

**Appendix 1 – Study of Ambient Air Quality at Cubley.
Environment Agency NMA/TR/2009/05.**

enhancing... improving... cleaning... restoring...
changing... tackling... protecting... reducing...
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advising... managing... adapting...

Study of Ambient Air Quality at Cubley 23 October 2008 and 5 May 2009

Main Report
August 2009

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Executive Summary

This report provides the results from a study of ambient air quality in the vicinity of Cubley, Derbyshire. The Environment Agency's Ambient Air Monitoring Team (in National Operational Services) carried out the study between 23 October 2008 and 5 May 2009 (195 days) on behalf of Midlands region. The Ambient Air Monitoring Team deployed its mobile monitoring facility (MMF2) at Stoneleigh Cottage Farm, Cubley during the study period.

The report presents the measured levels of particulate (PM₁₀ and PM_{2.5}), sulphur dioxide (SO₂), ammonia (NH₃), oxides of nitrogen (NO_x) and nitrogen dioxide (NO₂). PM₁₀, PM_{2.5}, SO₂, and NO_x have been compared with the objectives of the UK Air Quality Strategy (AQS). NH₃ has been compared with the WHO guidelines and H1 guidance.

The measurements for NO₂ and PM_{2.5} indicated that if the monitoring period was representative of general conditions over a year, then it would be unlikely that the AQS annual objectives for the protection of human health, for these pollutants would be exceeded.

The recorded levels of NO_x and SO₂ did not exceed the annual concentration objectives for the protection of vegetation and ecosystems given in the AQS for these pollutants.

Comparison of the PM₁₀ data with the annual mean AQS objective indicated that this objective was likely to be met at the monitoring site.

Comparison of the PM₁₀ data with the 24-hour (midnight-midnight) mean AQS objective indicated that this objective would be exceeded at the monitoring site.

The NH₃ data when compared with the short term and long term EALs for the protection of human health as stated in H1 showed that the guidelines were not exceeded at the monitoring site.

Comparison of the NH₃ data with WHO and H1 guidelines showed that the limit levels set to protect against ecotoxic effects showed that both the annual and monthly levels were exceeded during the monitoring period.

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1 Introduction

The Environment Agency's Ambient Air Monitoring Team (AAM Team), on behalf of Midlands Region, carried out a study to investigate ambient air quality in the vicinity of a poultry farm at Cubley in Derbyshire.

The Poultry farm consists of six poultry sheds, which house broiler chickens. The capacity of the sheds stated within the permit is 70,000 birds, but this can vary as the sheds are not always fully stocked for each cycle. The growth cycles of the poultry last for around seven weeks, there is usually a short period following where the sheds are empty.

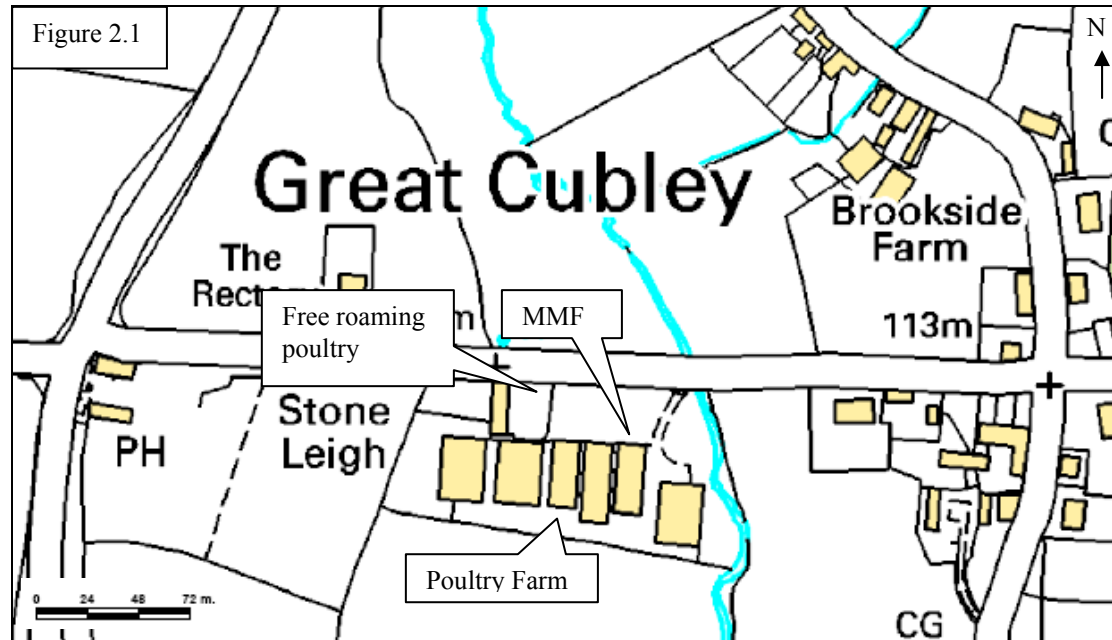
The study involved a programme of monitoring carried out between 23 October 2008 and 5 May 2009 (195 days). The Ambient Air Monitoring Team's Mobile Monitoring Facility (MMF) was used to measure the ambient concentrations of a range of pollutants. The reported pollutants are PM₁₀, PM_{2.5}, NH₃, NO_x and SO₂.

The overall objective of the study was to identify the local sources of air pollution and to quantify the environmental impact of the emissions from these sources on the surrounding area and the local community; within this objective, the following individual aims were identified:

- To assess the general air quality of the area relative to the AQS objectives
- To quantify the impact of nearby industrial sites on local air quality
- To identify specific sources causing an appreciable impact on air quality
- To identify and understand the conditions that give rise to episodes of poor air quality

2 Monitoring Location

The Ambient Air Monitoring team deployed its mobile monitoring facility (MMF2) on the grounds of Stoneleigh cottage farm in a rural area (Figure 2.1). A poultry farm is located on the premises of Stoneleigh cottage farm. There are a number of agricultural practices ongoing in the neighbouring fields of the monitoring site, including slurry spreading, and animal farming. The poultry farm is located at a bearing of 130° - 260° from the MMF.



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3 Monitoring Results

3.1 Meteorology

Wind speed and direction measurements were collected at MMF2 during the study period. The sensor was mounted on a mast extending 6m from the top of the MMF trailer giving an overall height above ground of 8m. It is advisable that the MMF be located over 100m from any buildings of greater or comparable height, so as to reduce any influence that surrounding buildings may have had on the wind distribution. As seen in Figure 2.1 the MMF was stationed close to one of the poultry sheds on site which was of greater height than the MMF and the site was also bordered by trees. Neither of the two factors stated were creating a barrier between the MMF and possible pollution sources from the poultry farm.

When setting up the instrument measuring wind direction at the beginning of the study, the mast was rotated such that the vane pointed in a known direction and this was used as datum from which other directions were determined by the sensor. An uncertainty of $\pm 5^\circ$ on the wind direction is introduced which affects all readings by the same amount. For the production of rose plots the wind direction data are resolved into 10° sectors for analysis and interpretation, therefore the uncertainty of each sector is $\pm 5^\circ$.

The frequency distribution of wind direction between 23 October 2008 - 5 May 2009 (195 days) for MMF2 is shown in Figure 3.1.1 and summarised in Table 3.1.1. The results show that over the period at MMF2 there were two distinct wind sectors $170^\circ - 260^\circ$ and $320^\circ - 50^\circ$ with wind coming from these sectors 33% and 52% of the time respectively. The bias between $10^\circ - 20^\circ$ suggests that a high percentage of the wind came from a near Northerly wind direction and at extremely low wind speeds, which is unusual.

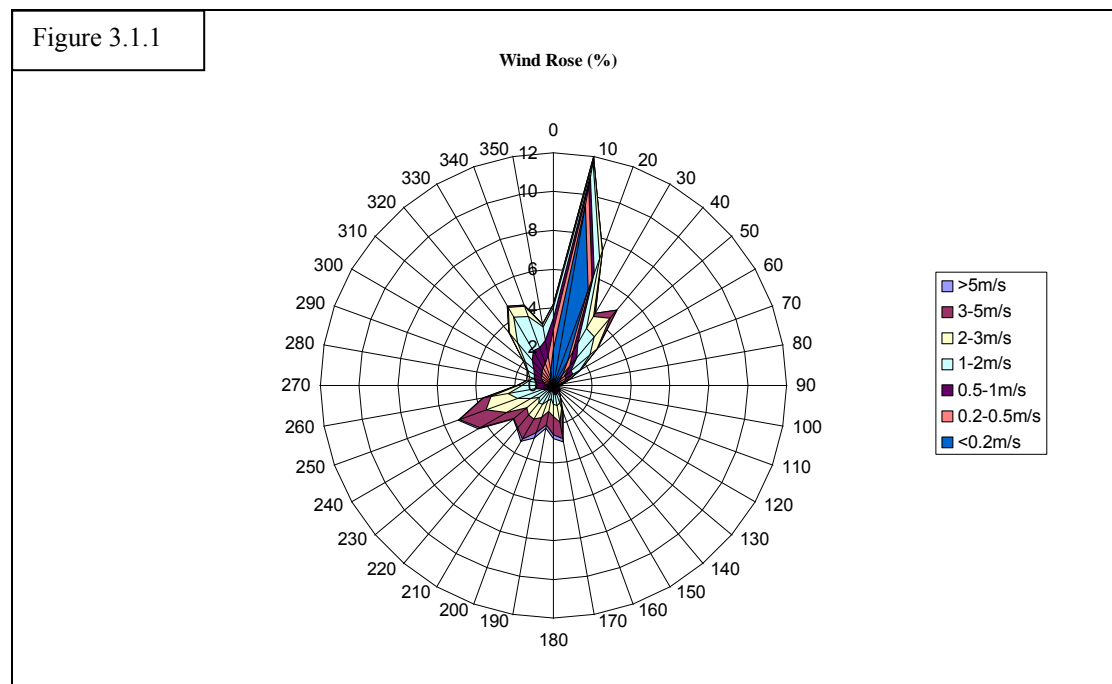
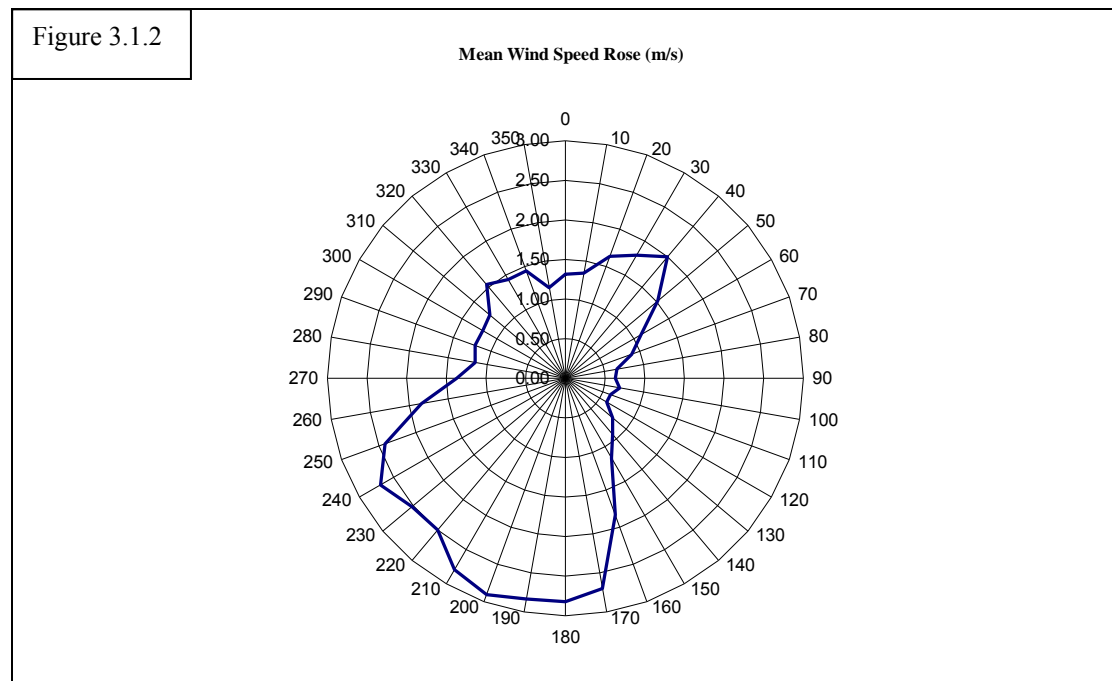


Table 3.1.1 Summary of wind speed frequencies

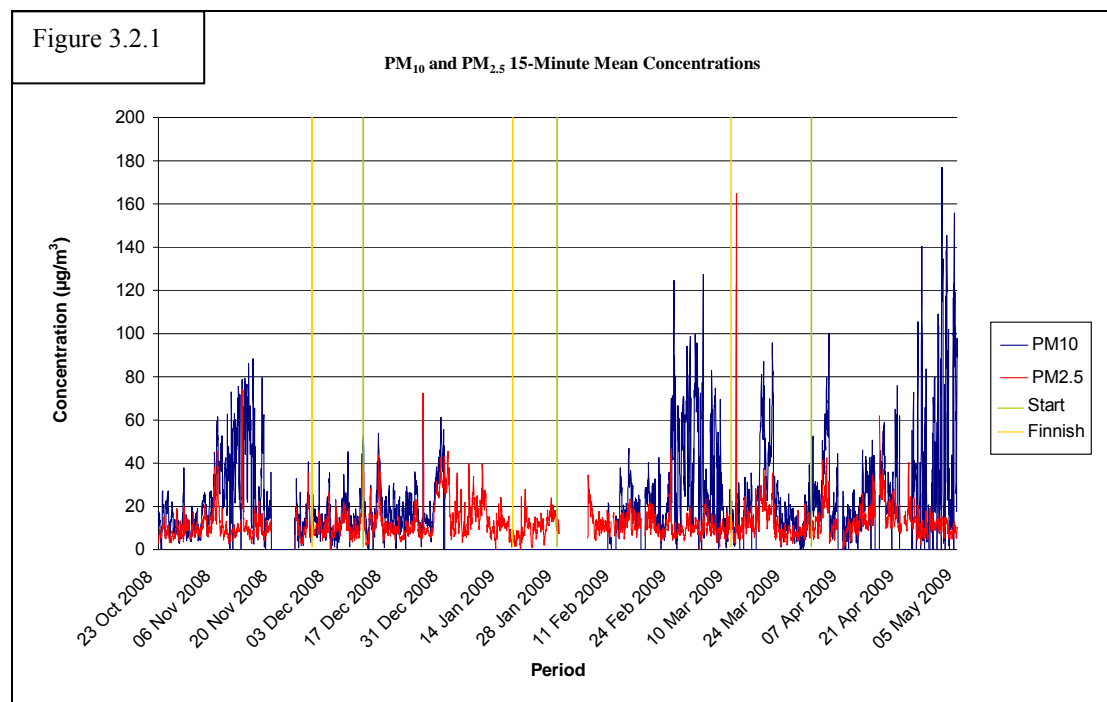
Wind Speed (m/s)	Frequency of wind speed (%)
>5	1.16
3-5	11.0
2-3	15.8
1-2	22.9
0.5-1	13.3
0.2-0.5	12.9
<0.2	23.0
Total	100

A plot of mean wind speed against wind direction for MMF2 is shown in Figure 3.1.2. The maximum mean wind speed at MMF2 was >2m/s and came from the wind sector 170° - 250°. The lowest mean wind speeds at MMF2 arrived from the wind sector 70° - 140°.



3.2 Particulates (PM₁₀ and PM_{2.5})

Between 23 October 2008 and 5 May 2009 (195 days) airborne PM₁₀ and PM_{2.5} concentrations at MMF2 were measured (at a height of 2m above ground) using TEOM instruments. Details of the instrumentation and methodology are given in Appendix C. Successful data collection for PM₁₀ and PM_{2.5} over the period was 71% and 90% respectively. A time series plot of 15-minute PM₁₀ and PM_{2.5} concentrations over the monitoring period is shown in Figure 3.2.1. Markers have been placed on the graph to indicate the start and finish date of the growth cycles at the poultry farm. Activities within the growth cycle (start-finish) include thinning (1-2 days) and catching of poultry (1-3 days). Activities outside of the growth cycles include cleaning (1-2 days).



