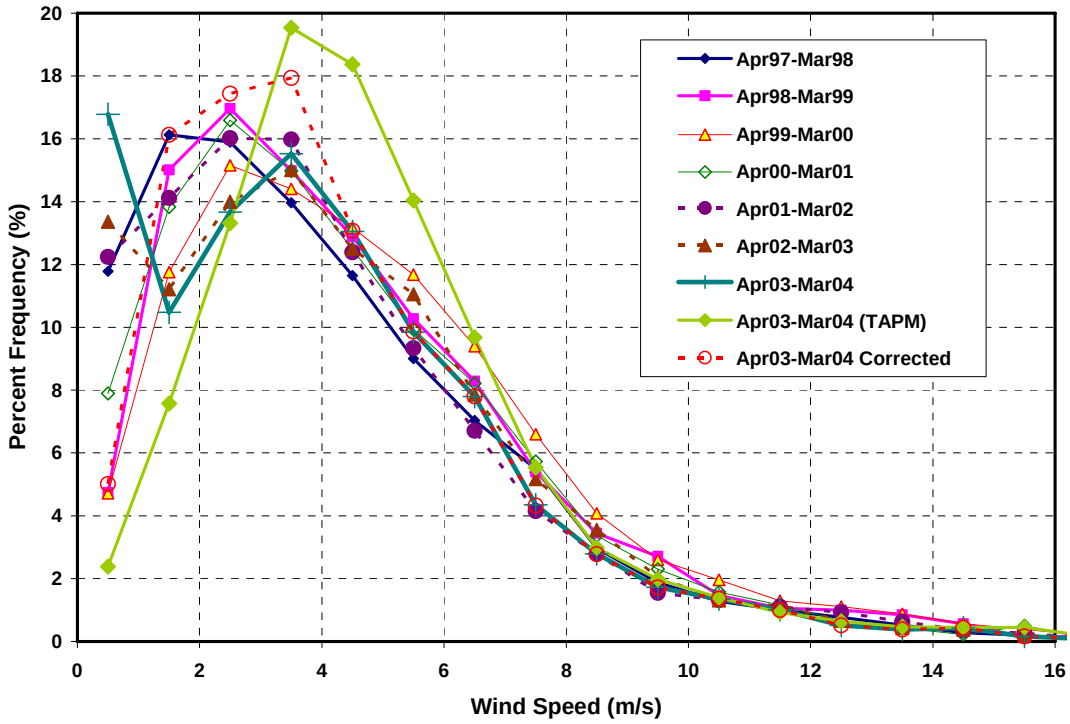


Figure A-5 Frequency of wind speeds at the RDA3 site for Various Years

A.2 Wind Direction

Wind directions from the Bancell road site have not been corrected as stalling of the wind direction sensor is considered to be small if existent. This is determined from analysis of the data and from discussions with site technicians who have stated that the deterioration in the wind bearings is primarily for the wind sensor and not the wind direction sensor. A comparison of winds for low wind speeds with the 30m wind Bancell road generally indicates good agreement

Resultant wind rose developed using the above procedure for the RDA3 winds along with the original 2003/2004 observations, the average winds for 1998 to 2001, which are considered representative of long term averages with a good anemometer and that predicted from TAPM are presented in **Figure 2.15**. This indicates reasonable agreement with the long term averages indicating support for the corrections applied here.

Appendix B Analysis of NO_X data at Boundary Road and Implications on the Winds near the Scarp

B.1 Boundary Road NO_X Data

Table B.1 presents the top seventeen 1-hour concentrations from Boundary road for the period 1 April to 12 December 2003. This period is selected as it corresponds to the available Upper Dam data, which makes determining background NO_X easier, with the data supplied for February and March 2004 appearing to have slight problems with an offset of the NO data.

Table B.1 Summary of NO_X Monitoring and Meteorological Conditions for 1 April to 12 December 2003 at Boundary Road

#	Time (hour ending)	NO_X (ppb)	NO_2 (%)	BR Wind	RDA3 wind	NW Wind	TAPM 100m wind	Source
1	13/6/03 09	52.5	12	0.3 @ 176	0.4 @ 188	0.3 @ 184	2.2 @ 132	Worsley/Collie/Muja? Refinery Fumigation?
2	9/06/03 07	49.9	13	0.7 @ 309	1.6 @ 342	2.5 @ 67	4.5 @ 2	Refinery
3	9/06/03 08	33.7	18	1.6 @ 20	1.9 @ 0	2.2 @ 61	4.6 @ 358	Refinery
4	12/06/03 09	32.2	23	0.9 @ 327	1.1 @ 351	0.1 @ 303	0.3 @ 307	Refinery
5	13/06/03 10	30.2	21	0.1 @ 350	0.4 @ 293	0.3 @ 165	2.4 @ 124	Worsley/Collie/Muja
6	15/9/03 06	29.2	24	0.4 @ 257	0.4 @ 289	2.1 @ 127	3.2 @ 153	Worsley/Collie/Muja
7	17/04/03 07	28.2	13	0.2 @ 353	1.5 @ 17	1.1 @ 61	1.9 @ 7	Refinery
8	19/06/03 07	26.3	40	1.2 @ 250	0.4 @ 61	2.0 @ 18	9.3 @ 40	Probably Refinery - rotor
9	19/06/03 06	25.3	48	0.8 @ 277	0.7 @ 74	2.1 @ 26	9.7 @ 40	Probably Refinery - rotor
10	18/06/03 08	23.8	52	1.0 @ 245	1.5 @ 68	1.9 @ 15	13.8 @ 48	Probably Refinery -rotor
11	05/04/03 21	22.2	84	0.5 @145	0.2 @ 158	0.4 @ 122	13.8 @ 127	Worsley/Collie/Muja
12	13/06/03 08	21.6	22	0.2 @ 99	0.4 @ 173	0.1 @ 93	2.0 @ 141	Worsley/Collie/Muja
13	9/06./03 09	20.9	31	2.6 @ 12	1.3 @ 347	1.4 @ 56	4.4 @ 357	Refinery
14	17/04/03 08	19.8	18	1.1 @ 52	3.2 @ 41	2.1 @ 64	2.4 @ 17	Refinery
15	28/04/03 09	18.9	32	0.6 @ 255	0.7 @ 208	0.6 @ 351	1.6 @ 97	Unknown -Refinery due to rotor?
16	28/04/03 08	18.2	35	1.3 @ 243	2.6 @ 191	3.1 @ 86	4.2 @ 90	Unknown - Refinery due to rotor?
17	12/06/03 10	17.9	34	1.0 @ 314	1.5 @ 332	0.5 @ 345	1.0 @ 272	Refinery

Notes:
1) BR is Bancell Road, RDA3 is the RDA3 wind sensor and NW is North Waroona.
2) Values in square brackets from the 30m sensor installed in July 2003, whilst all others are from the 10m sensor.
3) No NO_X data were available from Upper Dam from the 1 to 18 June 2004.

Table B.1 indicates that:

- All impacts, except one occur for very light winds and in the early morning;
- The Wagerup Refinery is the most significant source in terms of the number of events;
- There are significant impacts from other sources, notably from the SE which is expected to be from the sources at the Worsley refinery, Collie and Muja power stations. The maximum concentration of 52 ppb is thought possibly due to these sources, however this concentration is larger than the highest monitored NO_X concentration at the Worsley site T of 35 ppb which is closer to the these sources (SKM, 2005a). It is considered that there is the possibility that with the very low wind speeds at the surface, these high concentrations may be in fact a morning

fumigation event from the refinery plumes, with the upper winds actually being northerly at the time;

- Of the four events considered to be probably due to the Worsley/Collie/Muja sources as indicated by the general south easterly winds (excluding the 16 June 2003 as it is considered only probable), two events clearly record the same plume at Upper Dam on adjacent hours to the event (5 April 2003, **Figure B.2** and 19 September 2003, **Figure B.3**). This supports the view that the high NO_X concentrations are due to a plume from the south east of horizontal extent of up to 2km that "hits" the different monitors as the wind directions slowly change. It is interesting to note for both these events, the TAPM winds at 100m where south easterly, though the surface observations generally below the escarpment record south west to westerly winds. On the 5 April 2003, all monitors were south westerly except for a few hours at or near the event with south easterlies. For 19 September 2003, the winds were westerly at Bancell road and RDA3, whilst south easterly at North Waroona. Therefore, this indicates that under light south easterly synoptic flows, the winds at the base of the escarpment are being distorted to turn to generally south westerlies. This is a similar phenomenon as ascribed for the north easterly synoptic flows being turned to a northerly below the escarpment as discussed in **Section 2.1.3**. For the two other events there are no NO_X data available to confirm whether the plumes were from Collie as the Upper Dam NO_X analyser was not operational from the 1 to 18 June 2004; and
- There are two days (5 hours) where the source is not definite, but considered likely to be due to the refinery from a process of a rotor formation with a synoptic easterly flow. For the 19 June 2003, the winds are complex with the RDA3 sensor showing a E/NE, Bancell road 10m showing a SW, whilst the North Waroona (closer to the scarp shows a NNE with TAPM predicting NE (see **Figure 2.12**). As such, it appears that for a general NE flow, closer in to the scarp the winds may be northerly, with a counter SW flow at distances of 2 km from the scarp, whilst further out it returns to the NE flow pattern. A similar pattern with northerly winds close in to the scarp that is not picked up by the Bancell road monitor (which is 900m to the west of the boiler stack), is seen for the 28 April 2003 (see **Figure B.1**). Of interest is the good agreement between North Waroona observations and the TAPM predicted winds (except when North Waroona turns northerly for two hours) and that the two sites further from the scarp show south westerly winds for an extended period. This good agreement with the TAPM 100m winds and North Waroona winds is also seen on the 15 and 16 September 2003 when the other sites record winds from other directions.

Additionally, plots of the other days NO_X concentrations and winds are presented in **Figures B.4** and **B.6.**

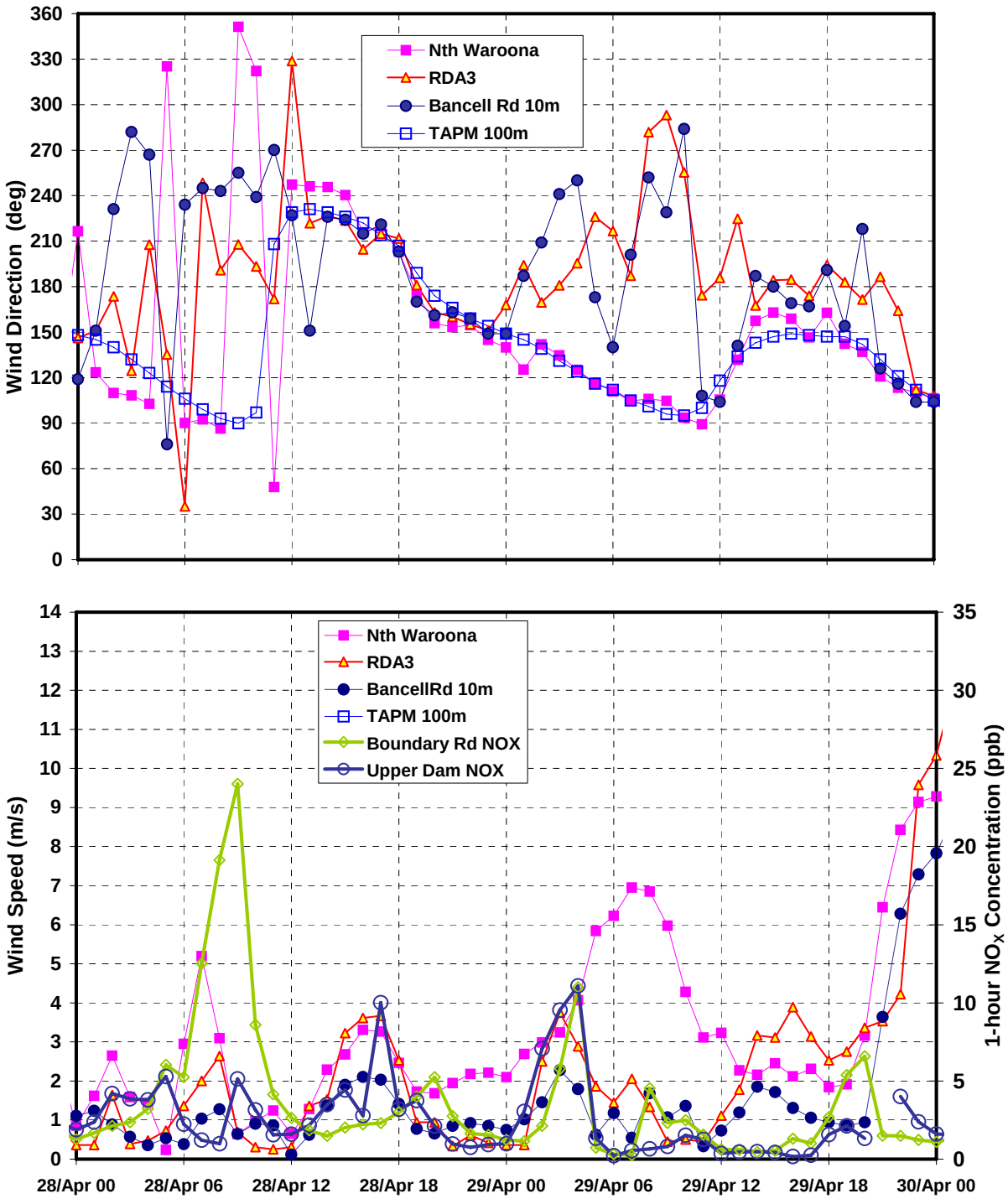


Figure B.1 Wind speed and wind direction and Observed NO_X at Boundary Rd for 28 to 29 April 2003

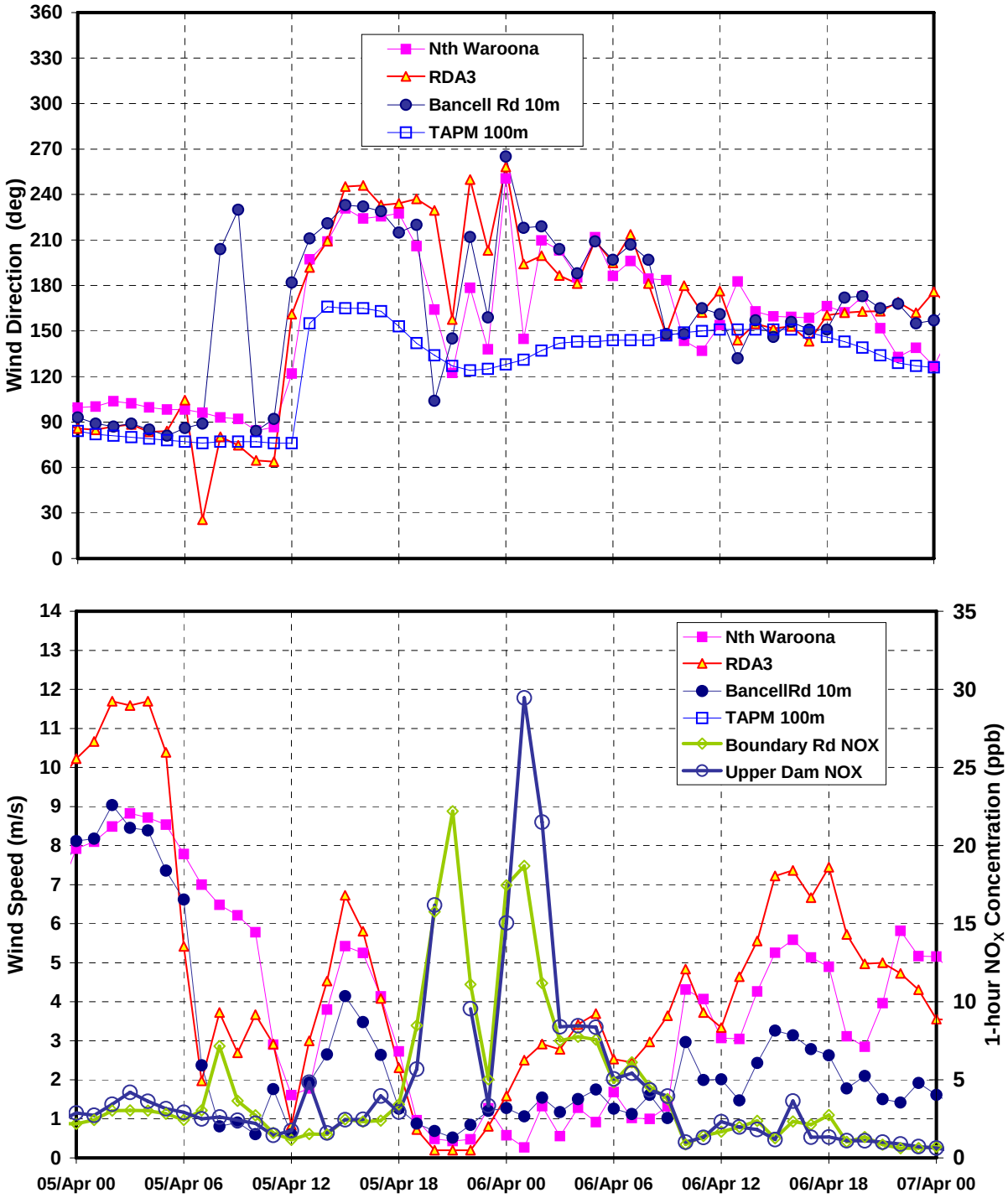


Figure B.2 Wind speed and wind direction and Observed NO_X at Boundary Rd for 5 to 6 April 2003

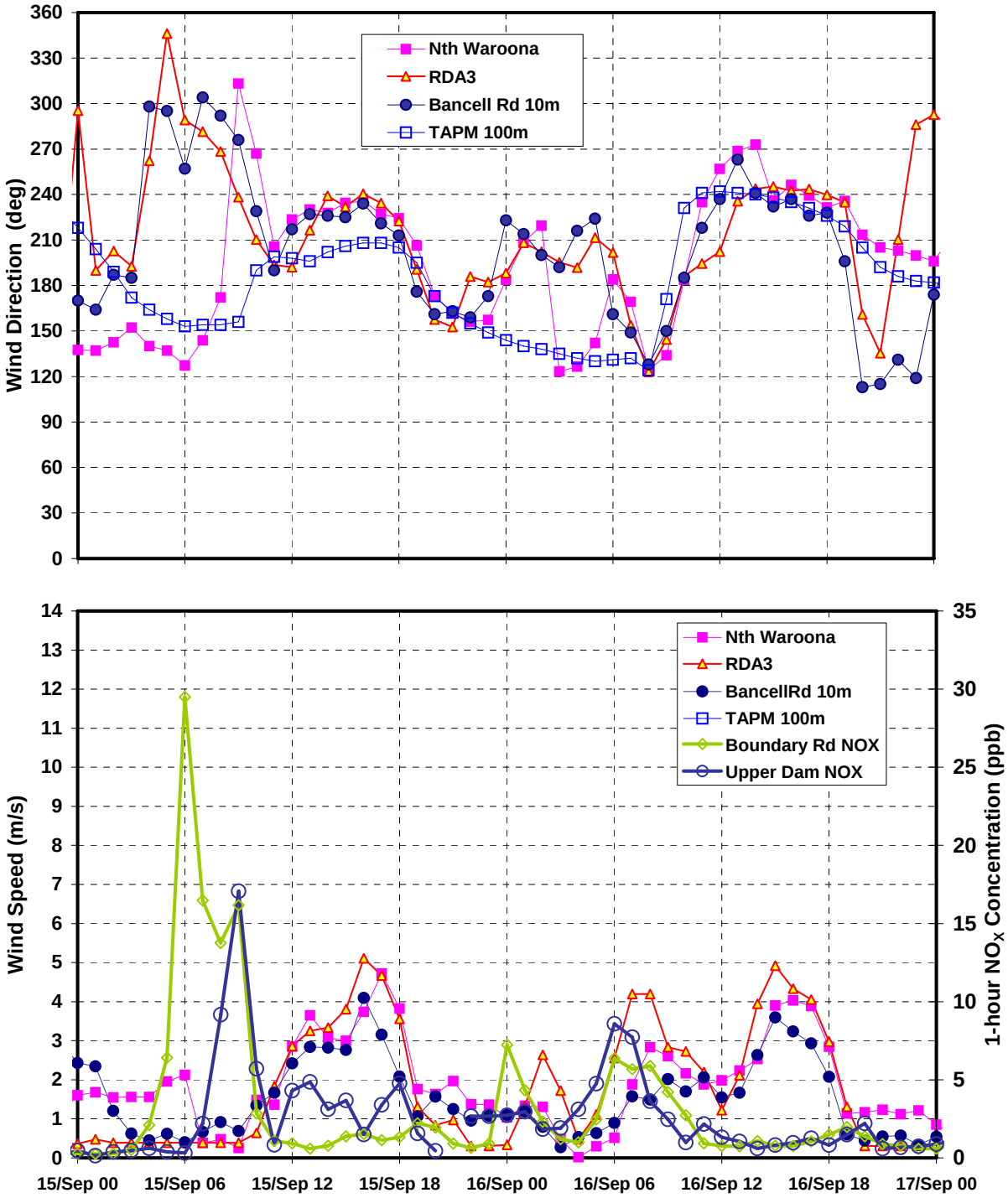


Figure B.3 Wind speed and wind direction and Observed NO_X at Boundary Rd for 15 to 16 September 2003