3.2.1 Comparison with Standards

3.2.1.1 Comparison with Air Quality Strategy (AQS) Objectives

As a consequence of PM₁₀ measurements being taken using a TEOM instrument, adjustments should be made using FDMS data where available for PM₁₀ (see Appendix C). PM_{2.5} should be adjusted using the 1.3 correction factor.

FDMS data acquired from Kings College London (KCL) Volatile Correction Model (VCM) has been used to correct the PM₁₀ data from MMF2. PM_{2.5} data has been corrected using the 1.3 factor. Concentrations that incorporate the 1.3 factor or FDMS data are quoted as µg/m³ (as in Figure 3.2.1), where as those that have not been multiplied by these factors are quoted as µg/m³[TEOM].

It has been shown that particulate measurements using a TEOM instrument with the 1.3 correction factor applied is not equivalent to the reference method for particulate matter and therefore not strictly comparable to the European Daughter Directive Limit Values, this should be taken into consideration when examining data which is breaching standards. Although using FDMS data to correct TEOM results is equivalent to the reference method, the FDMS data that has been used in this study is unratified.

The AQS has two objectives for PM₁₀, the first is to limit the annual mean concentration to 40µg/m³ and the second objective states that the 24-hour mean (midnight – midnight) must not exceed 50µg/m³ on more than 35 occasions during one year.

The mean PM₁₀ concentration over the monitoring period at MMF2 was 25.4 µg/m³. If the assumption is made that the conditions during the monitoring periods were representative of a typical year, then the results would indicate that the AQS annual mean objective would not be exceeded at the monitoring site.

Figure 3.2.2 shows the 24-hour (midnight-midnight) mean PM₁₀ concentrations at the monitoring site.

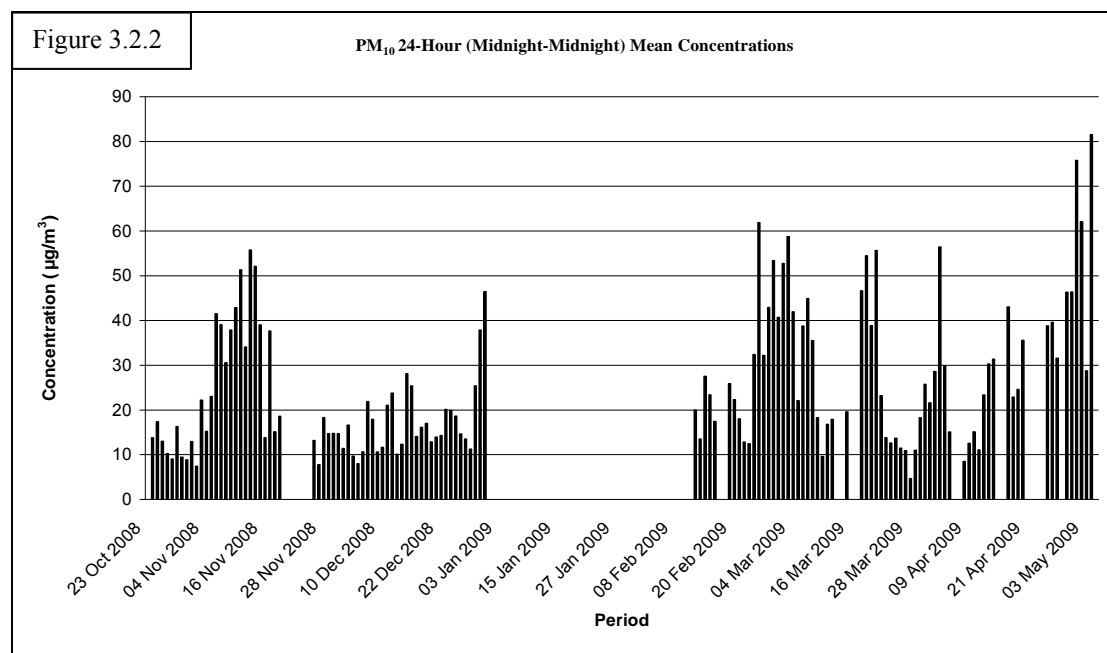


Figure 3.2.2 shows that for PM₁₀ the 24-hour (midnight-midnight) mean concentration at MMF2 was greater than 50µg/m³ on 13 occasions during the monitoring period, the maximum concentration being 81.5µg/m³. 10 of the 13 exceedances occurred later than 26 days into the poultry cycle. One of the exceedance occurred on the 5th day of a cycle and two of the exceedances occurred when the sheds were empty.

If the assumption is made that the conditions during the monitoring period were representative of a typical year, then over a year the 50µg/m³ level for 24-hour (midnight-midnight) mean concentrations would be exceeded on 37 occasions (26 occasions when looking at uncorrected TEOM data) and thus the AQS for 24-Hours (midnight-midnight) mean PM₁₀ concentrations would be exceeded at the monitoring site.

The AQS objective for PM_{2.5}, limits the annual mean concentration to 25µg/m³. The mean PM_{2.5} concentration over the monitoring period was 12.1µg/m³. If the assumption is made that the conditions during the monitoring period was representative of a typical year, then the results would indicate that the AQS annual mean objective for PM_{2.5} would not be exceeded at the monitoring site.

3.2.2 Detailed consideration of PM₁₀ pollution events

The periods where PM₁₀ 1-Hour concentrations (ug/m³) at the monitoring sites increased significantly above the average level have been considered as separate pollution events and have been examined in greater depth. For the purposes of this study the highest five recorded events were individually considered and the association between recorded PM₁₀ levels and the wind direction and wind speed at that time examined. The results are summarised in Table 3.2.1

Table 3.2.1 Summary of PM₁₀ pollution events

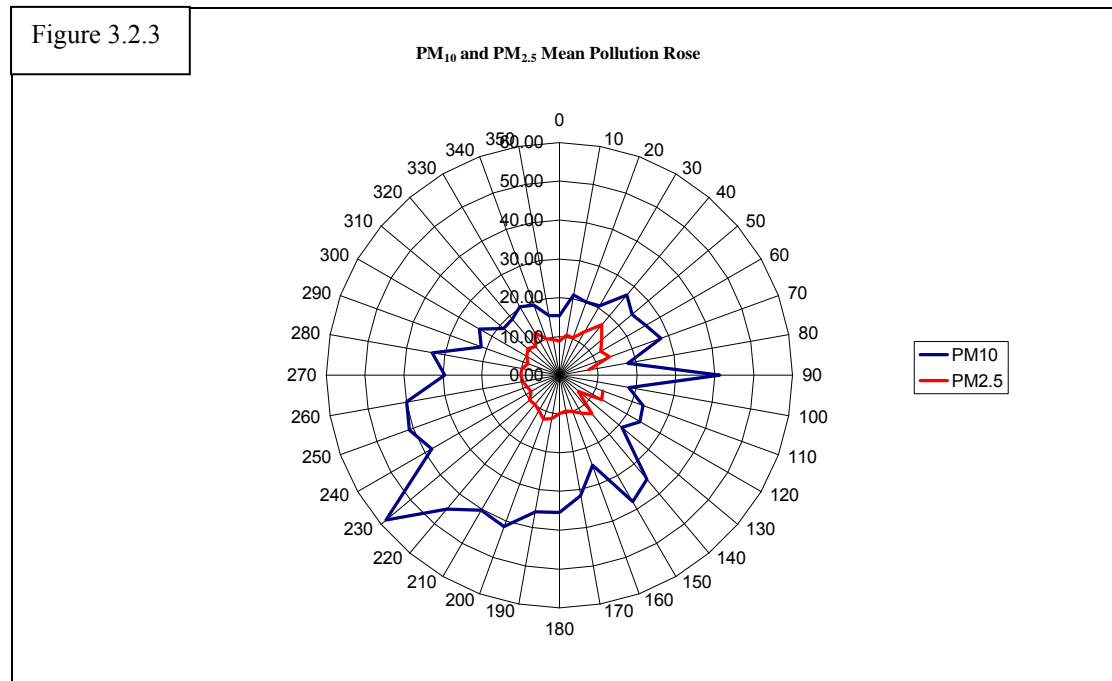
Pollution Event	Cycle Day	Date	Time	Maximum 1-Hour Concentration (µg/m ³)	Wind Direction (degrees)	Wind Speed (m/s)
1	31	01/05/09	15:00	177	226	2.3
2	34	04/05/09	15:00	156	236	3.7
3	32	02/05/09	19:00	145	254	1.1
4	28	26/04/09	18:00	140	227	1.1
5	36	04/03/09	16:00	127	216	2.3

Table 3.2.1 shows that high levels of PM₁₀ were recorded at the monitoring site when the wind was coming from between 216° - 254°, in the direction of the poultry farm, at wind speeds of 1.1 - 3.7 m/s. The pollution events occurred between the hours of 15:00 - 19:00. Two of the pollution episodes (04/05/09 & 04/03/09) occurred on days within the growth cycle where thinning was undertaken. All five pollution episodes occurred at a date which was later than 27 days into a growth cycle, with the length of a growth cycle during the study period ranging from 36-42 days.

3.2.3 Directional analysis

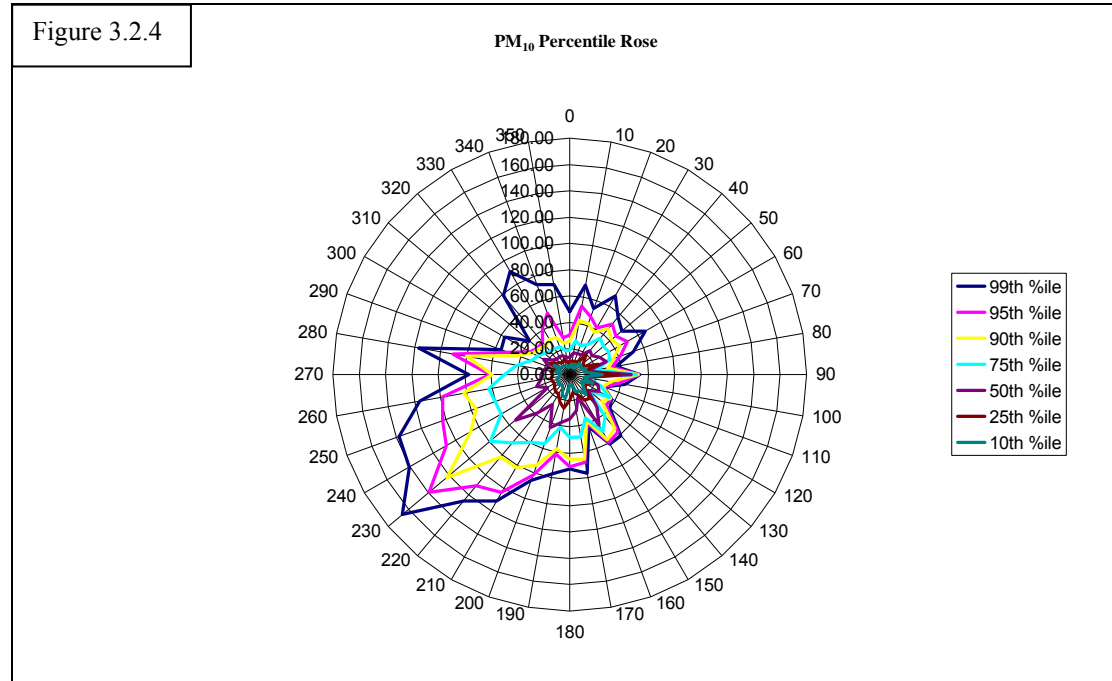
A Radial plot of mean PM₁₀ and PM_{2.5} concentrations (µg/m³) against wind direction for wind speeds above 0.5m/s, recorded at MMF2 are shown in Figure 3.2.3.

Figure 3.2.3 shows that the highest average PM₁₀ concentrations measured at the monitoring site were >30µg/m³ and came from wind directions between 140° - 150°, 170° - 280° and 90°. The highest levels of PM_{2.5} concentrations were measured when the wind direction was between 10° - 70°, 140° - 160°, 180° - 200° and 330° with concentrations ~10µg/m³.



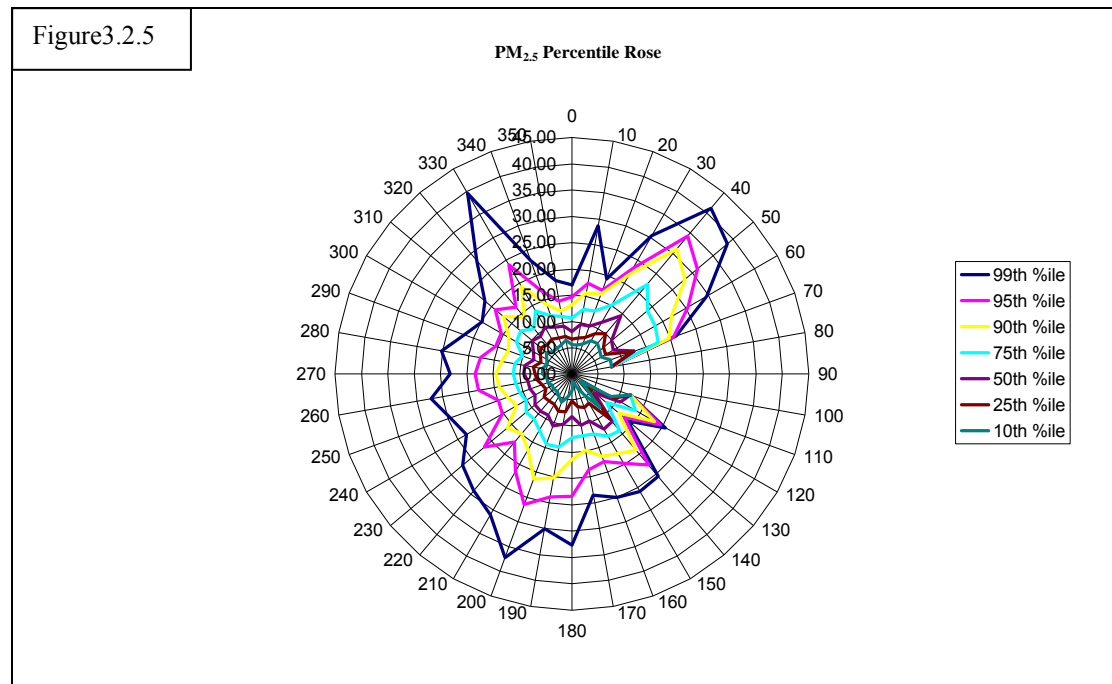
An array of plots showing the contribution to PM₁₀ and PM_{2.5} loading ($\mu\text{g}/\text{m}^3$) at the monitoring site for different percentiles are shown in Figures 3.2.4 and 3.2.5 respectively.

The PM₁₀ plots show that the contribution from the sources between 170° - 290° and 320° - 350°, is more evident in the higher percentiles than in the lower percentiles, which suggests that the sources are intermittent.



For PM_{2.5}, elevated sources between 140° - 260° and 310° - 340° are evident in the higher percentiles, suggesting an intermittent source coming from these wind directions. The plot shows that the contribution from the source at 140° , is evident in the lower percentiles.