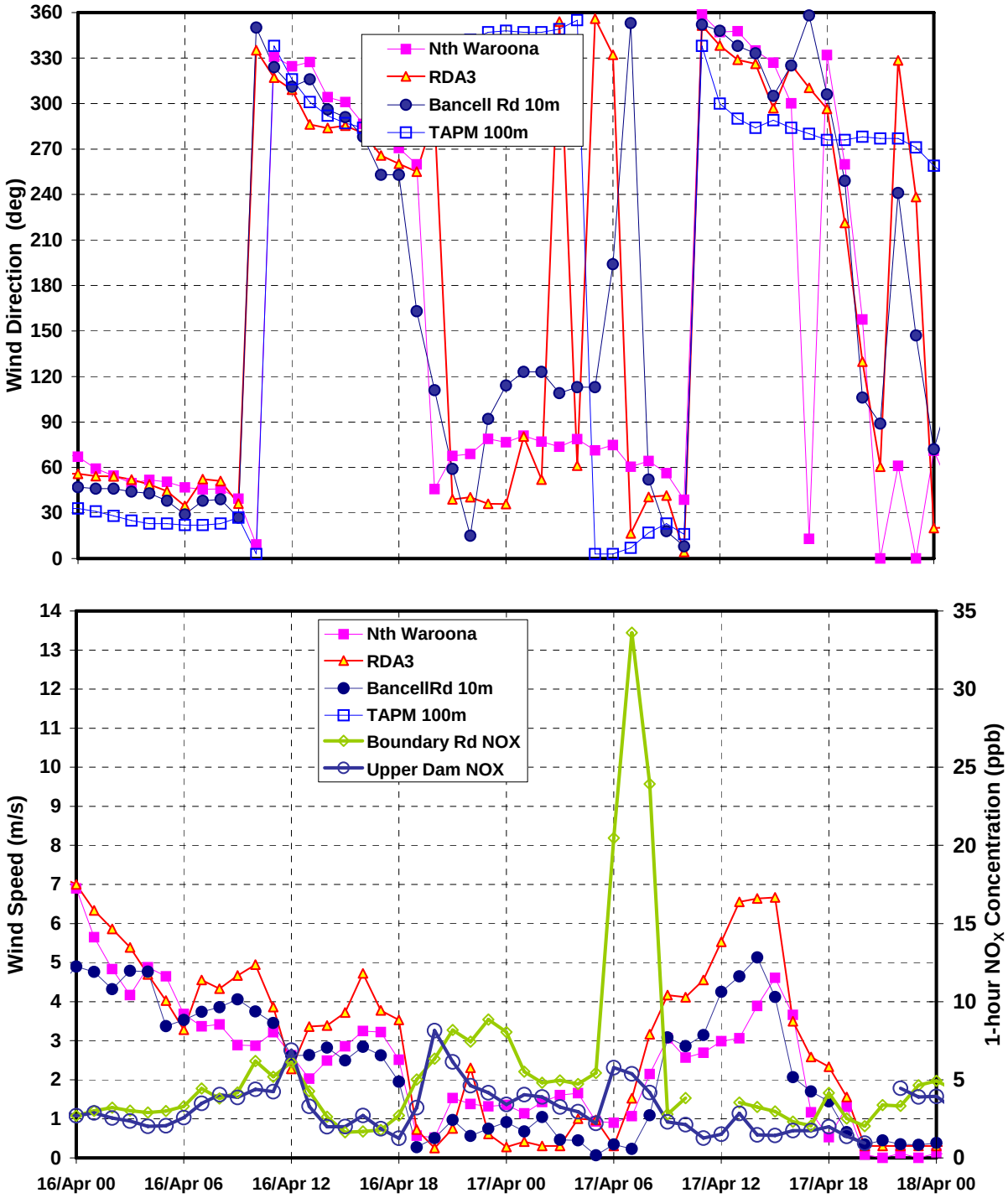


Figure B.4 Wind speed and wind direction and Observed NO_X at Boundary Rd for 16 to 17 April 2003

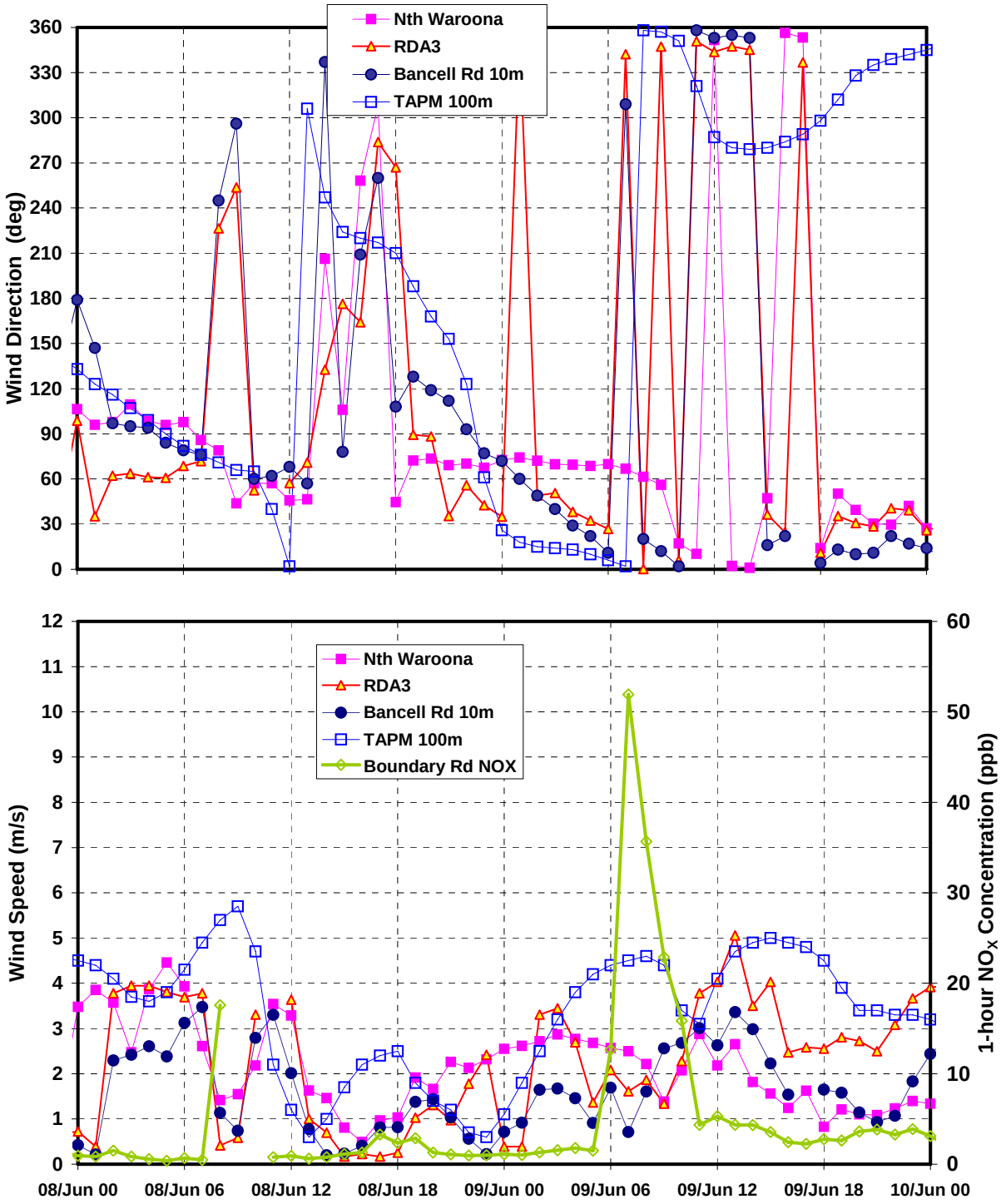


Figure B.5 Wind speed and wind direction and Observed NO_X at Boundary Rd for 8 to 9 June 2003

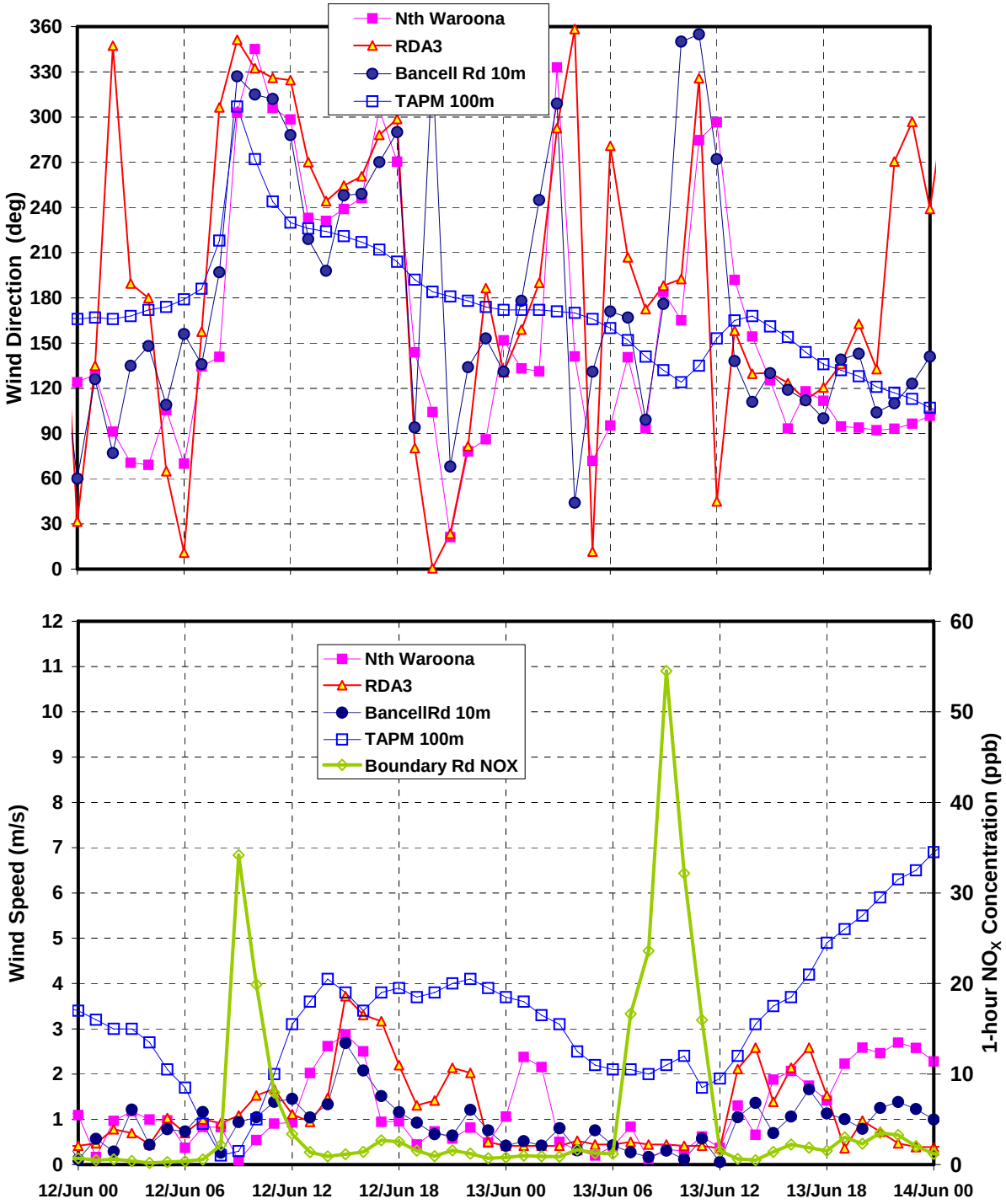


Figure B.6 Wind speed and wind direction and Observed NO_X at Boundary Rd for 13 to 14 June 2003

Appendix C Meteorological File Statistics at the RDA3 Site

File Derived with TAPM winds

Stability Classes

	A	B	C	D	E	F	Total
Number	62	665	1614	3627	1479	1337	8784
Percent	0.71	7.57	18.37	41.29	16.84	15.22	

Stability Class by Wind direction

	A	B	C	D	E	F
N	0.07	0.55	1.05	2.78	0.65	1.16
NE	0.13	0.87	1.92	5.19	2.27	2.31
E	0.17	0.88	1.35	10.35	1.92	1.87
SE	0.07	1.29	3.07	5.01	3.77	3.28
S	0.10	1.41	3.24	3.45	5.61	3.15
SW	0.09	1.12	3.83	6.12	1.22	1.63
W	0.03	0.94	2.74	5.05	0.94	0.89
NW	0.05	0.52	1.16	3.34	0.46	0.93

Stability Class by Hour of Day

Hour	A	B	C	D	E	F
1	0	0	0	151	119	96
2	0	0	0	151	118	97
3	0	0	0	148	120	98
4	0	0	0	144	116	106
5	0	0	0	142	113	111
6	0	0	8	191	81	86
7	0	4	47	221	46	48
8	0	19	104	243	0	0
9	0	50	141	175	0	0
10	1	79	158	128	0	0
11	8	109	155	94	0	0
12	18	113	153	82	0	0
13	19	106	171	70	0	0
14	13	89	188	76	0	0
15	3	57	171	135	0	0
16	0	32	182	152	0	0
17	0	6	92	268	0	0
18	0	1	43	263	18	41
19	0	0	1	188	80	97
20	0	0	0	75	156	135
21	0	0	0	104	138	124
22	0	0	0	128	131	107
23	0	0	0	147	122	97
24	0	0	0	151	121	94

Mixing heights — Time (hr)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
> 2000 m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1800 to 2000 m	0	0	0	0	0	0	1	0	0	0	0	0	0	2	21	41	57	48	12	0	0	0	0	0
1600 to 1800 m	3	2	3	2	1	2	0	0	0	0	0	0	19	61	91	90	76	75	35	0	0	0	2	3
1400 to 1600 m	9	11	8	10	9	6	1	0	0	0	0	26	75	89	65	57	52	40	11	0	0	3	4	6
1200 to 1400 m	10	7	10	7	7	5	0	1	0	0	30	89	90	69	69	63	63	23	10	0	0	7	6	9
1000 to 1200 m	11	16	15	16	18	17	8	0	0	26	89	83	70	75	73	74	53	9	6	0	6	4	10	14
800 to 1000 m	17	16	18	17	16	18	9	4	21	84	90	82	84	51	36	30	26	5	3	3	7	17	18	12
600 to 800 m	27	24	23	22	24	25	33	35	91	112	96	67	22	15	9	7	15	2	2	7	14	14	25	29
400 to 600 m	54	52	49	52	49	48	73	137	135	108	58	19	6	4	2	4	6	11	19	22	40	52	57	58
200 to 400 m	78	85	85	83	81	82	115	115	111	36	3	0	0	0	0	0	4	41	108	138	122	105	83	78
0 to 200 m	157	153	155	157	161	163	126	74	8	0	0	0	0	0	0	0	14	112	160	196	177	164	161	157

Wind Occurence Matrix

Speed (m/s)	N	NE	E	SE	S	SW	W	NW	Total
<0.5 (calm)									0.89
0.5 - 1.9	0.93	1.23	1.12	1.50	1.24	1.47	1.05	0.82	9.36
2.0 - 3.9	2.36	4.09	2.90	5.23	7.16	4.69	4.01	2.64	33.07
4.0 - 5.9	2.11	3.65	3.43	6.60	6.71	4.46	3.79	1.35	32.10
6.0 - 7.9	0.51	2.55	2.90	2.19	1.71	2.89	1.58	0.89	15.22
8.0 - 9.9	0.20	0.76	2.56	0.34	0.05	0.39	0.09	0.50	4.90
10.0 - 11.9	0.01	0.23	1.63	0.20	0.00	0.03	0.00	0.11	2.22
12.0 - 13.9	0.00	0.01	1.01	0.24	0.00	0.00	0.00	0.00	1.26
14.0 - 15.9	0.00	0.00	0.66	0.10	0.00	0.00	0.00	0.00	0.76
16.0 - 17.9	0.00	0.00	0.18	0.00	0.00	0.00	0.00	0.00	0.18
>18.0	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.03
Total	6.12	12.52	16.43	16.40	16.86	13.93	10.52	6.32	100.00

Speed (m/s)	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total
<0.5 (calm)																	0.9
0.5 - 1.9	0.4	0.6	0.7	0.4	0.6	0.7	0.7	0.7	0.7	0.7	0.8	0.6	0.6	0.5	0.4	0.4	9.4
2.0 - 3.9	1.1	2.0	2.2	1.4	1.4	1.9	2.6	3.7	3.9	2.4	2.3	2.2	2.2	1.9	1.1	0.9	33.1
4.0 - 5.9	1.1	1.4	1.9	1.8	1.7	2.1	3.4	4.3	3.3	2.2	2.4	2.0	1.9	1.3	0.6	0.5	32.1
6.0 - 7.9	0.2	0.3	1.1	2.3	1.5	0.8	1.0	1.4	0.8	0.8	1.9	0.8	1.0	0.6	0.4	0.3	15.2
8.0 - 9.9	0.1	0.0	0.3	1.2	1.4	0.5	0.2	0.0	0.0	0.0	0.3	0.0	0.1	0.1	0.3	0.2	4.9
10.0 - 11.9	0.0	0.0	0.1	0.6	1.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	2.2
12.0 - 13.9	0.0	0.0	0.0	0.2	0.7	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3
14.0 - 15.9	0.0	0.0	0.0	0.0	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
16.0 - 17.9	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
>18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	3.0	4.4	6.3	7.9	9.1	6.6	8.3	10.1	8.7	6.0	7.7	5.6	5.7	4.4	3.0	2.3	100.0

Ave wind speed = 4.73

Wind Speed range (m/s)	Count	Percentage (%)
0.00 - 0.99	201	2.29
1.00 - 1.99	699	7.96
2.00 - 2.99	1188	13.52
3.00 - 3.99	1717	19.55
4.00 - 4.99	1594	18.15
5.00 - 5.99	1226	13.96
6.00 - 6.99	835	9.51
7.00 - 7.99	502	5.71
8.00 - 8.99	265	3.02
9.00 - 9.99	165	1.88
10.00 - 10.99	111	1.26
11.00 - 11.99	84	0.96
12.00 - 12.99	64	0.73
13.00 - 13.99	47	0.54
14.00 - 14.99	35	0.40
15.00 - 15.99	32	0.36
16.00 - 16.99	9	0.10
17.00 - 17.99	7	0.08
18.00 - 18.99	3	0.03
19.00 - 19.99	0	0.00
20.00 - 20.99	0	0.00
21.00 - 21.99	0	0.00
22.00 - 22.99	0	0.00
23.00 - 23.99	0	0.00

File Derived with Observed winds

Stability Classes

	A	B	C	D	E	F	Total
Number	134	840	1443	3033	1048	2286	8784
Percent	1.53	9.56	16.43	34.53	11.93	26.02	

Stability Class by Wind direction

	A	B	C	D	E	F
N	0.03	0.65	1.29	2.56	0.80	1.91
NE	0.16	0.54	1.22	4.80	2.30	3.83
E	0.24	1.51	2.40	6.96	1.17	1.80
SE	0.35	1.58	2.27	3.01	2.53	3.68
S	0.15	1.58	2.61	2.82	3.36	8.83
SW	0.33	1.79	3.29	5.83	0.85	2.83
W	0.13	0.94	2.20	5.51	0.50	1.70
NW	0.14	0.97	1.16	3.04	0.42	1.45

Stability Class by Hour of Day

Hour	A	B	C	D	E	F
1	0	0	0	93	103	170
2	0	0	0	97	106	163
3	0	0	0	98	98	170
4	0	0	0	98	87	181
5	0	0	0	98	86	182
6	0	0	10	150	61	145
7	0	9	57	187	34	79
8	0	21	146	199	0	0
9	0	75	132	159	0	0
10	1	109	129	127	0	0
11	24	116	124	102	0	0
12	44	121	105	96	0	0
13	36	134	108	88	0	0
14	27	103	148	88	0	0
15	2	92	144	128	0	0
16	0	54	159	153	0	0
17	0	4	123	239	0	0
18	0	2	54	250	11	49
19	0	0	4	184	34	144
20	0	0	0	65	66	235
21	0	0	0	70	78	218
22	0	0	0	81	96	189
23	0	0	0	89	95	182
24	0	0	0	94	93	179

Mixing heights Time (hr)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
> 2000 m	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0
1800 to 2000 m	0	0	0	0	0	0	0	0	0	0	0	0	0	5	17	29	33	30	6	0	0	0	0	0
1600 to 1800 m	3	2	2	4	3	2	1	0	0	0	0	0	16	28	54	57	58	57	24	0	0	0	0	1
1400 to 1600 m	4	7	8	4	3	4	1	1	0	0	0	17	39	65	68	66	64	58	19	0	0	1	2	5
1200 to 1400 m	3	4	3	8	7	4	2	2	0	0	18	45	90	95	72	70	64	35	16	0	1	1	6	3
1000 to 1200 m	8	15	14	12	11	10	7	0	2	20	75	104	80	70	79	72	60	9	7	0	1	2	4	7
800 to 1000 m	12	5	8	6	9	11	10	6	38	88	87	80	72	66	49	49	37	9	3	2	3	7	8	12
600 to 800 m	21	19	11	14	12	12	17	48	75	96	94	86	54	31	25	21	22	7	5	9	6	12	16	14
400 to 600 m	27	27	30	20	29	24	31	103	117	90	75	31	15	6	2	1	7	11	24	24	24	24	29	35
200 to 400 m	59	60	59	62	57	56	128	99	78	63	17	3	0	0	0	0	4	23	61	50	75	84	67	69
0 to 200 m	229	227	231	236	235	243	169	107	56	9	0	0	0	0	0	0	15	127	201	281	256	235	234	220