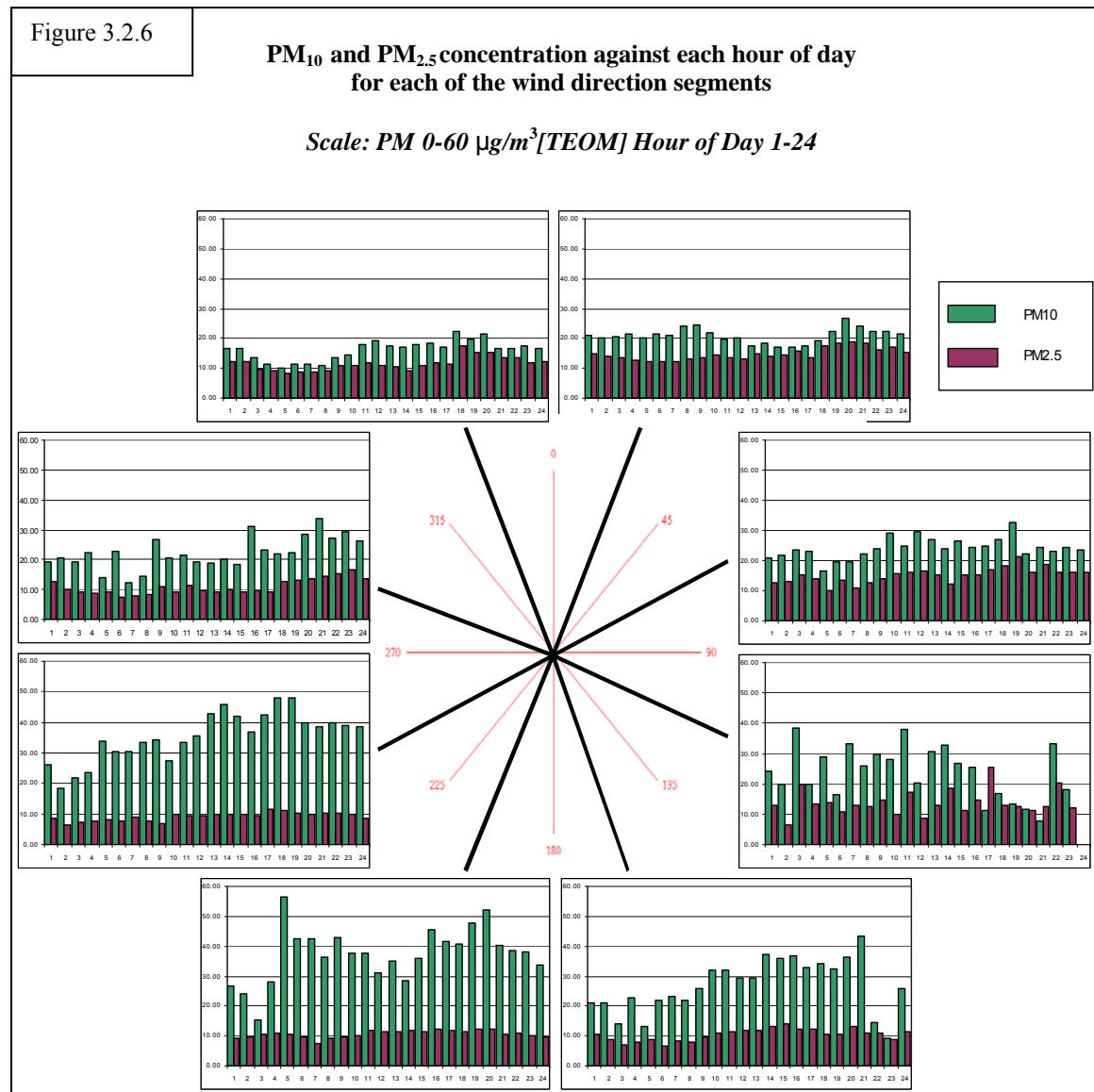
The PM_{2.5} plots show that the contribution from the source(s) between 10° - 70° can be seen to affect each of the percentile plots suggesting that the source(s) is continuous and commonly affects PM_{2.5} concentrations at the monitoring site when the wind is coming from this wind sector. However, the bias between 140° - 260° and 310° - 340° is more evident in the higher percentiles than in the lower percentiles, which suggests that the sources are intermittent. The bias at 140° is only evident in the lower percentiles, which suggests that the source is relatively continuous, as it is affecting a large percentage of the data, but is not causing appreciably high concentrations at the monitoring site.



3.2.4 Diurnal and Day of Week Variation

Figure 3.2.6 shows diurnal variation of average PM₁₀ and PM_{2.5} concentrations for each 45° wind direction sector at the MMF2 site. Consideration of the diurnal distribution of concentration levels can provide further useful information about the sources contributing to the ambient levels in each sector.

PM₁₀ data shows higher diurnal concentrations than that of PM_{2.5}, with a greater marked difference in wind sectors 135° – 270° in the direction of the poultry farm, where PM₁₀ concentrations are greater than that of other wind sectors. The elevated source of PM₁₀ between wind sectors 135° – 270° does not show a double diurnal peak associated with traffic or a single peak which is greatest at around mid day, which would be associated with industrial and stack emissions.



3.2.5 Additional Analysis

In order to further understand the possible sources causing an impact on PM₁₀ concentrations at the MMF2 site, additional directional analysis has been undertaken. Analysis includes using the elevated PM₁₀ wind sectors identified in the mean pollution roses, to calculate whether a significant number of exceedances are coming from a particular wind sector, based on the comparison of exceedance and wind direction data. A ratio >1 suggests that there is a high number of exceedances for the wind sector considering the amount of the time that the wind blew from this direction. If the wind sector has >35 exceedances then it can be considered as a significant source to the exceedance of PM₁₀ 24-hour standard.

Table 3.2.2 shows the average (midnight – midnight) wind direction associated with each of the exceedances of the 24-hour (midnight – midnight) average AQS objective for PM₁₀.

When looking at the results in Table 3.2.2, it is important to keep in mind that it is the average wind direction over the 24-hour period in which the exceedance occurred, that has been used. Although typically, wind direction does not change greatly over a 24 hour period, an assumption is being made that the 24-hour average is representative of the wind direction(s) contributing to the exceedance.

Table 3.2.2 shows that the majority of exceedances (69%) are measured from the wind direction 170° - 270°. The ratio value between 170° - 270° in the direction of the poultry farm is high at 1.98, suggesting that there were a considerable number of exceedances that can be attributed to wind from this direction, considering the percentage of time that wind was blowing from this sector.

Table 3.2.2 Average wind directions associated with exceedances of the 24-hour AQS objective for PM₁₀

Wind Sector (degrees)	Exceedances During Monitoring	Exceedances Pro Rata	Percentage of all Exceedances [A]	Wind from this sector (% Monitoring Period) [B]	Ratio [A] / [B]
140° - 150°	0	0.00	0.00	1.19	0.00
170° - 270°	9	25.3	69.2	34.9	1.98
80° - 100°	0	0.00	0.00	0.97	0.00
Other Directions	4	11.2	30.8	62.9	0.49
TOTAL	13	36.5	100	100	-

3.2.6 Conclusions

Comparison of the PM₁₀ data with the AQS objective for the 24-hour (midnight-midnight) mean indicated that the current standard would be exceeded at the monitoring site.

The mean PM₁₀ concentration over the monitoring period was 25.4µg/m³. If the assumption is made that the conditions during the monitoring periods were representative of a typical year, then the results would indicate that the AQS annual mean objective of 40µg/m³ would not be exceeded at the monitoring site.

The mean PM_{2.5} concentration over the monitoring period was 12.1µg/m³. If the assumption is made that the conditions during the monitoring periods were representative of a typical year, then the results would indicate that the AQS annual mean objective for PM_{2.5} of 25 µg/m³ would not be exceeded at the monitoring site.

Pollution rose analysis indicates that the highest average PM₁₀ concentrations measured at MMF2 were from a wind direction between 140° - 150°, 170° - 280° (in the direction of the poultry farm) and 90°. Highest average PM_{2.5} concentrations measured at the monitoring site were from a wind direction between 10° - 70°, 140° - 160°, 180° - 200° and 330° which also suggests a source from the poultry farm.

Percentile rose analysis for MMF2 suggests that there is an intermittent PM₁₀ source between 170° - 290° (in the direction of the poultry farm) and at 320° - 350° that commonly affects PM₁₀ concentrations at the monitoring site when the wind is from these directions.

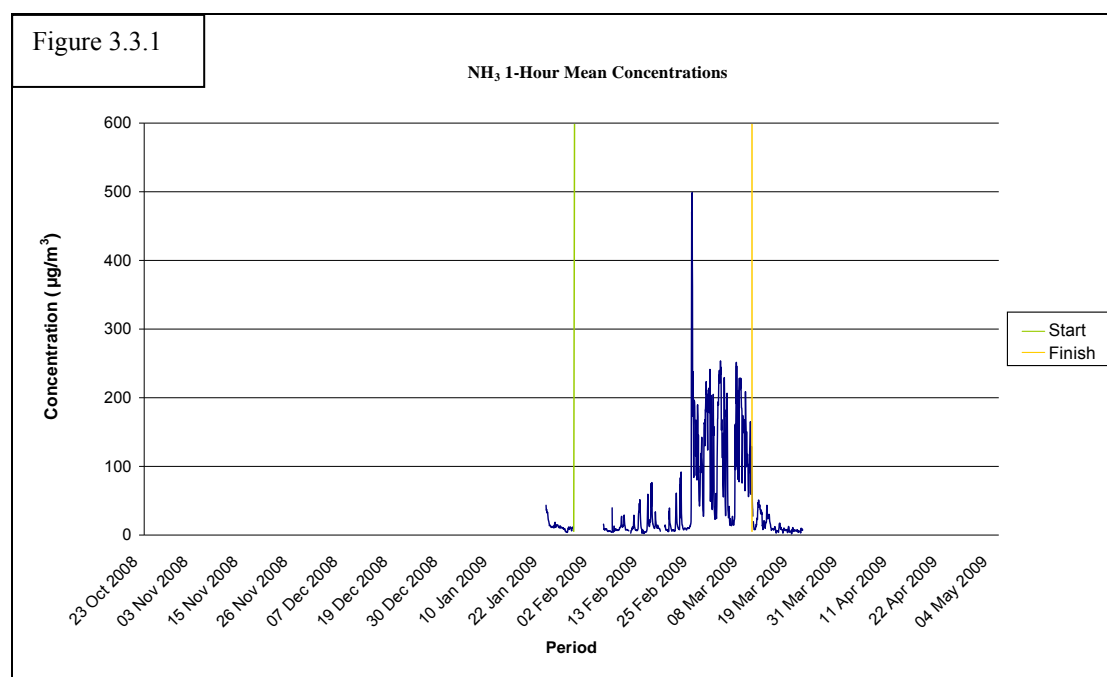
Diurnal analysis, shows that there is a continuously elevated source of PM₁₀ from 135° - 270°, there does not seem to be any elevated source of PM_{2.5}.

Additional analysis suggest that there are a considerable number of exceedances from the wind direction 170° - 270° considering the percentage of time that wind was blowing from this sector. This source is from the direction of the poultry farm.

3.3 Ammonia (NH₃)

Between 23 October 2008 and 15 May 2009 (195 days) airborne NH₃ concentrations were measured at a height of 2m above ground. Successful data collection over the monitoring period was very low at 26% due to issues with the reliability of the NH₃ analyzer. Details of the instrumentation and methodology are given in Appendix D.

A time series plot of 1-hour NH₃ concentrations (µg/m³) over the monitoring period is shown in Figure 3.3.1. Markers have been placed on the graph to indicate the start and finish date of the growth cycles at the poultry farm. It can be seen that during the poultry cycle that has been captured that there were a number of periods where hourly mean NH₃ concentrations were commonly greater than 100µg/m³ and on occasions the levels reached in excess of 400µg/m³. The maximum 1-hour concentration recorded at the site was 499 µg/m³ and the average concentration over the monitoring period was 45.5µg/m³.

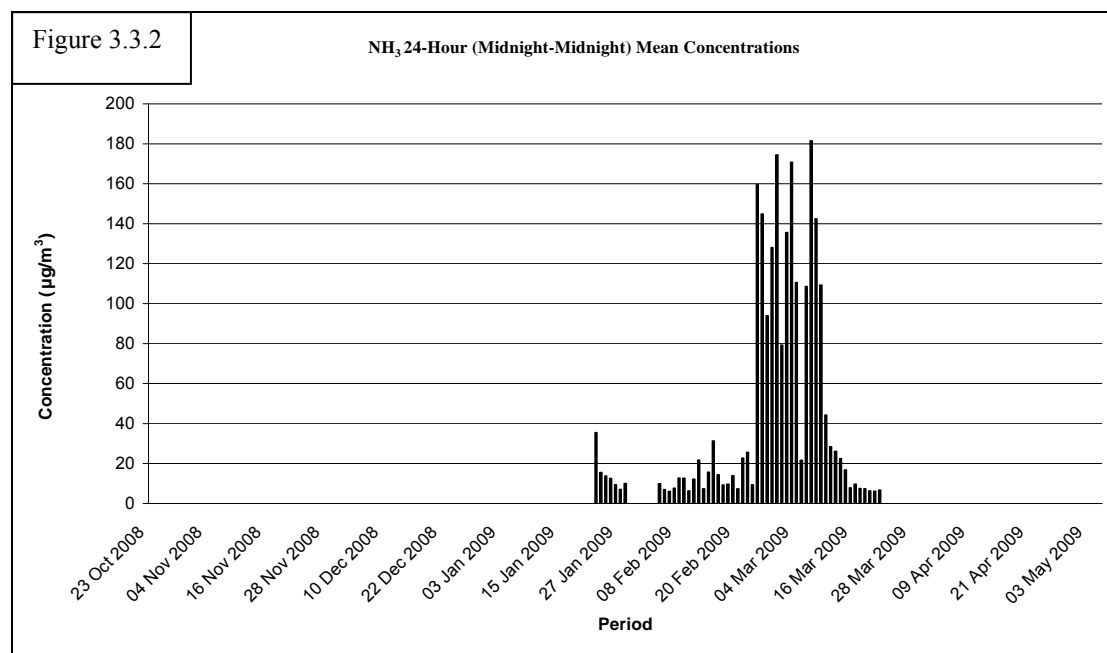


3.3.1 Comparison With WHO Guidelines

Figure 3.3.2 shows the 24-hour (midnight-midnight) mean concentrations over the monitoring period.

The World Health Organisation (WHO) Air Quality Guidelines for Europe (2000) provide guideline values for critical levels for nitrogen containing air pollutants in order to protect against ecotoxic effects. For short-term exposures the guidelines suggest a critical level of 270 µg/m³ as a 24-hour mean for NH₃. Figure 3.3.2 shows that over the monitoring period the maximum recorded 24-hour (midnight-midnight) mean concentration was 181 µg/m³, 67% of the suggested critical level of 270 µg/m³.

WHO recommend a critical level (for the protection of vegetation) for a 1-year period to cover relatively long term effects of NH₃ to be 8 µg/m³. The mean NH₃ concentration over the monitoring period was 45.5µg/m³. If the assumption is made that the conditions during the monitoring period were representative of a typical year then the WHO critical level would be exceeded under current emissions.



The Environment Agency Guidance Document H1 takes the WHO guidelines one step further and also suggests a critical level for an hourly mean of NH₃ as 3300µg/m³ and a monthly mean of NH₃ as 23µg/m³. The maximum hourly and monthly means during the monitoring period were 499µg/m³ and 59.8µg/m³ respectively, indicating that the monthly mean level was exceeded at the monitoring site.

The H1 document also provides both a short term and long term NH₃ Environmental Assessment Levels (EAL's) for the protection of human health which are derived from the Health and Safety Executive's Occupational Exposure Limits (OELs) using the calculations stated in the document. The short term EAL of 2500µg/m³ (hourly average) was not exceeded as the maximum 1-hour concentration recorded was 499µg/m³. Taking the average over the monitoring period to be an annual average the long term EAL of 180µg/m³ (annual average) was not exceeded at the monitoring site as the annual average concentration was 45.5µg/m³, but this is based on a data set that only covers 53 days data.

DEFRA have produced guidance suggesting that the odour threshold for NH₃ starts at around 100µg/m³. The 15-minute data collected at the monitoring site showed that this level was exceeded 17% of the time. However, because the concentration in the air would only have to exceed the odour threshold for a few seconds to be noticeable comparison with 15-minute data may considerably underestimate the occasions during which unpleasant odour at the monitoring site was a problem.

3.3.2 Detailed consideration of NH₃ pollution events

The periods where NH₃ 15-minute concentrations at the monitoring sites increased significantly above the average level have been considered as separate pollution events and have been examined in greater depth. For the purposes of this study the highest five recorded events were individually considered and the association between recorded NH₃ levels and the wind direction and wind speed at that time examined. The results are summarised in Table 3.3.1.