Wind Occurence Matrix

Speed (m/s)	N	NE	E	SE	S	SW	W	NW	Total
<0.5 (calm)									1.57
0.5 - 1.9	1.67	2.21	1.28	2.50	5.03	2.74	2.11	1.81	19.35
2.0 - 3.9	2.76	4.96	3.64	5.26	9.37	4.66	2.38	2.22	35.25
4.0 - 5.9	1.48	2.94	2.91	4.06	3.76	4.45	2.68	1.09	23.37
6.0 - 7.9	0.72	1.57	2.16	1.42	0.91	2.41	2.06	0.85	12.11
8.0 - 9.9	0.33	0.77	1.25	0.05	0.03	0.39	1.13	0.48	4.43
10.0 - 11.9	0.07	0.19	1.37	0.02	0.01	0.06	0.22	0.38	2.31
12.0 - 13.9	0.01	0.01	0.75	0.00	0.00	0.00	0.08	0.03	0.89
14.0 - 15.9	0.00	0.00	0.55	0.00	0.00	0.00	0.01	0.05	0.60
16.0 - 17.9	0.00	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.09
>18.0	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.02
Total	7.04	12.66	14.03	13.32	19.11	14.71	10.66	6.91	100.00

Speed	N	NNE	NE	ENE	E	ESE	SE	SSE	S	SSW	SW	WSW	W	WNW	NW	NNW	Total

(m/s)

<0.5 (calm)																	1.6
0.5 - 1.9	0.9	1.2	1.1	0.7	0.7	0.7	1.4	1.8	2.8	1.8	1.5	1.0	1.0	1.0	0.8	0.8	19.4
2.0 - 3.9	1.4	2.2	2.6	1.7	1.9	2.2	2.7	3.0	5.5	3.7	2.0	1.9	1.1	1.0	1.2	1.1	35.2
4.0 - 5.9	0.6	1.2	1.6	1.2	1.6	1.6	2.0	2.2	1.9	1.3	2.2	2.6	1.4	0.7	0.5	0.7	23.4
6.0 - 7.9	0.2	0.5	0.8	1.0	1.1	1.0	0.5	0.6	0.4	0.6	1.0	1.9	1.1	0.5	0.4	0.6	12.1
8.0 - 9.9	0.1	0.2	0.4	0.5	0.8	0.1	0.0	0.0	0.0	0.1	0.1	0.3	0.7	0.4	0.3	0.2	4.4
10.0 - 11.9	0.0	0.1	0.1	0.3	1.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	2.3
12.0 - 13.9	0.0	0.0	0.0	0.1	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
14.0 - 15.9	0.0	0.0	0.0	0.0	0.5	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
16.0 - 17.9	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
>18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	3.3	5.3	6.5	5.5	8.6	5.9	6.5	7.6	10.6	7.5	6.9	7.8	5.6	3.8	3.3	3.7	100.0

Ave wind speed = 4.15

Wind Speed range (m/s)	Count	Percentage (%)
0.00 - 0.99	409	4.66
1.00 - 1.99	1429	16.27
2.00 - 2.99	1506	17.14
3.00 - 3.99	1590	18.10
4.00 - 4.99	1159	13.19
5.00 - 5.99	894	10.18
6.00 - 6.99	688	7.83
7.00 - 7.99	376	4.28
8.00 - 8.99	238	2.71
9.00 - 9.99	151	1.72
10.00 - 10.99	115	1.31
11.00 - 11.99	88	1.00
12.00 - 12.99	48	0.55
13.00 - 13.99	30	0.34
14.00 - 14.99	39	0.44
15.00 - 15.99	14	0.16
16.00 - 16.99	6	0.07
17.00 - 17.99	2	0.02
18.00 - 18.99	2	0.02
19.00 - 19.99	0	0.00
20.00 - 20.99	0	0.00
21.00 - 21.99	0	0.00
22.00 - 22.99	0	0.00
23.00 - 23.99	0	0.00

Appendix D Predicted Concentrations from the Meteorological File developed from Observed Winds

D.1 Predicted TSP Concentrations

Predicted TSP concentrations using the observed winds are presented in **Figure D.1** to **Figure D.12**. Compared to the concentrations predicted using the TAPM winds in **Section 7.1** the areas of good agreement with the observations are somewhat different, with:

- Good agreement predicted with the west monitor concentrations, excepting the maximum 24-hour event;
- Reasonable agreement for the S and SW monitors;
- Significant under-prediction at the NW monitor. This under-prediction is considered to be partially due to the local sources there which have not been removed from the data;
- Slight under and over-prediction at the top events at the NE and East monitors;
- Large over-prediction at the south monitor; and
- Predicted concentrations at the BRW monitor are still well below the "observed" contribution from Alcoa, but higher than that predicted using the TAPM winds.

In general, the use of the observed winds predicts lower maximum 24-hour concentrations to the NW of the residue area, whilst predicting higher concentrations to the south/south east than is predicted using the TAPM derived winds.

Table D.1 Monitored and Predicted TSP Concentrations (µg/m^3) for 2003/2004

	RSE (1)	RS	RSW	RW	RNW	RE	RNE (1)	BRW (1)	RDA7 (1)
Monitored									
Mean	1.1	4.4	7.2	13.1	8.3	10.1	41.0	15.0	7.1
90th Percentile	3	8	12	34	17	19	86	29	17
95th Percentile	6	15	21	49	21	23	106	31	26
98th Percentile	15	37	76	57	26	27	152	36	34
99th Percentile	17	49	91	80	29	32	185	39	35
2nd Highest	18.4	116	211	87.6	32.5	38.0	184	38.2	35.1
Maximum	22	120	238	142	34	58	246	44	40
Modelled (Observed Winds)									
Mean	3.4	6.8	10.2	4.9	1.0	5.0	35.2	0.8	3.9
90th Percentile	9	17	24	11	2	11	102	2	10
95th Percentile	11	22	54	33	5	19	155	3	15
98th Percentile	20	32	68	66	8	26	169	7	21
99th Percentile	21	40	104	79	9	41	180	9	24
2nd Highest	35.1	73.5	139	96.2	11.7	47.7	180.8	9.6	24.0
Maximum	35	107	188	102	14	63	202	19	58

Notes:

1) Monitoring and modelled results from RSE from 1/4/03 to 10/12/03, RDA7 from 1 /12/03, RNE from 17/12/03. and BRW from 18/12/03

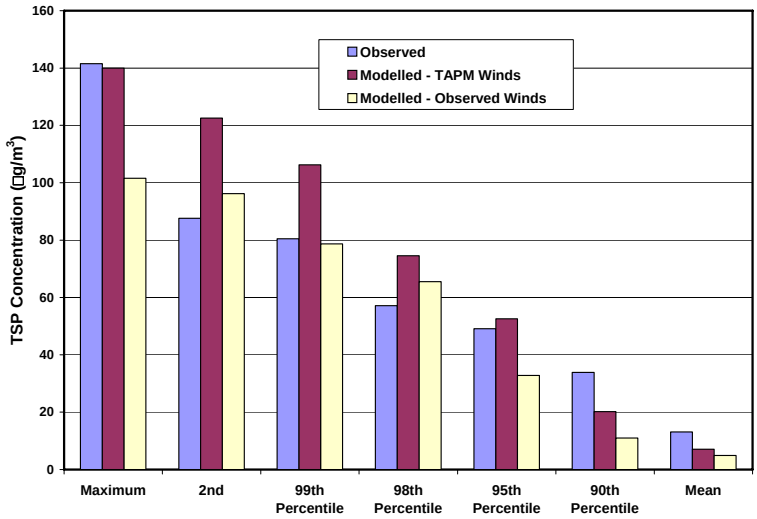


Figure D.1 Monitored and Predicted TSP Concentrations at the West Monitor

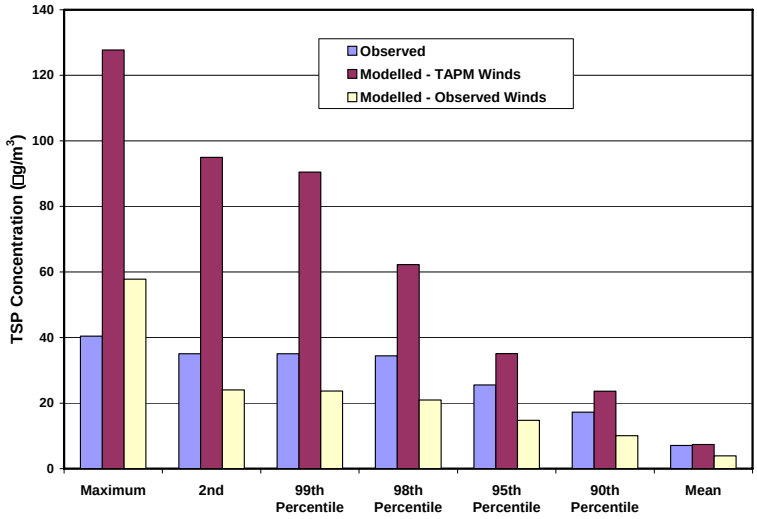


Figure D.2 Monitored and Predicted TSP Concentrations at the RDA7 Monitor

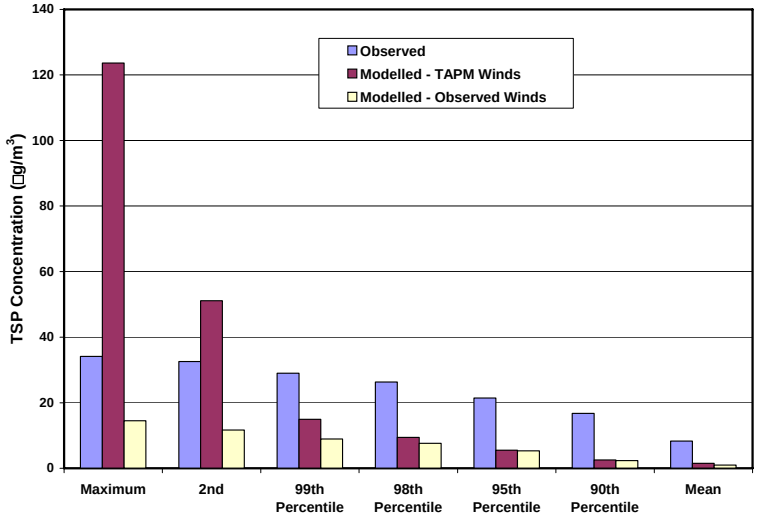


Figure D.3 Monitored and Predicted TSP Concentrations at North West Monitor

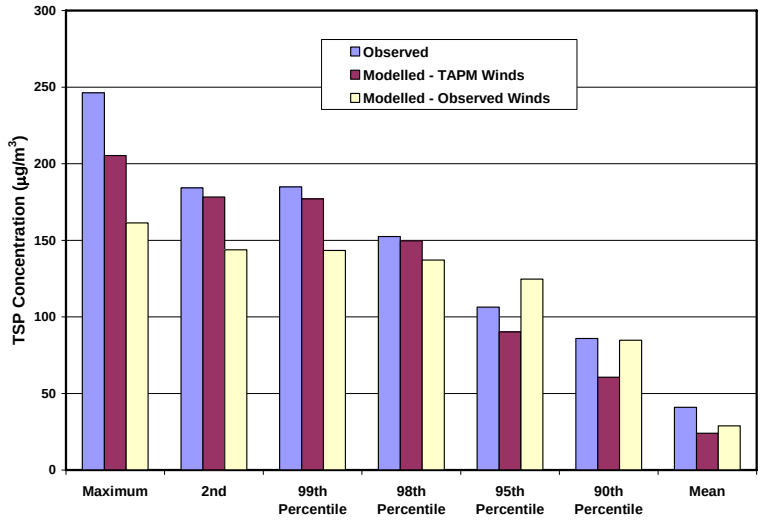


Figure D.4 Monitored and Predicted TSP Concentrations at the North East Monitor

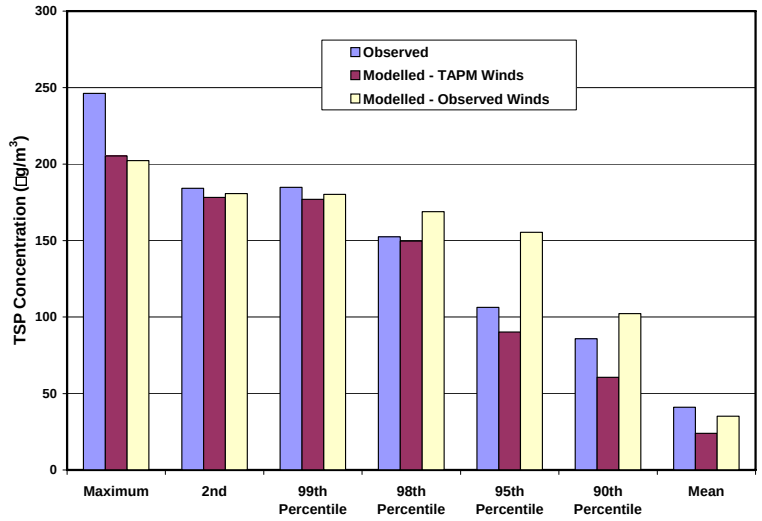


Figure D.5 Monitored and Predicted TSP Concentrations at the East Monitor

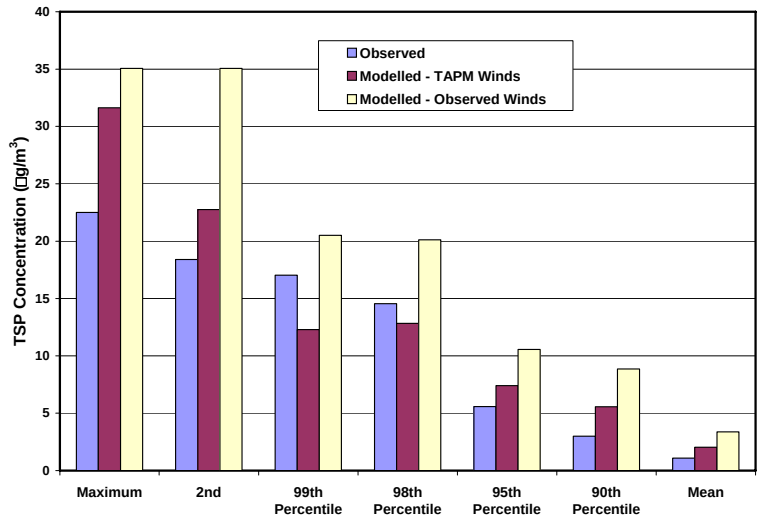


Figure D.6 Monitored and Predicted TSP Concentrations at the South East Monitor

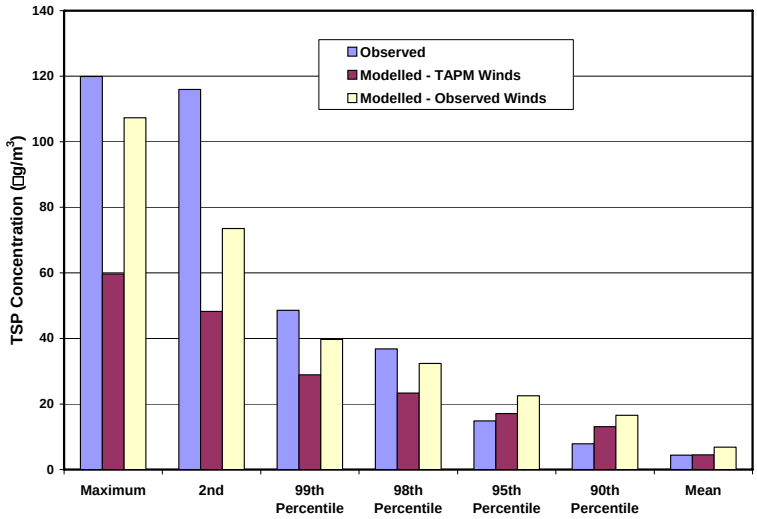


Figure D.7 Monitored and Predicted TSP Concentrations at the South Monitor

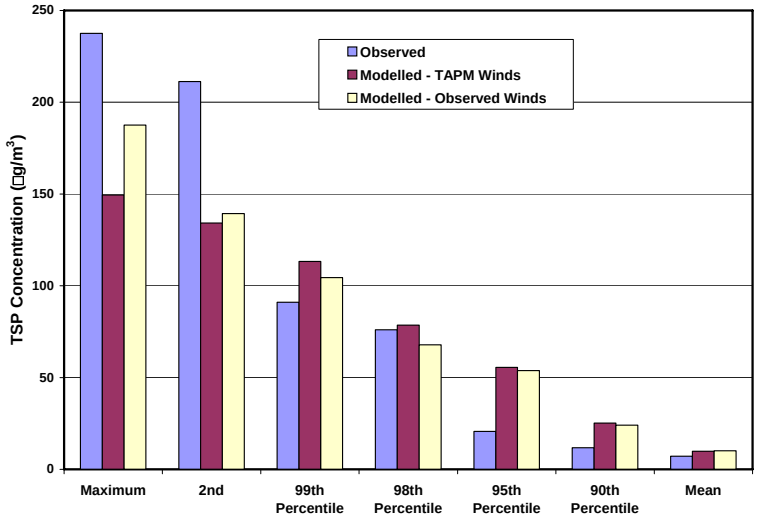


Figure D.8 Monitored and Predicted TSP Concentrations at the South West Monitor

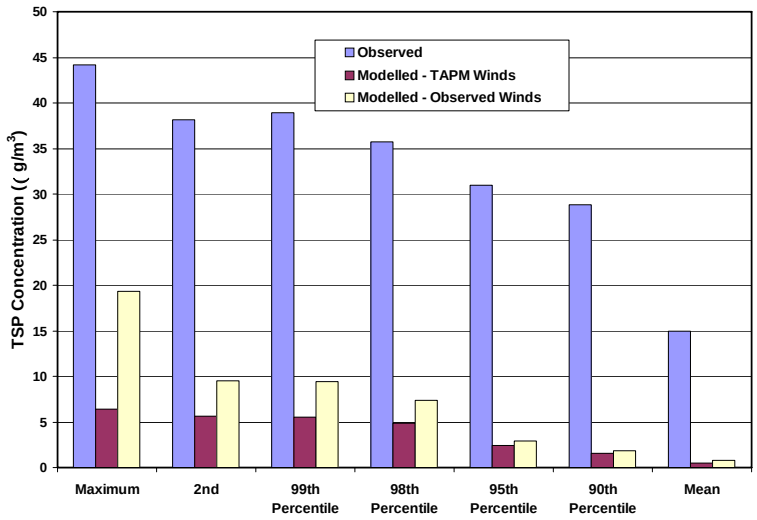


Figure D.9 Monitored and Predicted TSP Concentrations at the BRW Monitor

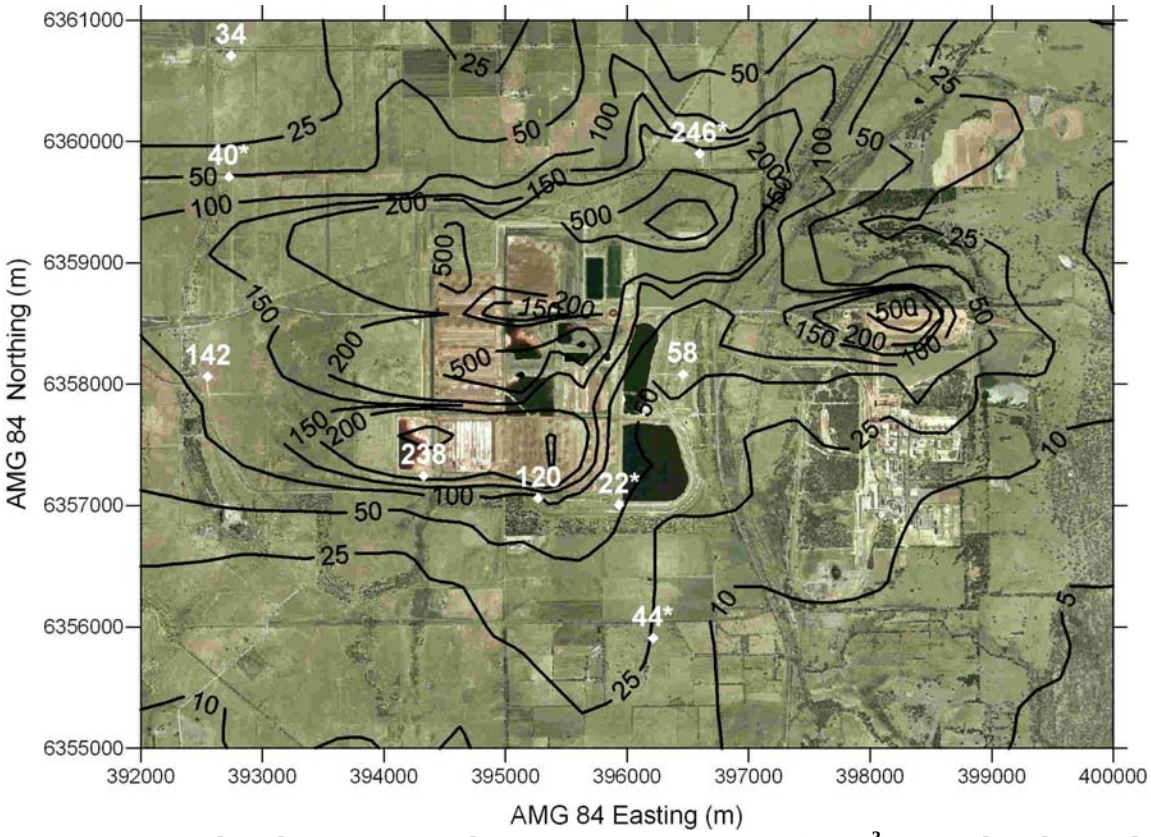


Figure D.10 Predicted Maximum 24-hour TSP Concentrations (µg/m^3) using the Observed Winds