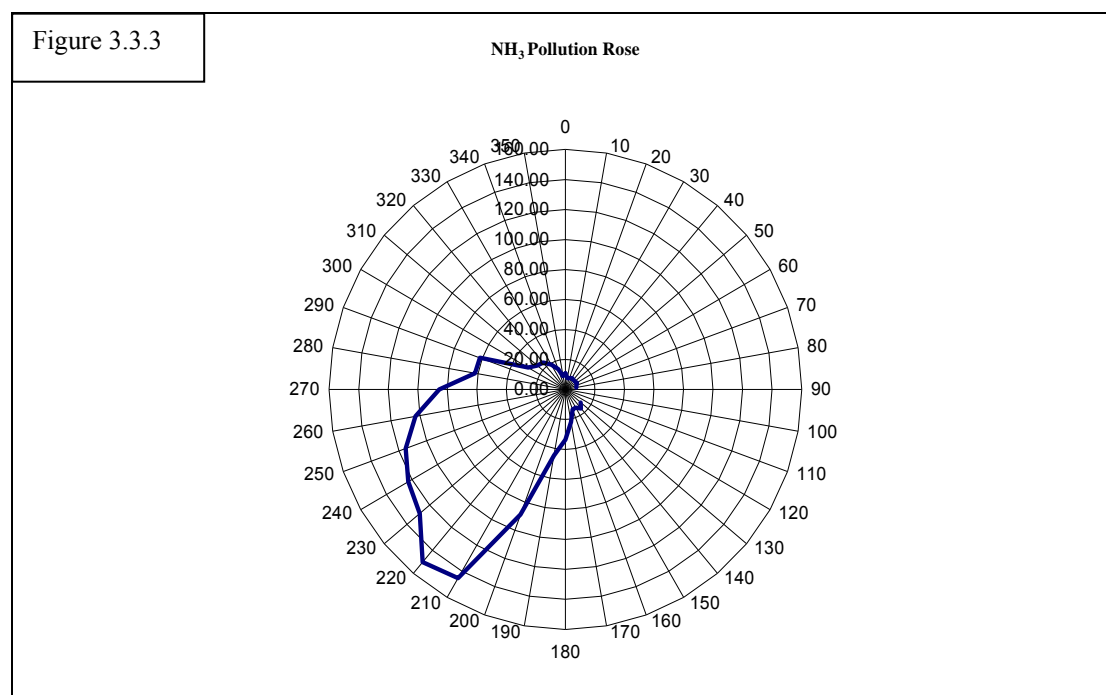
Table 3.3.1 Summary of NH₃ pollution events

Pollution Event	Cycle Day	Date	Time	Maximum 1-Hour Concentration (µg/m ³)	Wind Direction (degrees)	Wind Speed (m/s)
1	28	24/02/09	15:00	591	343	0.7
2	38	06/03/09	17:30	276	249	1.0
3	35	03/03/09	05:30	263	213	1.8
4	32	28/02/09	19:00	261	240	1.0
5	39	07/03/09	06:00	252	219	0.6

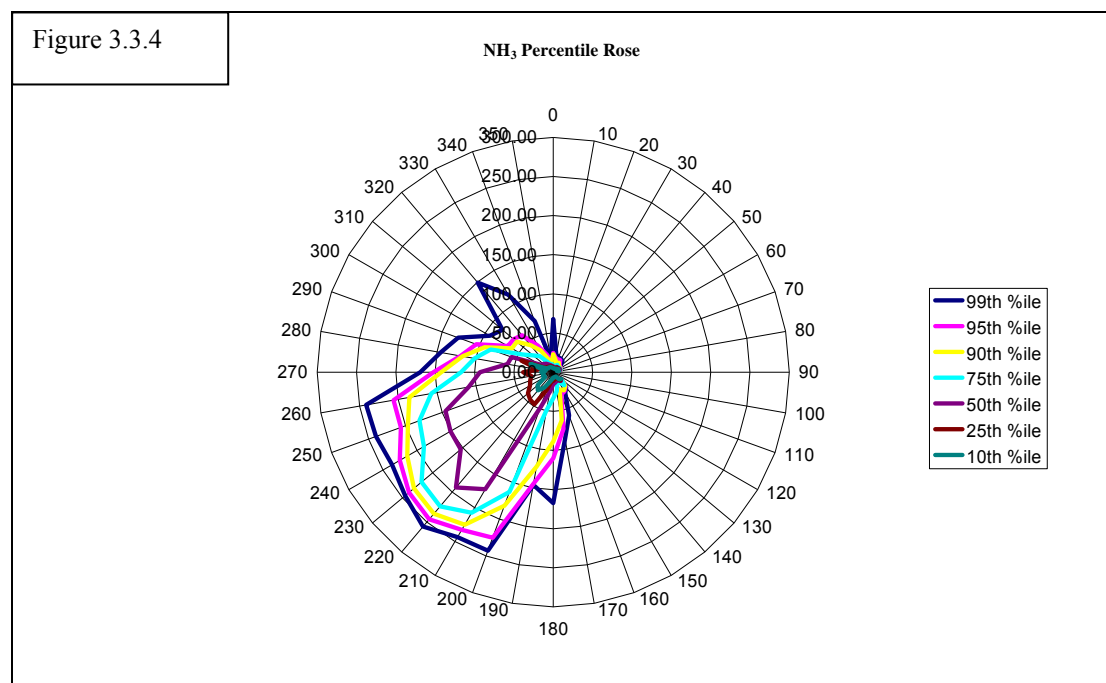
Table 3.3.1 shows that high levels of NH₃ were recorded at the monitoring site when the wind was coming from between 213° - 343° (in the direction of the poultry farm) at low wind speeds of 0.6 - 1.8 m/s. Two of the pollution episodes (03/03/09 & 28/02/09) occurred on days within the growth cycle where thinning was undertaken. The pollution episode on the 6th of March occurred on a catching day. All five pollution episodes occurred at a date which was later than 27 days into a growth cycle, with the length of a growth cycle during the study period ranging from 36-42 days.

3.3.3 Directional Analysis

A radial plot of mean NH₃ concentrations against wind direction for wind speeds above 0.5 m/s is shown in Figure 3.3.3. The plot indicates that the highest average NH₃ concentrations were recorded at the monitoring site when the wind direction was from between 200° - 290°, the direction of the poultry farm, with average levels >60µg/m³.



An array of plots showing the contribution to NH₃ loading at the monitoring site for different percentiles are shown in Figure 3.3.4. The NH₃ plots show that the contribution from the source(s) between 200° - 290°, as indicated in Figure 3.3.3, can be seen to affect each of the percentile plots suggesting that the source(s) is continuous and commonly affects NH₃ concentrations at the monitoring site when the wind is from these directions. However, the fact that the higher (99th - 50th) percentiles are so much higher in concentration than the lower percentiles indicates that the source either produces very high levels of NH₃ at the monitoring site or relatively low levels.



3.3.4 Diurnal and Day of Week Variation

Figure 3.3.5 shows diurnal variation of average NH₃ concentrations for each 45° wind direction sector at the MMF2 site. Consideration of the diurnal distribution of concentration levels can provide further useful information about the sources contributing to the ambient levels in each sector.

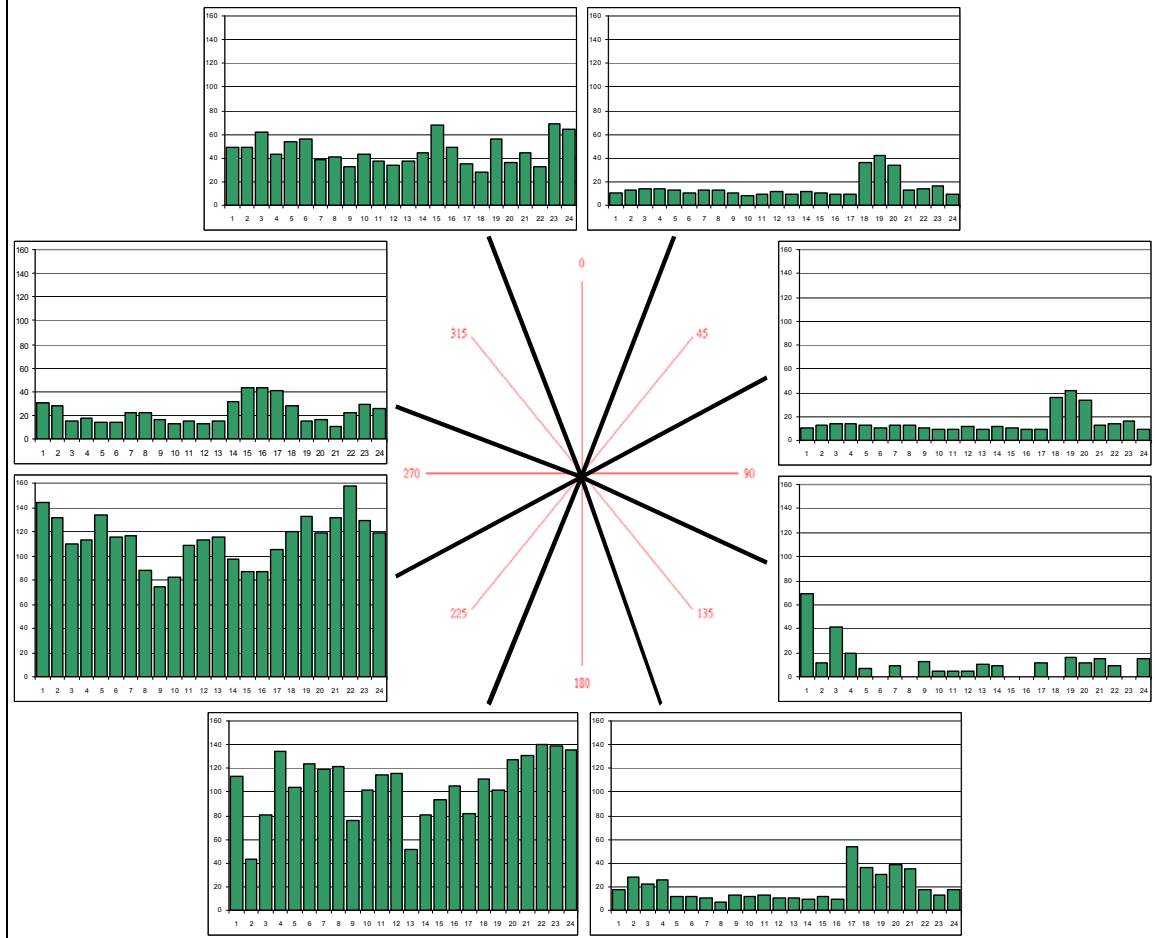
Between wind sectors 0° - 180° there are relatively low concentrations of NH₃ throughout the day. An elevation in NH₃ between the hours of 18:00 - 20:00 can be seen in sectors 0° - 180° with the exception of 90° - 135°. NH₃ concentrations are highest in wind sectors 180° - 270° with several dips throughout the day.

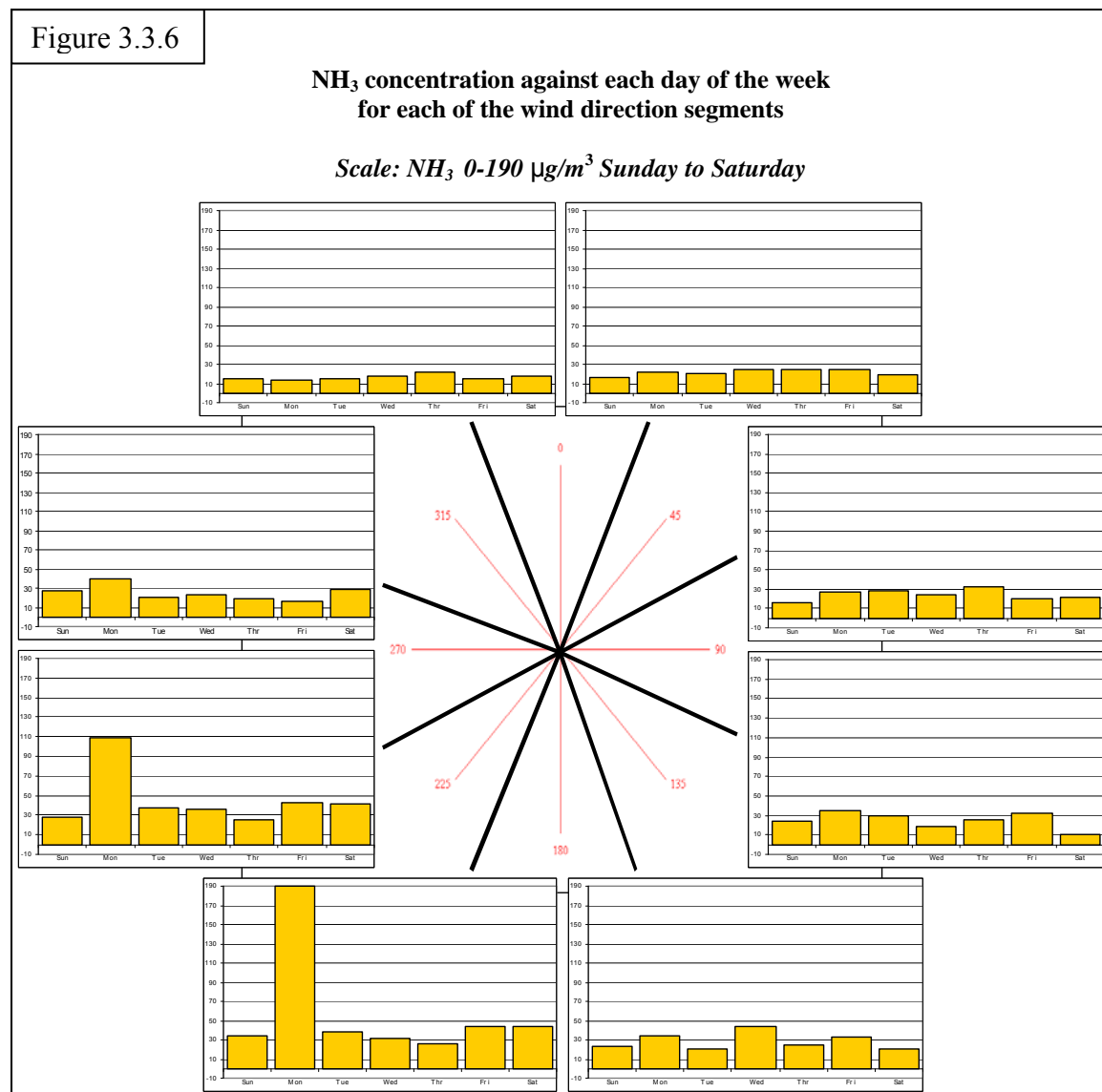
Figure 3.3.6 shows the weekly variation of average NH₃ concentrations for each 45° wind direction sector at the site. The majority of the sites show similar concentrations on each day with the exception of wind sectors 180° - 270° which show higher average concentrations on the Monday.

Figure 3.3.5

**NH₃ concentration against each hour of day
for each of the wind direction segments**

Scale: PM 0-160 $\mu\text{g}/\text{m}^3$ Hour of Day 1-24





3.3.5 Conclusion

The mean NH₃ concentration over the monitoring period was 45.5µg/m³. The results indicated that if the monitoring period was taken to be representative of a typical year then the WHO critical annual average level of 8µg/m³ would be exceeded.

The highest monthly mean NH₃ concentration was 59.8µg/m³, which is 260% of the monthly average critical level of 23µg/m³ set by the H1 document, and therefore exceeds the guideline. The hourly and daily averages were within the guideline values.

Comparison of NH₃ data with short term and long term EALs for the protection of human health as stated in H1 showed that neither of these guidelines were exceeded at the monitoring site.

Pollution rose analysis indicates that maximum mean levels of NH₃ were recorded at the monitoring location when the wind direction was coming from between 200° - 290°, where average levels were >140µg/m³. This wind sector encompasses the bearing of the poultry farm from the monitoring location.

Percentile rose analysis indicated that there is a continuous source from the wind direction of 200° - 290°.