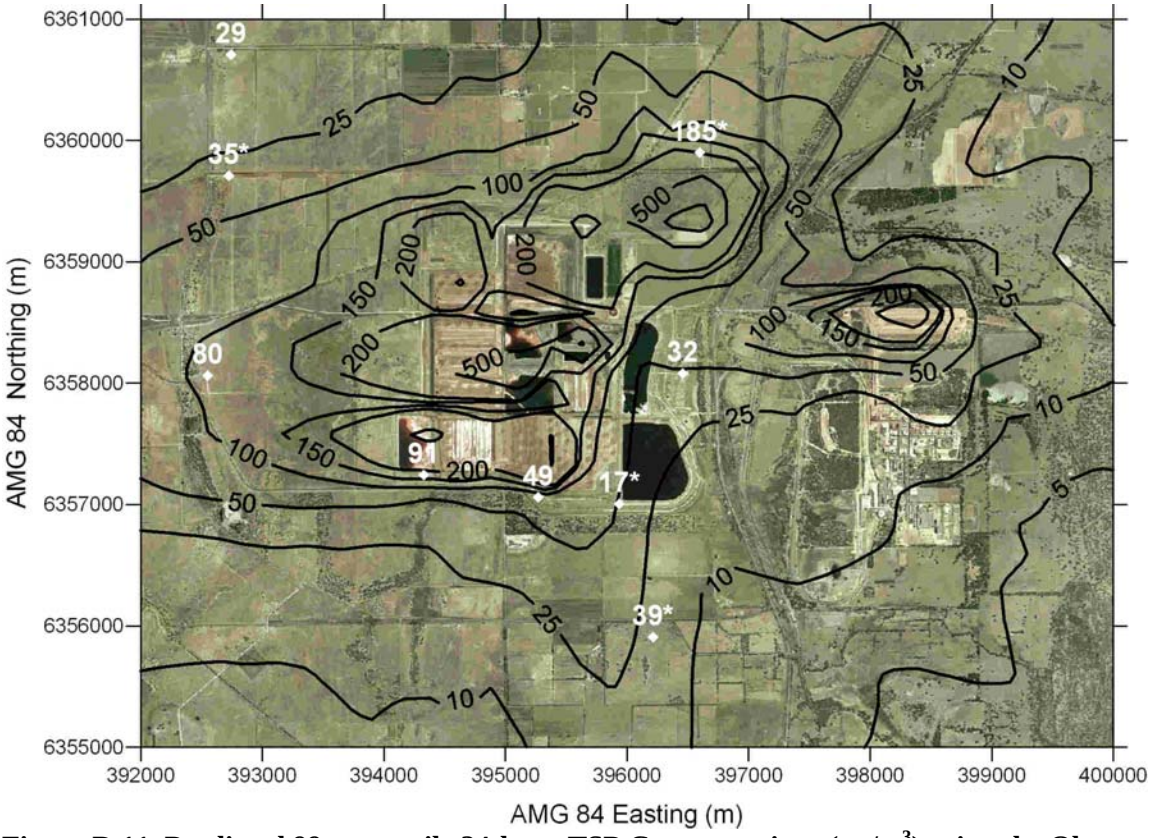


Figure D.11 Predicted 99 percentile 24-hour TSP Concentrations (µg/m^3) using the Observed winds

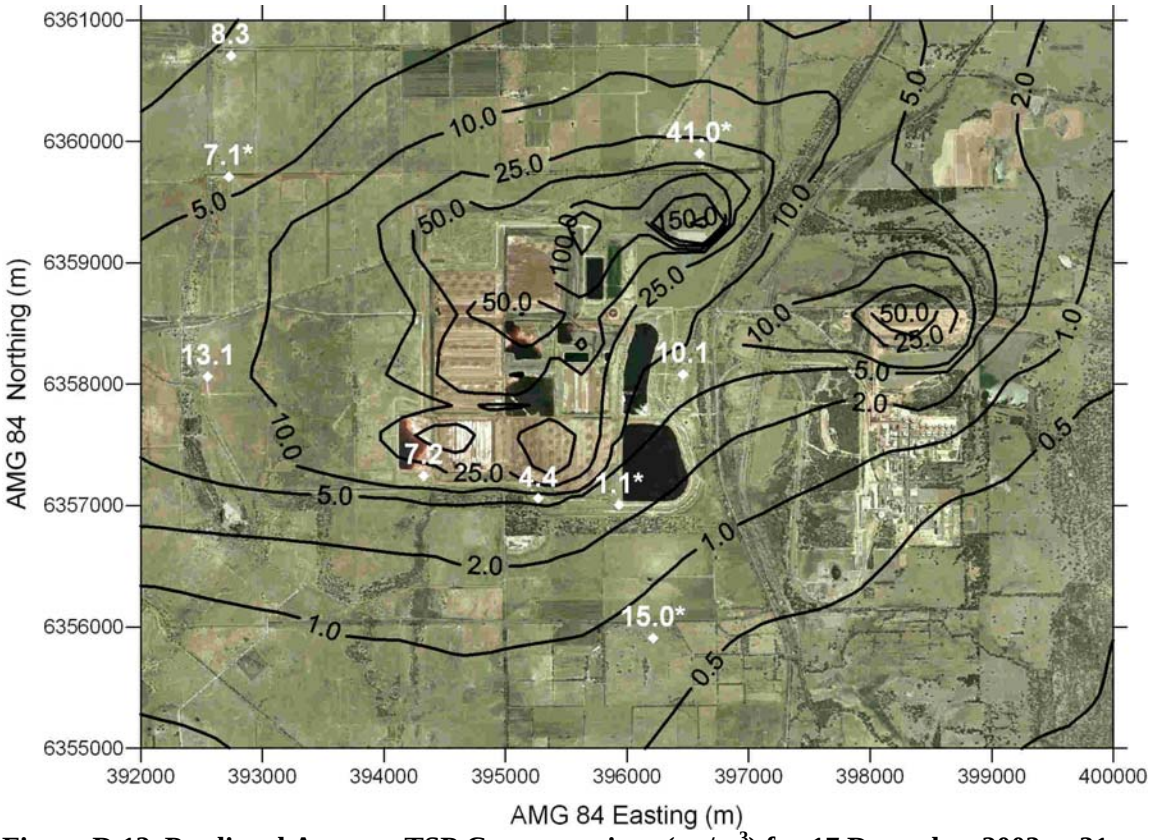


Figure D.12 Predicted Average TSP Concentrations (µg/m^3) for 17 December 2003 to 31 March 2004 using the Observed winds

D.2 Predicted VOC Concentrations

Predicted 1-hour 99.9, 24-hour 99.5 percentile and annual average VOC concentrations for the base case are presented in **Figure D.13** to **Figure D.16** using the winds from TAPM and using the observed winds. These indicate that the:

- Predicted 99.9 percentile 1-hour concentrations are very similar from the two meteorological input files with the concentrations predicted using the observed winds extending slightly further to the south west and the concentrations predicted using the TAPM winds extending slightly further to the north east;
- Predicted 99.5 percentile 24-hour concentrations again are very similar, except for several kilometres to the north east where the concentrations predicted using the TAPM winds may be higher by a factor of two; and
- Predicted annual concentrations are similar with the concentrations predicted using the TAPM winds being slightly higher in the east and west directions. Concentrations predicted using the observed winds are higher to the north and south of the residue area, with this being around a factor of 2 in some areas.

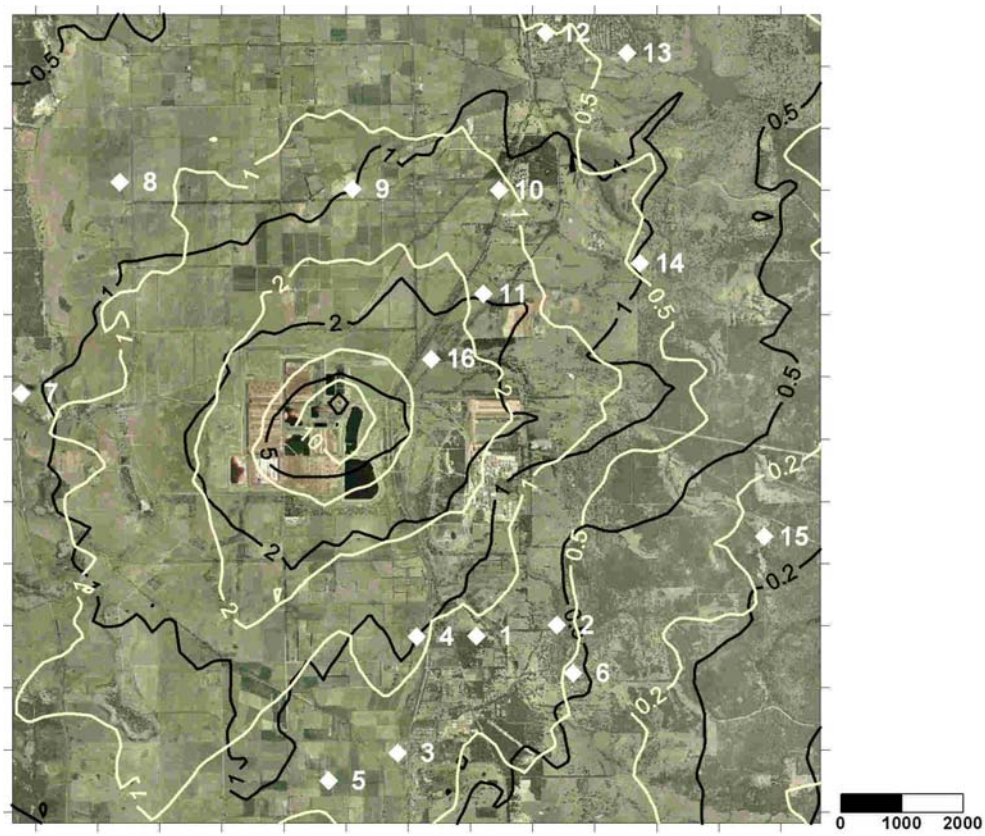


Figure D.13 Predicted 1-hour 99.9 Percentile Acetaldehyde Concentrations (µg/m^3) from the Base Case. TAPM winds (Dark Lines) and Observed Winds (Light Lines)