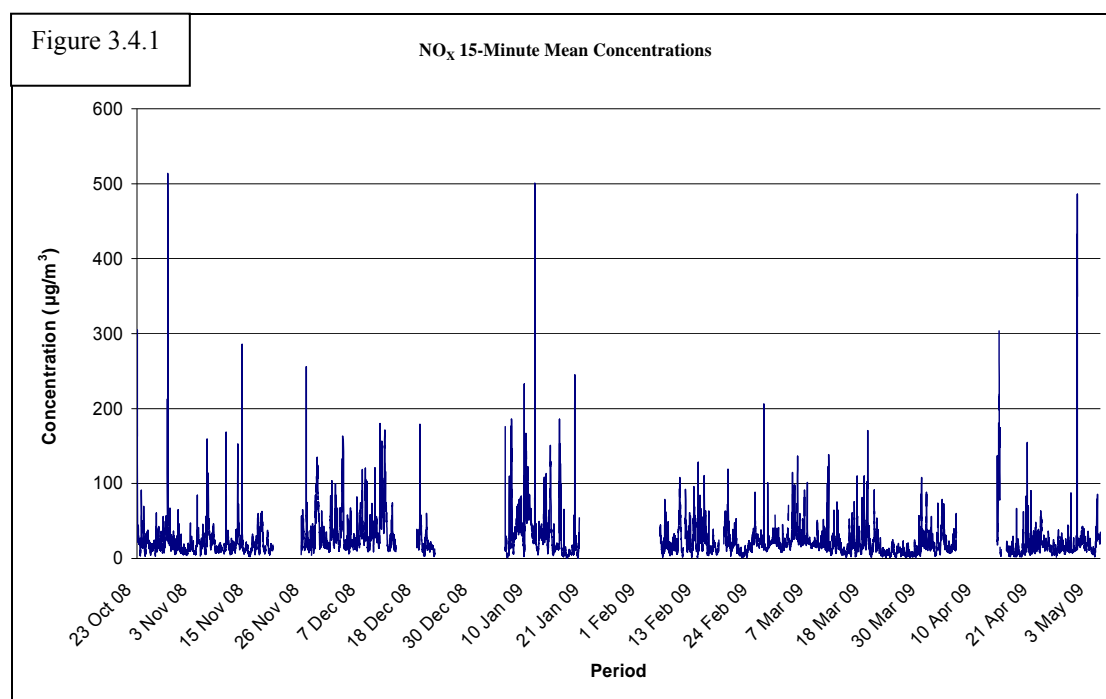
Diurnal analysis showed that the source of NH₃ from wind sectors 180° – 270° was elevated throughout the day. Weekly analysis suggested that the source was greater on Mondays when the wind was coming from the direction of 180° – 270°.

3.4 Oxides of Nitrogen (NO_x)

Between 23 October 2008 and 5 May 2009 (195 days) airborne NO_x and NO₂ concentrations were measured at a height of 2m above ground. Details of the instrumentation and methodology are given in Appendix E. Successful data collection was 71%.

A consideration of NO_x in the atmosphere can give a more direct indication of local pollution sources than looking solely at NO₂. Combustion processes generally emit a greater proportion of NO than NO₂, the NO subsequently oxidising to form NO₂ (typically hours-days later although oxidisation can occur more rapidly during ozone episodes). The NO_x signature of an emission is, therefore, more easily attributed to particular sources than that of NO₂. There is also the advantage that NO_x can be treated as a conserved quantity (i.e. a quantity that is not changed by chemical reaction) during short-range, local dispersion.

A time series plot of MMF 15-minute concentrations of NO_x is shown in Figures 3.4.1. The plots shows that NO_x concentrations remained predominantly below 100µg/m³ with discrete excursions above this level. The average concentration over the period was 24.8µg/m³.

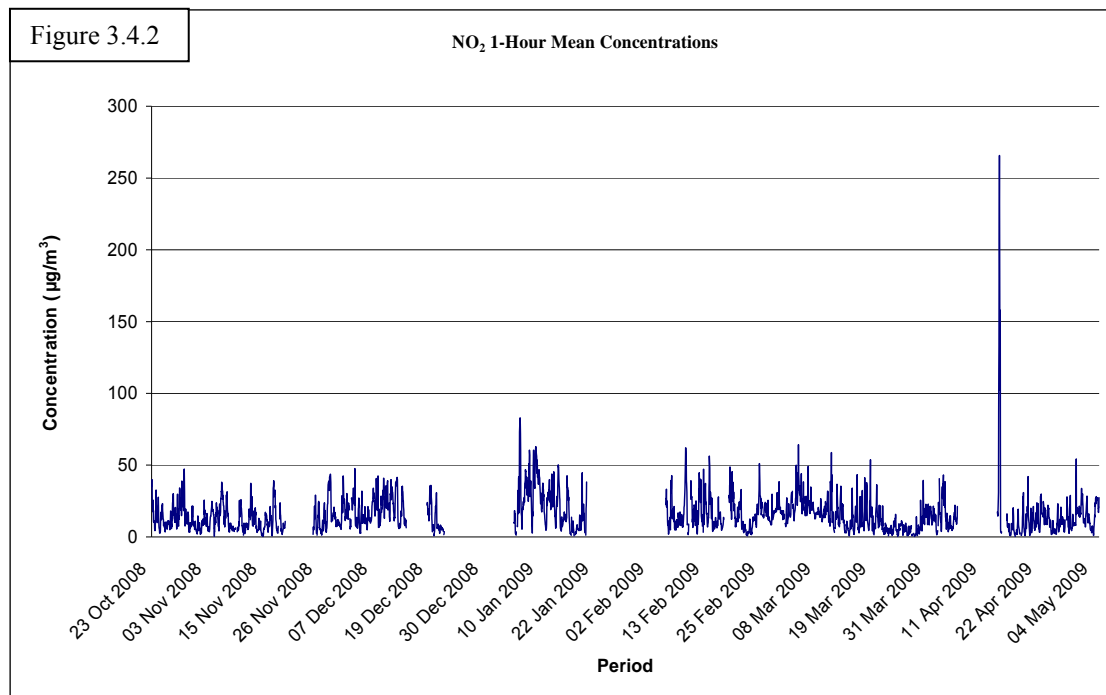


3.4.1 Comparison with Standards

3.4.1.1 Comparison with Air Quality Strategy (AQS) Objectives

While consideration of NO_x levels can be more informative when determining the source of pollution, the level of NO₂ concentration is more important from a human health stand point. NO₂ is the constituent of NO_x that is harmful to health and consequently a National Air Quality Strategy Objective exists for NO₂ levels. NO₂ has therefore been considered, in addition to NO_x, as it is a pollutant in its own right.

The AQS has objectives for 1-hour mean and annual mean NO₂ concentrations. The AQS objectives for the 1-hour mean concentrations states that a value of 200µg/m³ (105ppb) must not be exceeded on more than 18 occasions during one year. A time series plot of 1-hour concentrations of NO₂ measured at the monitoring site is shown in Figures 3.4.2.



The plot shows that the 1-hour NO₂ concentrations were greater than 200 $\mu\text{g}/\text{m}^3$ on two occasions, the maximum concentration being 266 $\mu\text{g}/\text{m}^3$. If the assumption is made that the conditions during the monitoring period were representative of a typical year, then over a year the limit of 200 $\mu\text{g}/\text{m}^3$ (105ppb) would be exceeded on five occasions and thus the AQS for 1 Hour NO₂ mean concentrations would not be exceeded at the monitoring site.

The annual objective for NO₂ states that a concentration value of 40 $\mu\text{g}/\text{m}^3$ (21ppb) must not be exceeded in one year. The average NO₂ concentration during the monitoring period was 15.7 $\mu\text{g}/\text{m}^3$. If the assumption is made that conditions during the monitoring period were representative of a typical year, then the results would indicate that the AQS objectives, for both 1-hour and annual means of NO₂, would not be exceeded with the emission rates that existed during the monitoring period.

3.4.1.2 Comparison with other relevant standards

The AQS objective has an annual standard for NO_x of 30 $\mu\text{g}/\text{m}^3$, for the protection of vegetation and ecosystems. The mean NO_x concentration during the monitoring period was 24.8 $\mu\text{g}/\text{m}^3$, and is therefore not exceeding the annual standard.

3.4.2 Detailed consideration of NO_x pollution events at the MMF site.

Periods where NO_x concentrations, at the site, increased significantly above the average level have been considered as separate 'pollution events'. The five highest levels of NO_x, have been identified from the 15-minute mean concentrations (Figure 3.4.1) These 'pollution events', have been further examined and compared with wind direction and wind speed in an effort to understand the conditions leading to elevated levels of NO_x at Cubley. The results of the pollution event analysis are summarised in Table 3.4.1.

Table 3.4.1 Summary of NO_x pollution events

Pollution Event	Date	Time	Maximum 15-Minute Concentration (µg/m ³)	Wind Direction (degrees)	Wind Speed (m/s)
1	29/10/08	15:00	514	196	2.7
2	11/01/09	11:45	500	197	2.5
3	30/04/09	15:00	486	169	3.5
4	23/10/08	12:30	305	199	4.7
5	14/04/09	21:30	304	48	1.5

Table 3.4.1 shows that elevated concentrations can be seen coming from wind directions 169° – 199° and at 48°, from varying wind speeds of 1.5 – 4.7 m/s.

3.4.3 Directional Analysis

A radial plot of mean NO_x concentrations (µg/m³) against wind direction for wind speeds above 0.5m/s is shown in Figures 3.4.3. The plot shows that the highest average NO_x concentrations were measured at the monitoring site when the wind was coming from between 50° - 70°, 90° - 100°, 130° and 170° - 210°, where average levels are >25µg/m³.

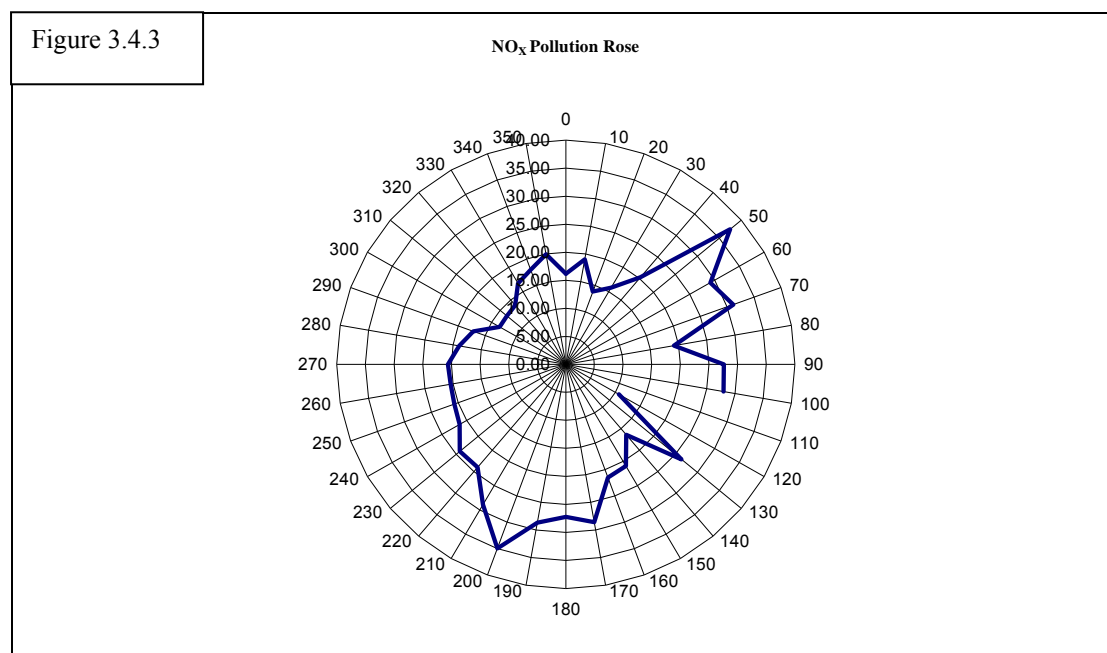
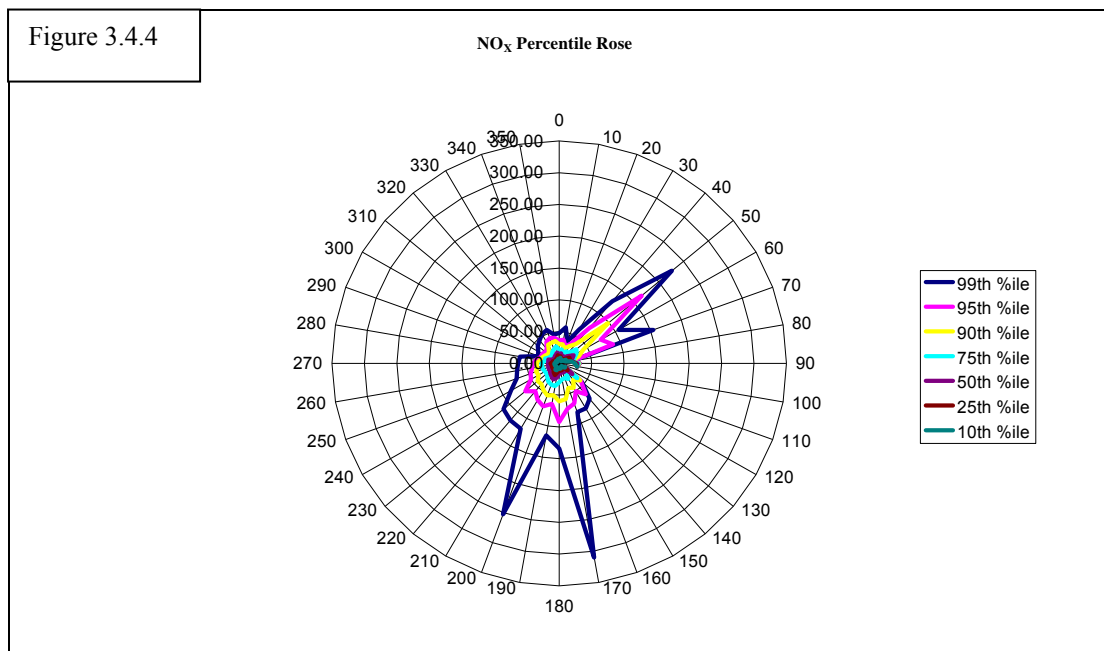


Figure 3.4.4 shows an array of plots showing the contribution to NO_x loading at the monitoring site for different percentiles. The NO_x plots show that the contribution from the source(s) between 40° – 70° and 170° - 200° can be seen to affect each of the percentile plots, suggesting that the sources are continuous and commonly affect NO_x concentrations at the monitoring site when the wind is from these directions.

Figure 3.4.4



3.4.4 Conclusions

Comparison of the NO₂ data with the AQS objective for the 1-hour mean concentrations indicated that air quality at the monitoring site at Cubley would comply with this objective under current emissions.

The mean NO₂ concentrations over the monitoring period was $15.7\mu\text{g}/\text{m}^3$. If it is assumed that the conditions during the monitoring periods were representative of a typical year, then the results would indicate that the AQS annual mean objective would not be exceeded.

The mean NO_x concentration over the monitoring period was $24.8\mu\text{g}/\text{m}^3$, which would indicate that the AQS annual mean objective would not be exceeded at the monitoring site.

Pollution rose analysis indicates that the highest average NO_x concentrations were measured at the when the wind was coming from 50° - 70°, 90° - 100°, 130° and 170° - 210°, where average levels are $>25\mu\text{g}/\text{m}^3$. Percentile analysis suggested that there are relatively continuous sources between 40° - 70° and 170° - 200°.

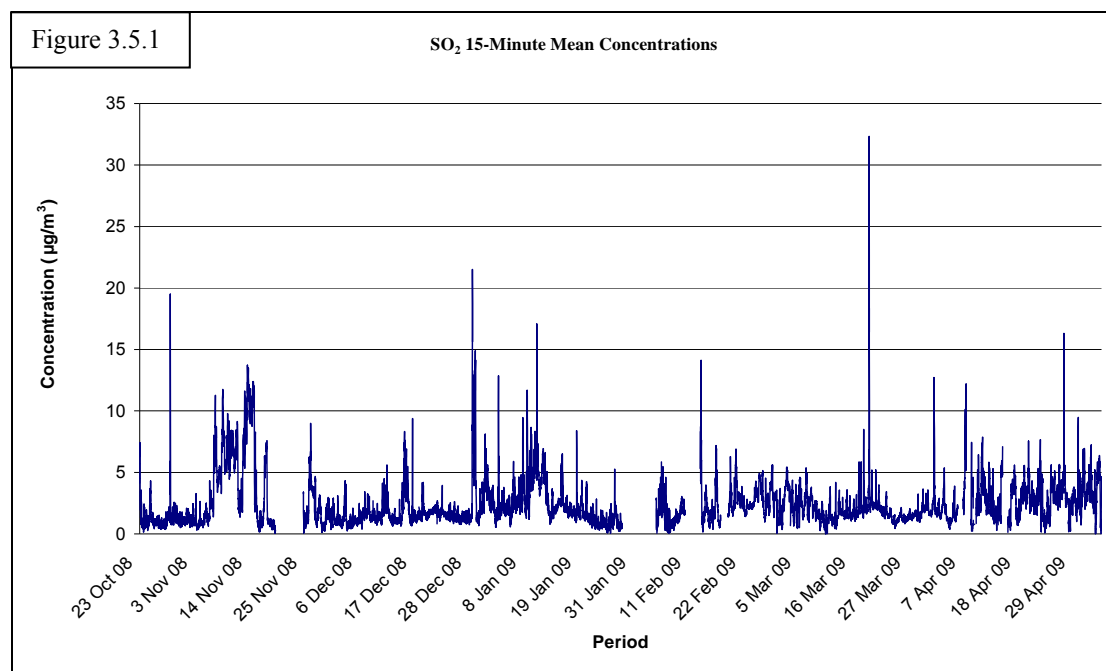
3.5 Sulphur Dioxide (SO₂)

Between 23 October 2008 and 5 May 2009 (195 days) airborne concentrations of SO₂ were measured at a height of 2m above ground. Details of the instrumentation and methodology are given in Appendix F. Successful data collection over the period was 88%.

3.5.1 Comparison with Standards

3.5.1.1 Comparison with AQS Objectives

The AQS objective states that the limit of 266µg/m³ (100ppb) as 15-minute averages must not be exceeded more than 35 times during one year. A time series plot for 15-minute mean concentrations of SO₂ is shown in Figure 3.5.1.



The plot shows that the measured 15-minute mean did not exceed 266µg/m³ on any occasion during the monitoring period, the maximum concentration being 32.3µg/m³. If the assumption is made that the conditions during the monitoring period were representative of a typical year, then the AQS for 15 minute SO₂ mean concentrations would not be exceeded at the monitoring site.

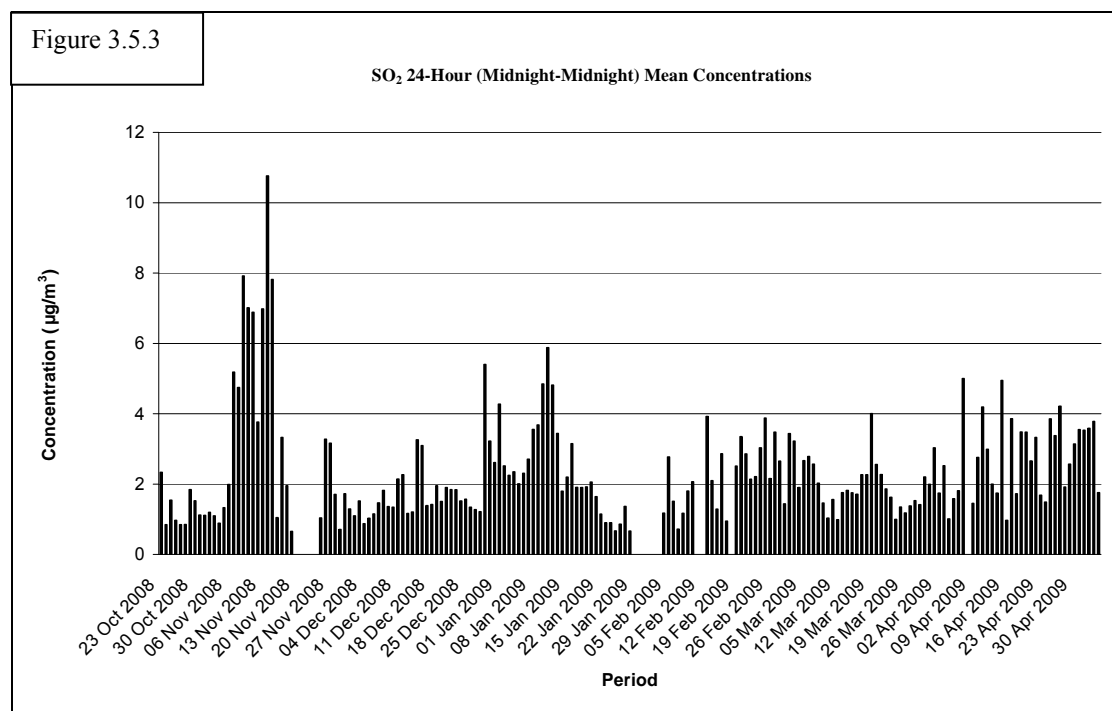
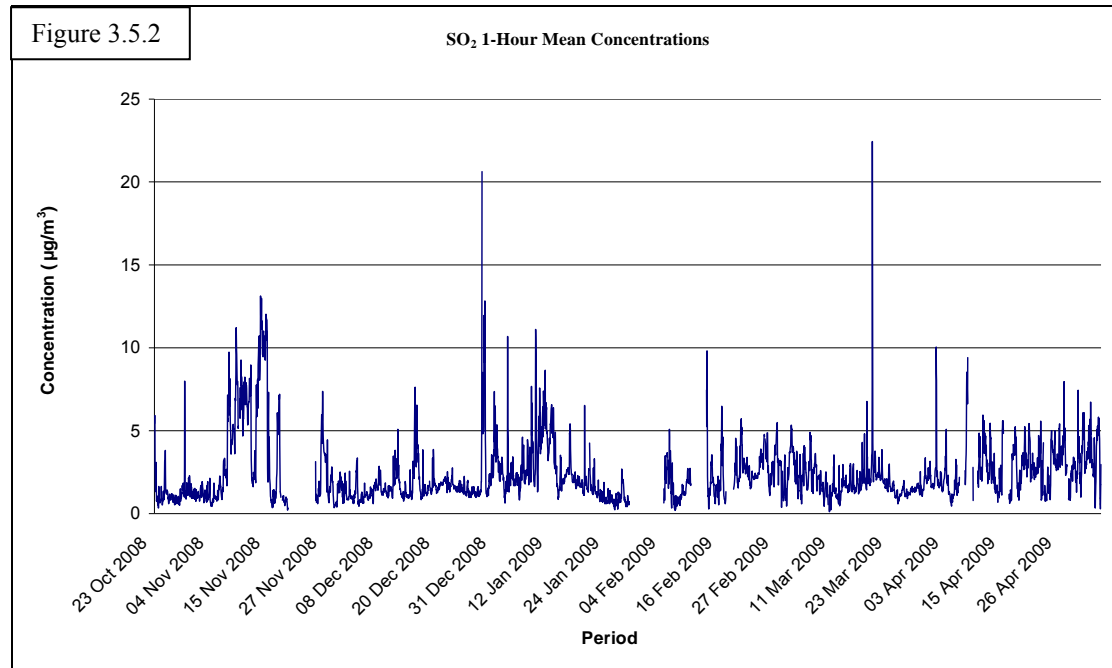
The AQS objective for 1-hour mean concentrations of SO₂ states that a limit of 350 µg/m³ (132ppb) must not be exceeded more than 24 times during one year. A time series plots for 1-hour mean concentrations of SO₂ is shown in Figure 3.5.2.

The plot shows that the measured 1-hour mean was not greater than 350 µg/m³ during the monitoring period, the maximum concentration being 22.4µg/m³. If the assumption is made that the conditions during the monitoring period were representative of a typical year then it is unlikely that the AQS objective for 1-hour SO₂ mean concentrations would be exceeded.

The 24-hour (midnight-midnight) AQS objective states that a value of 125 µg/m³ (47ppb) must not be exceeded on more than 3 occasions during one year. A Time series plot for 24-hour (midnight – midnight) mean concentrations of SO₂ is shown in Figure 3.5.3.

The plot indicates that over the monitoring period no 24-hour mean concentrations were recorded that exceeded the AQS objective, the maximum concentration being 10.8µg/m³. If the assumption is made

that the conditions during the monitoring period were representative of a typical year then it is unlikely that the AQS objective for 24-hour SO₂ mean concentrations would be exceeded under current emissions.



3.5.1.2 Comparison with other relevant standards

The AQS has introduced an annual mean limit of $20\mu\text{g}/\text{m}^3$ (8ppb) in an effort to protect vegetation and ecosystems. The mean SO₂ concentrations over the monitoring period was $2.39\mu\text{g}/\text{m}^3$ which is well below the $20\mu\text{g}/\text{m}^3$ limit.

3.5.2 Detailed consideration of SO₂ pollution events at the MMF site

Periods where SO₂ concentrations increased significantly above the average level have been considered as separate 'pollution events'. For the purposes of this study, the five highest levels of SO₂ have been identified from the 15-minute mean concentrations. These 'pollution events', although not exceeding the AQS objective, have been further examined and compared with wind direction and wind speed in an effort to understand the conditions leading to elevated levels of SO₂ at Cubley. The results of the pollution event analysis are summarised in Tables 3.5.1.

Table 3.5.1 Summary of SO₂ pollution events

Pollution Event	Date	Time	Maximum 15-Minute Concentration (µg/m ³)	Wind Direction (degrees)	Wind Speed (m/s)
1	19/03/09	11:15	32.3	73	1.1
2	29/12/08	12:15	21.5	84	0.3
3	29/10/08	15:00	10.5	196	2.7
4	11/01/09	11:45	17.1	197	2.5
5	27/04/09	17:15	16.3	228	0.7

Table 3.5.1 shows that pollution episodes at the site occurred when the wind was coming from the directions 73° – 84° and 196° – 228°, at wind speeds ranging from 0.3 – 2.7 m/s. All five of the pollution episodes occurred between the hours of 11:15 and 17:15.

3.5.3 Directional Analysis

A radial plot of mean SO₂ concentrations (µg/m³) against wind direction for wind speeds above 0.5m/s is shown in Figure 3.5.4. The plot shows that the highest average SO₂ concentrations were measured at the monitoring site when the wind was coming from between 90° - 100° and 190° - 250°, where average levels were >3µg/m³.

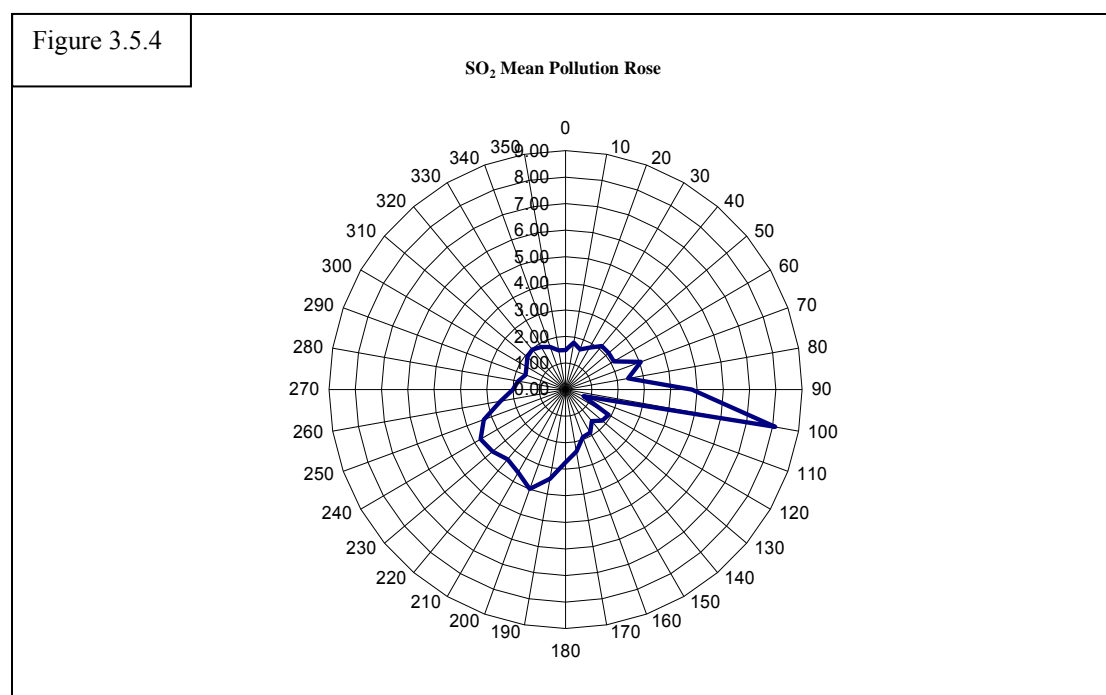
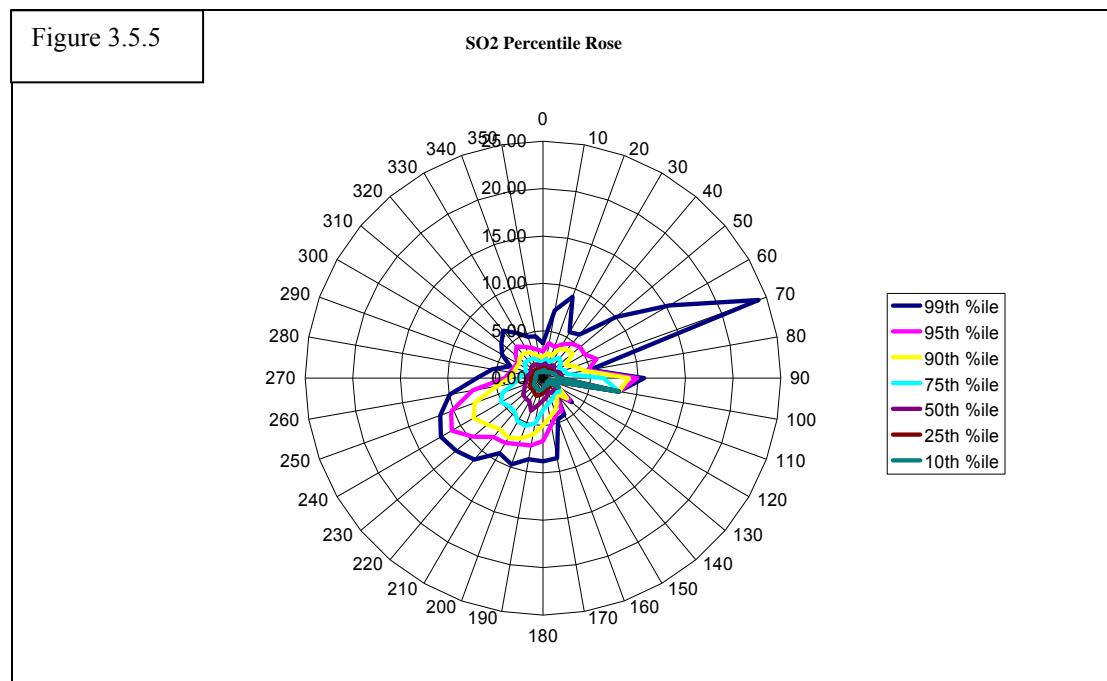


Figure 3.3.5 shows an array of plots showing the contribution to SO₂ loading at the monitoring site for different percentiles. The SO₂ plots show that the contribution from the sources between 190° - 250° and 90° - 100° can be seen to affect each of the percentile plots suggesting that the sources are relatively continuous and commonly affect SO₂ concentrations at the monitoring site when the wind is from these directions. The bias at 60° - 70° is only evident in the higher percentiles which suggests that the source is intermittent and only occasionally causes high levels of SO₂ at the monitoring site.



3.5.4 Conclusion

Comparison of the SO₂ data with the AQS objective for the 15-minute, 1- hour and 24-hour (midnight-midnight) mean concentrations indicated that SO₂ concentrations at Cubley would comply with all of these objectives.

Pollution rose analysis indicates that the highest average SO₂ concentrations measured were from a wind direction of 90° - 100° and 190° - 250°. Percentile rose analysis suggests that the sources from these wind sectors were relatively continuous.

4 Conclusion

Comparing the collected data from the monitoring at Cubley with the AQS objectives showed that the monitoring location was subject to concentrations of PM_{2.5}, SO₂, NO_x, NO₂ levels that were likely to meet their respective AQS objectives.

Comparison of the PM₁₀ data with the annual mean AQS objective indicated that this objective was likely to be met at the monitoring site.

Comparison of the PM₁₀ data with the 24-hour (midnight-midnight) mean AQS objective indicated that this objective would be exceeded at the monitoring site.