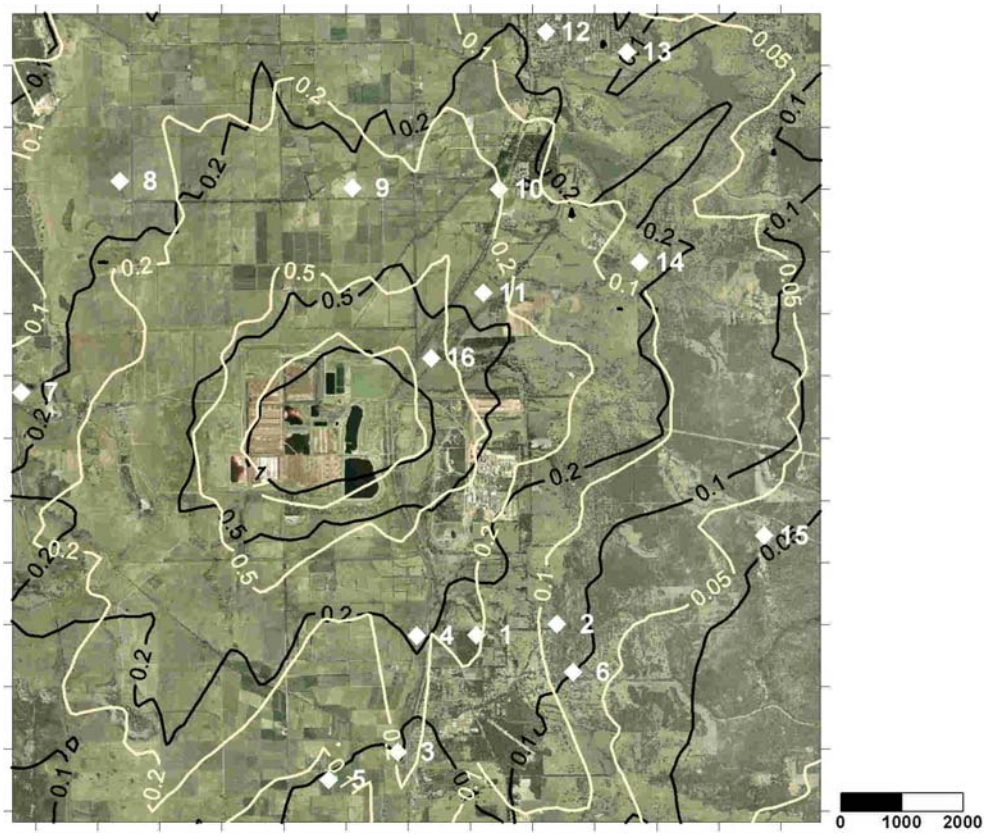


Figure D.14 Predicted 1-hour 99.5 Percentile Acetaldehyde Concentrations (µg/m^3) from the Base Case using. TAPM winds (Dark Lines) and Observed Winds (Light Lines)

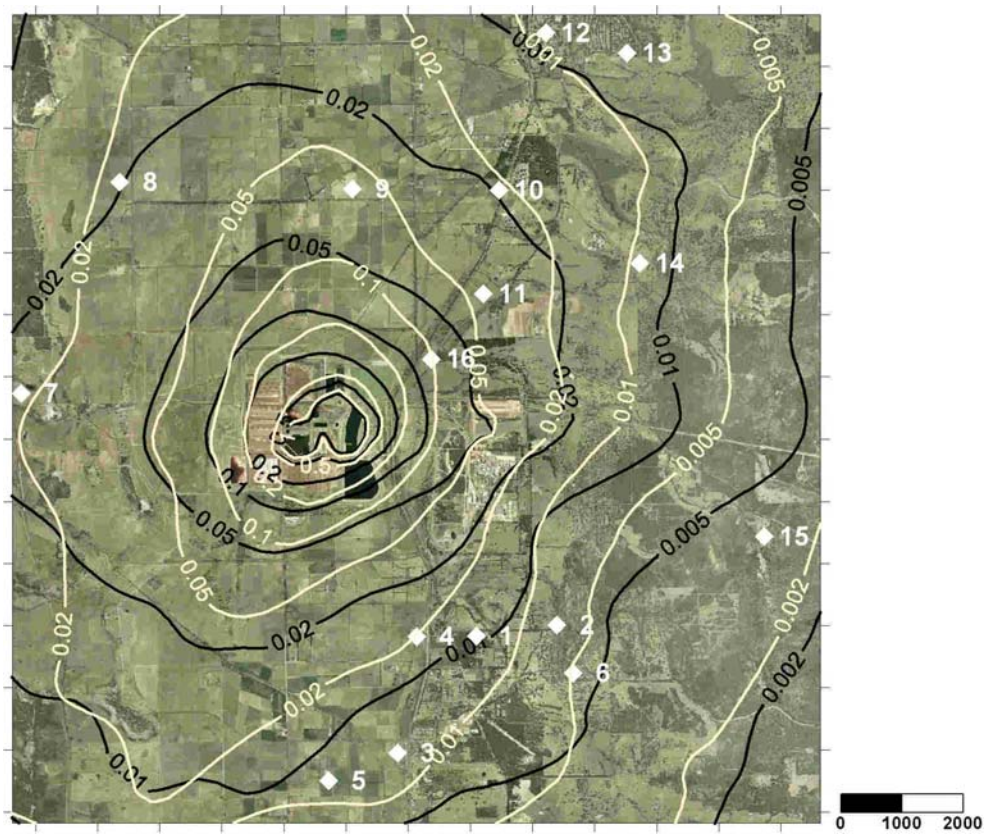


Figure D.15 Predicted Annual Average Acetaldehyde Concentrations (µg/m^3) from the Base Case. TAPM winds (Dark Lines) and Observed Winds (Light Lines)

Therefore, in general there is reasonable agreement in the range of concentration statistics presented for the VOC sources from the two wind data sets. This agreement occurs even though TAPM under-predicts the very light winds as the highest concentrations off site occur for a range of wind speeds from 0.5 to 4 m/s under stable to neutral conditions. This occurs as the emissions are a function of the wind speed at the surface and this increase in emissions with higher wind speeds to some degree counteracts the increased dispersion due to higher dilution and greater plume spread.

Appendix E Additional Analysis of the wind Speed Dependency of Cooling Pond Emissions

In the finalisation of the report, it was recommended by a reviewer that the down wind TO-11a samples that were used to back calculate emission fluxes from the cooling pond should also be analysed to determine if they show a wind speed dependence. Of the TO-11a samples, acetone was the only compound readily detected and is plotted as a function of the wind speed at the time of sampling in **Figure E.1.**

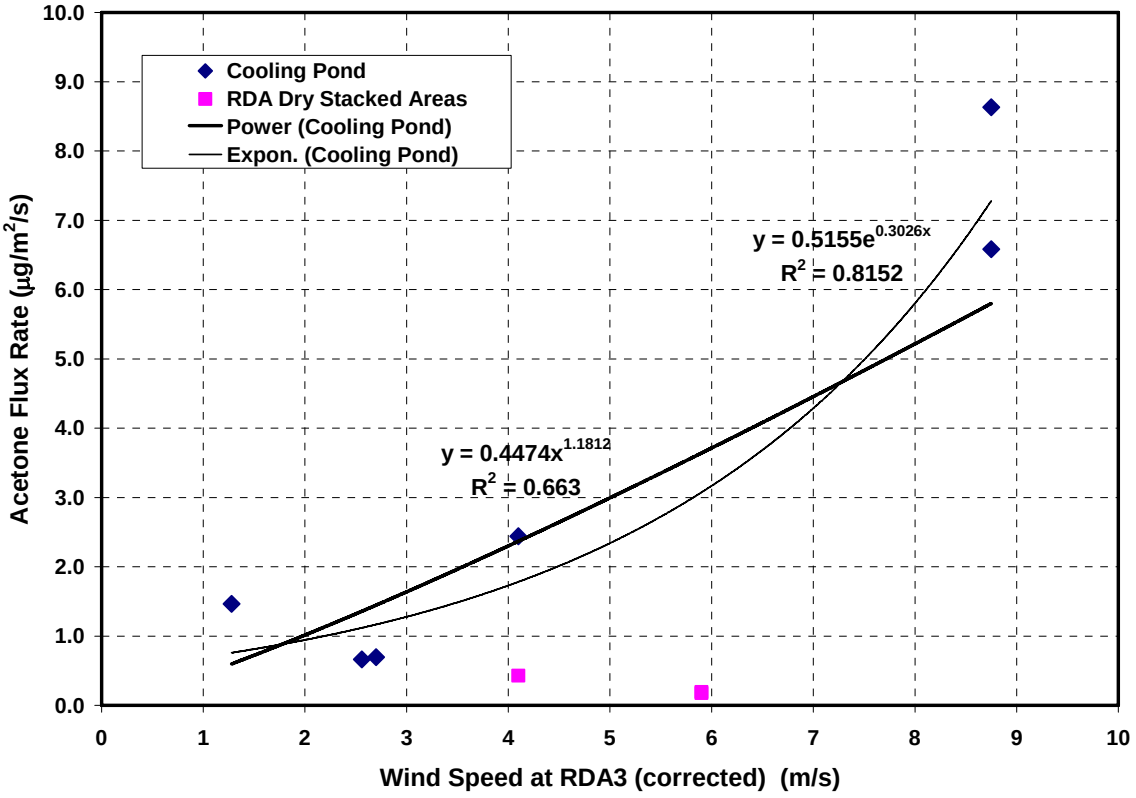


Figure E.1 Back Calculated Acetone Fluxes from the Cooling Pond and RDAs as a function of the Wind Speed

Figure E.1 indicates that there is large wind speed dependency for the acetone from the cooling pond in agreement with the back calculated odour emissions. The data it is noted is however somewhat limited and assumes that the cooling pond has minimal variation in emissions across it. Using a wind speed to the power relationship, the exponent is 1.18, which is greater than that modelled of 0.5 for the HRA modelling and 0.78 as used in the odour modelling. The exponential relationship of 0.3026 is less than the large 0.942 dependence found for the offsite cooling pond measurements by Environmental Alliances (2005). As such, for acetone and for the other compounds which have similar Henry's law constants, such as formaldehyde, acetaldehyde and ammonia a similar relationship could be expected. Compounds such as benzene and toluene however with much higher Henry law constants should not show much if any wind speed dependence.