The NH₃ data when compared with the short term and long term EALs for the protection of human health as stated in H1 showed that the guidelines were not exceeded at the monitoring site.

Comparison of the NH₃ data with WHO and H1 guidelines showed that the limit levels set to protect against ecotoxic effects showed that both the annual and monthly levels were exceeded during the monitoring period.

Time series plots for each of the recorded pollutants are shown in Figure 4.1.

Tables 4.1 and 4.2 summarise the extent of likely compliance/exceedance for each of the species with respect to the AQS objectives at the monitoring site. Tables 4.3 summarise the extent of likely compliance, where appropriate, with other relevant standards. A projected compliance ratio ≤ 1 indicates compliance, whilst a value >1 indicates non-compliance.

Table 4.4 summarises the results from the mean pollution roses, where wind directions showing a significant bias for a particular pollutant are shaded in red and the bearing of the poultry farm from the MMF is shaded in yellow. The Table clearly shows an elevation in pollutants when the wind is coming from the direction of the poultry farm.

Table 4.5 summarises the 24 hour (midnight - midnight) exceedances that were greater than 50 $\mu\text{g}/\text{m}^3$ at the monitoring site.

Table 4.1 Impact summary for short-term air quality objectives.

Pollutant	Averaging Time	AQS	Standard ($\mu\text{g}/\text{m}^3$)	Maximum Concentration ($\mu\text{g}/\text{m}^3$)	Permitted Exceedance (A)	Measured Exceedance* (B)	Projected Compliance Ratio (B/A)
PM ₁₀ [♦]	24-hr (midnight-midnight)	2000	50	81.5	35/year	37/year	1.06
SO ₂	15-min	2000	266	32.3	35/year	0/year	0.00
	1-hr	2000	350	22.4	24/year	0/year	0.00
	24-hr (midnight-midnight)	2000	125	10.8	3/year	0/year	0.00
NO ₂	1-hr	2000	200	266	18/year	5/year	0.28

* Extrapolated from effective monitoring period

♦ Calculated using the King's College Volatile Correction Model (VCM)

Table 4.2 Impact summary for long-term air quality objectives.

Pollutant	Averaging Time	AQS	Standard (A) ($\mu\text{g}/\text{m}^3$)	Measurement* (B) ($\mu\text{g}/\text{m}^3$)	Projected Compliance Ratio (B/A)
PM ₁₀ ♦	Year	2000	40	25.4	0.64
PM _{2.5} ■	Year	2007	25	12.1	0.48
NO ₂	Year	2000	40	15.7	0.39

* Extrapolated from effective monitoring period

♦ Calculated using the King's College Volatile Correction Model (VCM)

■ Calculated using the 1.3 correction factor

Table 4.3 Impact summary for other relevant^Δ, long-term standards.

Pollutant	Averaging Time	Standard	Standard (A) ($\mu\text{g}/\text{m}^3$)	Measurement* (B) ($\mu\text{g}/\text{m}^3$)	Projected Compliance Ratio (B/A)
NO _x	Year	2000 AQS	30	24.8	0.83
SO ₂	Year	2000 AQS	20	2.39	0.12

Δ Provisional AQS objectives, proposed AQS objectives and 2000 NAQS objectives for the protection of vegetation and ecosystems.

* Extrapolated from effective monitoring period

Table 4.4 Summary of Mean Pollution Roses at MMF2

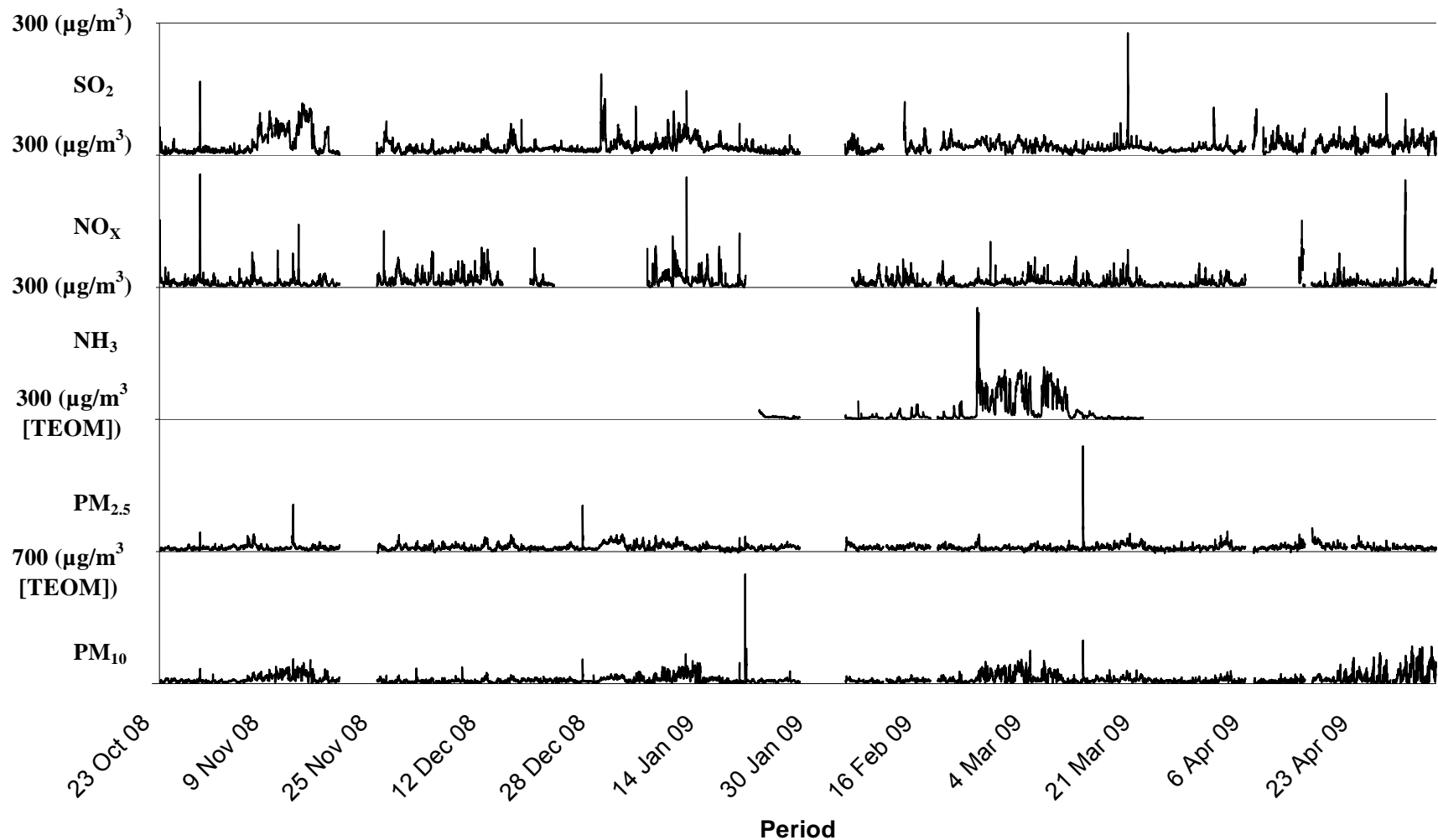
	Wind Direction (Degrees)																	
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180
PM ₁₀									■					■	■		■	■
PM _{2.5}	■	■	■	■	■	■	■							■	■	■		■
SO ₂									■	■								
NO _x					■	■	■		■	■			■				■	■
NH ₃																		

	Wind Direction (Degrees)																	
	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360
PM ₁₀	■	■	■	■	■	■	■	■	■	■								
PM _{2.5}	■	■													■			
SO ₂	■	■	■	■	■	■	■											
NO _x	■	■	■															
NH ₃		■	■	■	■	■	■	■	■	■	■							

Table 4.5 Summary of 24 hour (midnight – midnight) exceedances

Date	Wind Directions (degrees)	Wind Speed (m/s)	24-Hour Mean Concentration (ug/m³)
04/May/2009	250	2.0	81.5
01/May/2009	212	1.5	75.8
02/May/2009	304	0.6	62.1
25/Feb/2009	262	1.7	61.8
03/Mar/2009	207	3.3	58.7
03/Apr/2009	26	0.6	56.4
13/Nov/2008	244	1.6	55.7
21/Mar/2009	345	1.2	55.6
19/Mar/2009	39	0.6	54.5
28/Feb/2009	227	1.5	53.4
02/Mar/2009	264	1.9	52.7
14/Nov/2008	245	2.6	52.1
11/Nov/2008	238	3.4	51.3

Figure 4.1 Inorganic Time Series for the Monitoring Site at Cubley (15-Minute Mean Concentrations)



5 References

1. Department for Environment, Food and Rural Affairs (2007), *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland*, (HMSO).
2. World Health Organisation (2000), *WHO Air Quality Guidelines for Europe*.
3. EH40 (2002), *Occupational Exposure Limits 2002*, HSE.
4. IPPC (2002), *IPPC Guidance note H1 – Environmental Assessment and BAT Appraisal (version 3)*.
5. DERRA (2004), *Consultation on the Draft Code of Practice and Local Authority Guide on Odour Nuisance from Sewage Treatment*.

Appendix A Mobile Monitoring Facility

Appendix A Mobile Monitoring Facility

The Monitoring and Assessment process carries out ambient air monitoring on behalf of regions using Mobile Monitoring Facilities (MMFs). These facilities allow the Agency to carry out flexible, short-term studies examining the impact of specific IPC, IPPC and waste authorised processes on local communities. The facilities contain a number of analysers designed to sample the atmosphere for a selection of pollutants commonly associated with industrial emissions. The equipment is contained within a trailer that can conveniently be towed. This allows it to be strategically sited at temporary locations with the intention of quantifying pollution loadings and determining sources. The MMF used in the Cubley study was MMF2. The pollutants that can be measured using MMF2 are:

- particles (PM₁₀)
- nitrogen dioxide
- sulphur dioxide
- Ammonia

METEOROLOGICAL INSTRUMENTS

In addition to analysers measuring the concentration of pollutants in the air the facility contains equipment that can measure meteorological conditions. This provides the opportunity to consider measured pollutant levels relative to the prevailing meteorological situation. This can supply important information allowing a more detailed understanding of the pollutants' dispersion in the atmosphere and consequently a more accurate assessment of their origins. The meteorological parameters that can be measured are:

- wind direction,
- wind speed,
- ambient air temperature
- relative humidity.

All meteorological measurements are taken at an elevation of 8m above the ground and from positions where the wind approach was unobstructed. The temporal resolution of all logged meteorological data is 15 minutes.

Wind direction is an important consideration as it provides direct information about the orientation of any source relative to the monitoring site. It must be noted, however, that pollutants will be carried along a wind's trajectory that may, over distances of several kilometres, be curved so that in these cases the wind direction will not simply 'point' to the source's direction. Wind speed and temperature both have a significant influence on the amount of mixing within the atmosphere, having profound effects on the vertical distribution of pollutants through the atmospheric boundary layer. Relative humidity is important because the level of moisture within the air affects the rates of reaction and removal of some air pollutants.

Appendix B Quality Assurance and Quality Control

Appendix B Quality Assurance and Quality Control

Quality assurance covers practices that are undertaken prior to data collection in order to ensure that the sampling arrangements and analysers are capable of providing reliable measurements. Quality Control covers practices applied after data collection in order to ensure that the measurements obtained are repeatable and traceable.

In order to ensure that data from the MMF are representative of pollutant concentrations and meet appropriate standards of quality, a number of QA and QC procedures are routinely implemented in the monitoring facility's execution.

Quality assurance included:

- Training - all personnel involved with the running of the facility have received appropriate training in the execution of the tasks they are expected to undertake. This training has been recorded in the personal training log of the individuals concerned.
- Procedures - all routine activities undertaken in the operation of the facility are clearly and unambiguously laid out in a documented set of procedures.
- Analyser selection - careful consideration has been given to the choice of analysers, ensuring that they meet the required standards of accuracy and precision. Also that they can be relied on to be robust and flexible enough to present the data in a suitable format.
- Trailer positioning - attention is given to how representative the location of the facility is when compared against the objectives of the study.

Quality control included:

- Routine calibration - calibrations are performed every two weeks, using traceable gas standards and any adjustments made to the analysers documented.
- Routine maintenance - undertaking of stipulated checks and changes of filters.
- Periodic maintenance - employment of a qualified engineer to service the analysers twice a year.
- Instrument history - all invasive work carried out on analysers is documented and recorded.
- Data review - all data is checked to ensure correct scaling, rejecting negative or out-of-range readings, questioning rapid excursions, generally considering the integrity of recorded levels.
- Data handling - following recognised procedures to ensure that data capture is maximised. The data is analysed frequently so that measurements affected by instrument fault are recognised quickly.
- Data comparison - comparing the collected data sets with data sets from other monitoring studies that are carried out in close enough proximity to be relevant. Consideration of the relationship between different pollutants i.e. some pollutant levels will be expected to rise and fall together.

Appendix B Quality Assurance and Quality Control

- Data rectification - the adjustment of data to minimise the effects of analyser drift.

- Independent assessment - the analysers are regularly assessed by independent specialists to provide documented evidence that the analysers are performing to nationally accepted criteria.

Appendix C Particulate (PM₁₀ & PM_{2.5})

Appendix C Particulate (PM₁₀ & PM_{2.5})

Airborne particulate matter can be found in a wide range of particle sizes (nm- μ m) and chemical constituents. PM₁₀ and PM_{2.5} levels have been monitored in this study. PM₁₀ is defined as particulate matter with an aerodynamic diameter less than 10 μ m. PM_{2.5} is defined as particulate matter with an aerodynamic diameter less than 2.5 μ m. The description of PM₁₀ and PM_{2.5} is restricted to its physical characteristic and no particular chemical composition is implied (The size-selective samplers used to collect small particles preferentially are designed to collect 50% of 10 μ m aerodynamic diameter particles, more than 95% of 5 μ m particles, and less than 5% of 20 μ m particles). The size is of importance because it is this that determines where in the human respiratory tract a particle deposits when inhaled. Most concern is given to particles small enough to penetrate into the lungs reaching the alveoli where the delicate tissues involved in the exchange of oxygen and carbon dioxide are to be found. When inhaled almost all particles larger than 7 μ m are deposited in the nose and throat, and only 20-30% of particles between 1 and 7 μ m are deposited in the alveoli. However, up to 60% of particles below 0.1 μ m are deposited in the alveoli. The size of the particles also determines how long they spend in the atmosphere with smaller particles remaining in suspension for longer and can be transported over long distances. The measurement of PM₁₀ and PM_{2.5} relies on the use of a size-selective instrument, which collects small particles preferentially.

Sources

There are a number of important natural sources of particulate in the air with forest fires and volcanic eruptions being two sources which, can cause extreme pollution episodes and can be very adverse to human health. Sea spray and the erosion of soil and rocks by wind are important sources in many localities. There are also many biological sources with considerable numbers of pollen grains, fungal spores and their fragments contributing to the total loading of airborne particles. Man-made airborne particles result mainly from combustion processes, from the working of soil and rock, from industrial processes and from the attrition of road surfaces by motor vehicles.

The major PM components are sulfate, nitrates, ammonia, sodium chloride, carbon, mineral dust and water. Particles can be classified as being either primary or secondary: the former are released directly into the air, while the latter are formed in the atmosphere by the chemical reaction of gases, first combining to form less volatile compounds which in turn condense into particles. Primary particles have an immediate effect on the particulate loading in the vicinity of the source. The main sources of primary PM₁₀ and PM_{2.5} in the UK in 2001 were⁽¹⁾:

- Road transport; nationally, road transport contributed around 27% of primary PM₁₀ and 38% of primary PM_{2.5} emissions, however, the contribution can be much higher in urban areas.
- Industrial processes; including a range of different industrial processes leading to the release of dust as well as construction, mining and quarrying activities. Nationally, it is estimated that these processes accounted for around 27% of primary PM₁₀ emissions and 21% of primary PM_{2.5} emissions.
- Domestic coal burning; traditionally the major source of airborne particles, but its decline has reduced the contribution to around 17% nationally for primary PM₁₀ and 16% for primary PM_{2.5} emissions, and mostly in a small number of specific locations.
- Electrical supply industry power generation; is estimated to have been responsible for 9.8% of primary PM₁₀ emissions and 8.6% of primary PM_{2.5} emissions.

Secondary particles are less easy to ascribe to their original sources. They comprise mainly ammonium sulphate and nitrate, originating from the oxidation of gaseous sulphur and nitrogen oxides to acids, which are then neutralised by atmospheric ammonia, derived from agricultural sources. The chemical processes involved in the formation of these secondary particles are relatively slow (in the order of days) and their persistence in the atmosphere is similarly prolonged. Thus, while road traffic may be the main source of the original oxides of nitrogen, and coal and oil burning the main sources of sulphur oxides, the secondary particles are distributed more evenly throughout the air with less difference between urban and rural areas. They may also drift for considerable distances, this can result in the transport of pollution across national boundaries.

Particulate Analyzer

The analyser used to measure PM₁₀ & PM_{2.5} concentration is a Rupprecht & Patashnick (R&P) Tapered Element Oscillating Microbalance (TEOM). It provides measurements in real time and stores them as 15-minute averages. PM₁₀ and PM_{2.5} fractions were measured using two separate TEOM systems with specific PM₁₀ and PM_{2.5} filter inlets. The system measures PM concentration by continuously determining the particle mass deposited on a filter. The filter is attached to a hollow tapered element that vibrates at its natural frequency of oscillation (f). As particles collect on the filter, the frequency changes by an amount inversely proportional to the square root of the mass deposited (m).

$$m = k/f^2$$

Where k is a constant determined during calibration of the instrument.

The flow rate through the system is controlled using thermal mass flow controllers and automatically measured so that the mass concentration can be calculated. The analyser consists of a sample inlet head that has an airflow of 16.67 litres per minute. The action of the air through the head selects particles of aerodynamic diameter less than 10 μ m. After the air has passed through the head the flow is divided using a flow splitter to direct 3 litres per minute through the filter cartridge.

It is a requirement of the TEOM instrument that the filter is kept at a constant temperature of 50°C. This can lead to a difference between mass concentrations determined using a TEOM and co-located gravimetric filter samplers, for which the collection filters are unheated and therefore at ambient temperature. The effect of this difference is variable depending on the nature of the particulate being measured. It is considered most probable that the discrepancy is a consequence of evaporation of semi-volatile secondary particles such as ammonium nitrate and some organic compounds. Therefore, care must be taken when predicting the secondary particle contribution to the total mass concentration.

The Airborne Particles Expert Group (APEG now the Air Quality Expert Group) have published a report which concluded that at concentrations around 50 μ m/m³ the TEOM tends to under-read compared with a gravimetric sampler by between 15 and 30%. However, this effect is not constant, and varies depending upon the mass concentration, the distance from a specific source, and the environmental conditions. Further studies have been commissioned by DETR to investigate these effects, and to provide a more robust relationship between the TEOM and the European transfer gravimetric reference method.

The air quality objectives are based upon measurements carried out using the European transfer reference method or equivalent. Therefore a potential inconsistency between measurements of PM₁₀ concentrations made using a TEOM analyser and the objectives – for example, a daily mean concentration of 45 μ m/m³ measured using a TEOM analyser could be underestimating the gravimetric concentration by 15 μ m/m³ or more. It is therefore necessary to apply a correction factor when assessing TEOM measured concentrations against the objectives.

Recent findings have suggested that the correction factor of 1.3 originally recommended by the NQAS guidance for use with PM₁₀ and PM_{2.5} data is not equivalent to the reference method for particulate matter and therefore not strictly comparable to the European Daughter Directive Limit Values.

Kings College London on behalf of DEFRA have developed a volatile correction model (VCM) which can be used to correct PM₁₀ TEOM measurements for the loss of volatile components caused by the high sampling temperature, with corrected measurements being comparable to the gravimetric reference equivalent. The VCM works by using volatile particulate measurements from nearby Filter dynamics measurement system (FDMS) within a radius of 130km, this allows for the loss of volatiles from the TEOM measurements to be calculated and added to the measurements obtained from the TEOM.

Reference Equivalent PM₁₀ = TEOM – 1.87 FDMS purge

Appendix C Particulate (PM₁₀ & PM_{2.5})

FDMS Purge is usually a negative value due to the loss of volatiles. It can be measured at a remote site, allowing for the possibility of using one FDMS to correct many TEOM instruments within suitable distance.

The model provides adequate coverage for the whole of the UK, except Scotland and Northern Ireland.

The constant factor of 1.3 has been used to calculate PM_{2.5} concentrations, as a VCM applicable to PM_{2.5} data has not yet been produced.

The manufacture's specification states that the TEOM is accurate to within 4 µg/m³.

This instrument is used extensively in the UK automatic monitoring networks and has been designated as an equivalent method for the determination of 24-hour average PM₁₀ concentrations by the USEPA.

References

1. Air Quality Expert Group, June 2005, Report on Particulate Matter in the United Kingdom, DEFRA, p.416.
2. DETR – May 2000 - Pollutant Specific Guidance

Appendix D Ammonia (NH₃)

Appendix D Ammonia (NH₃)

Sources of Ammonia

The main source of atmospheric ammonia in the UK is agriculture, which accounts for 83% of all emissions. Agricultural emissions are largely from cattle farming, which accounts for 44% of total emissions, with other agricultural emissions coming from other livestock (pigs, poultry and sheep) and from fertilisers (9% of the total). Non agricultural emissions are from sewage treatment, catalytic converters on motor vehicles, fertiliser manufacture and from wild mammals and domestic pets.

Once in the atmosphere, ammonia may be directly deposited onto land surfaces or may react with other chemicals in the atmosphere to produce ammonia containing compounds. Both ammonia and ammonium-N can then be either absorbed as gaseous particles on land or water surfaces (dry deposition) or may be dissolved in rainfall (wet deposition).

Reasons for Concern

Dry deposition of ammonia and ammonium-N is largely within close proximity to the source of emission. In the UK, the greatest ammonia emissions are in the south-east. However, ammonia dissolved in rainfall can travel much further afield from the original emission source. This means that the greatest wet deposition of ammonia and ammonium-N is in areas with high rainfall, such as the upland areas of north-west England.

Typically, ammonia and ammonium-N will be deposited on low nitrogen soils. This is because soils rich in nitrogen, usually heavily fertilised agricultural land, are a net source of nitrogen. Instead, ammonia is deposited on land with relatively low N levels. This is typically non-fertilised land, namely natural ecosystems and conservation areas. Plant species in these areas have adapted to tolerate such low N soil conditions. When the level of Nitrogen increases from the deposition of ammonia, many plant species can not tolerate the elevated levels. In addition, one or two more common species thrive under the new conditions and grow rapidly, to the detriment of the other species. This situation is typical of many upland and heath land areas and damages important areas of heather, moss and lichen. It is known as terrestrial eutrophication.

Although some plant species may tolerate increased levels of nitrogen in the soil, high levels of nitrogen within foliage have been shown to make plants more susceptible to environmental stresses such as drought, frost and insect infestation. Excessive levels of soil N may also lead to increased soil acidity. Acidic soil conditions make toxic elements within the soil more available to plants and reduce the availability of other essential elements. In addition, toxic elements may leach from the soil and lead to the acidification of freshwater ecosystems.

In relation to human health, ammonia emissions to the atmosphere are of concern because of the ability of ammonia to readily react and form gaseous particles in the atmosphere. This contributes to the overall levels of particulate matter.

Ammonia Analyser

Ammonia is analysed using a Monitor Labs ML9842A analyser. The ammonia analyser works by measuring ambient levels of all nitrogen compounds (N_x), assumed to be a mixture of ammonia (NH₃), nitrogen dioxide (NO₂) and Nitric Oxide (NO). A thermal oxidiser converts the NH₃ and NO₂ into nitric oxide (NO). This NO then passes through to a detector, where it is converted to activated NO₂ by reaction with ozone (O₃). The activated NO₂ produce radiation, which is measured using a photo-multiplier tube (PMT). The measured level reflects the total N_x concentration of the sampled ambient air. Simultaneously, an ambient air sample is drawn into a Moly Converter, which converts the NO₂ within the ambient air to NO. This NO, along with the NO already present is then passed through the detector and measured giving the ambient levels of NO_x. By subtracting this NO_x from the total N_x, the NH₃ concentration can be deduced.

Appendix E Oxides of Nitrogen (NO_x)

Appendix E Oxides of Nitrogen (NO_x)

Nitrogen dioxide is a gas produced by the reaction of nitrogen and oxygen in combustion processes. The nitrogen is most commonly atmospheric nitrogen, although nitrogen atoms in the combustion fuel can also be involved. The reaction usually takes place in two stages, the first, at high temperature, between one nitrogen atom and one oxygen atom to form a nitric oxide (NO) molecule. This molecule will then be oxidised by the addition of a further oxygen atom to form nitrogen dioxide (NO₂), this may occur some time later at ambient temperatures. As nitric oxide is a precursor in the formation of nitrogen dioxide its levels are often of interest, these two oxides of nitrogen are, for local air quality purposes, collectively known as NO_x.

Once formed, nitrogen dioxide takes part in chemical reactions in the atmosphere that convert it to nitric acid and nitrates, both of which can be removed by rain. However, nitrates can also remain in the air as very small particles, for example as ammonium nitrate, which can be dispersed widely in the atmosphere, contributing to the airborne concentrations of PM₁₀.

Sources

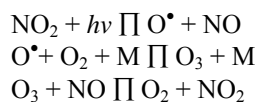
There are several natural sources of oxides of nitrogen in the atmosphere, including lightning and forest fires. However, by far the largest amount is formed as a consequence of combustion of fossil fuels - petrol, oil, coal and gas. In the UK in 1994 fossil fuelled power stations accounted for 24% of total NO_x emissions with combined forms of transport accounting for 56% and other industrial combustion processes accounting for 10%⁽²⁾.

As mentioned, once nitric oxide is emitted it combines further with atmospheric oxygen to form nitrogen dioxide. The source of this oxygen atom is sometimes by reaction with atmospheric oxygen, however, this mechanism is relatively slow and is thought only to be significant during stagnant, cold weather conditions that sometimes occur in wintertime. The main way in which nitrogen dioxide is produced is through oxidation by ozone where action between atmospheric ozone and nitric oxide result in the formation of nitrogen dioxide, described by the equation:



This reaction is fast and approaches completion in approximately one minute. However, within pollution plumes and close to sources of nitric oxide the ozone supply may be depleted resulting in a slower rate conversion.

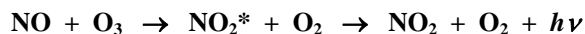
Nitrogen dioxide in the atmosphere can photodissociate to reform nitric oxide. In this reaction an oxygen radical (O[•]) is produced which in turn reacts with oxygen molecules to form ozone:



It can be seen from these reactions that concentrations of ambient nitrogen dioxide are dependent on the amount of solar radiation present. It should be expected, therefore, that concentration levels will vary through the day as the sunlight changes in intensity.

NO_x Analyser

The analyser used to measure oxides of nitrogen is a ML 9841B. This instrument is designed to measure the concentration of nitric oxide (NO), total oxides of nitrogen (NO_x) and (by calculation) nitrogen dioxide (NO₂). NO in the sample air stream reacts with ozone (O₃) in an evacuated chamber to produce activated NO₂ which in turn produces chemiluminescent radiation:



Appendix E Oxides of Nitrogen (NO_x)

The intensity of the chemiluminescent radiation is measured using a photo-multiplier tube (PMT). With the PMT tube output voltage being proportional to the NO concentration. The ambient air sample is divided into two streams. From one, levels of NO are obtained. In the other, NO₂ is reduced to NO using a heated molybdenum catalyst before reaction allowing measurement of total oxides of nitrogen NO_x (= NO + NO₂). The NO₂ concentration is calculated from the difference (NO₂ = NO_x - NO).

The total uncertainty calculation is made for the NO₂ 1 hour 2000 NAQS limit value of 105ppb.

Assessment of compliance for NO₂ chemiluminescence analyser according to ISO 14956			
MonitorLabs ML 9841B Nitrogen Dioxide Analyser			
2000 NCAS for NO₂ concentrations		1 hour limit value 105ppb	
Measurement performance related to dynamic conditions			
Performance Characteristic	Value	Distribution Type	Standard Uncertainty at 100ppb
Linearity	1% of reading	Rectangular	0.6ppb
Precision	0.5ppb or 1% of reading	Normal	1ppb
Zero Drift	2ppb	Rectangular	0.6ppb
Span Drift	0.5% of reading	Rectangular	0.3ppb
Noise	0.25ppb	Rectangular	0.15ppb
Losses in collection system (i.e. sample lines, filters etc)	10%	Rectangular	6ppb
Standard uncertainty of Calibration gas	10%	Rectangular	6ppb
Total standard uncertainty			8.5ppb
Total uncertainty for NO₂ (95% confidence)			14ppb

Data for the uncertainty analysis was taken from the specifications reported by both the instrument and calibration gas manufacturer's and from the report: 'Quality Assessment of Ambient NO, NO₂ and SO₂ Measurements in European Monitoring Networks', Payrissat M, Gerboles M, Sieja B and De Saeger E (1997).

These instruments are used extensively in the UK automatic monitoring network and have been designated as reference methods for the determination of oxides of nitrogen by the USEPA.

Appendix F Sulphur Dioxide (SO₂)

Appendix F Sulphur Dioxide (SO₂)

Sulphur dioxide is formed by the oxidation of sulphur. At normal temperature and pressure it is a gas. It dissolves in water to give an acidic solution which oxidises to sulphuric acid.

Sources

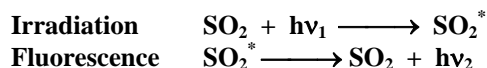
Traditionally sulphur dioxide pollution has been associated with the burning of coal in the domestic, commercial and industrial sectors. However, following the smogs of the 1950s and the Clean Air Act of 1956 the pattern of sulphur dioxide emissions changed considerably. Cleaner fuels have replaced coal in the domestic sectors and in many industrial applications. Power generation in urban areas has predominantly moved to large and efficient plants situated at rural sites.

The consequence of this changing pattern has been an overall decrease in sulphur dioxide emissions in the UK by some 50% since 1970. In the UK in 1993 fossil fuel power stations accounted for 66% of the total sulphur dioxide emissions with a further 25% coming from other industrial combustion processes. The contribution made by road traffic is 2% of the total emission with diesel fuelled vehicles being the main emitter.

In addition, the distribution of pollution has changed, emissions are no longer dominated by low-level sources, which resulted in elevated long-term average concentrations in towns and cities, with episodes of particularly high concentrations occurring during cold, still weather conditions in winter. Now emissions are dominated by a relatively small number of point sources often with tall chimney stacks. The pattern of sulphur dioxide pollution in most of the UK is now characterised by short-term peak concentrations, typically lasting a few hours, caused by a plume reaching ground level.

SO₂ Analyser

The analysers used to measure sulphur dioxide was a ML 9850B. The operation of these analyser is based on the measurement of fluorescence from SO₂ due to absorption of UV energy. An ultraviolet (UV) lamp emits radiation that passes through a filter admitting only light with a wavelength of 214nm. This radiation excites SO₂ molecules in the sampling air, which produce fluorescence that can be measured by a Photo multiplier tube (PMT) with a secondary UV filter. The equations describing the reactions are:



The UV light at any point in the system is given by:

$$I_a = I_0[1 - \exp(-ax(\text{SO}_2))]$$

where I_0 is the UV light intensity, a the absorption coefficient of SO₂, x the path length, and (SO_2) the concentration of SO₂. When the SO₂ concentration is relatively low and the path length of excited light short, the fluorescence radiation impinging upon the PMT can be considered directly proportional to the concentration of SO₂. The PMT transfers the light energy into an electrical signal, which is directly proportional to the light energy in the sample stream being analysed.

An UV detector measures the UV light. Software calculates the ratio of the PMT output and the UV detector in order to compensate for variations in the UV light energy. Stray light from background is determined by passing gas with zero SO₂ concentration through the analyser. Once the effect of background light is accounted for, the Central Processing Unit will convert the electrical signal into a concentration value that is directly proportional to the number of SO₂ molecules.

The total uncertainty calculation is made for the SO₂ 15 minute 2000 NAQS limit value of 100ppb.

Appendix F Sulphur Dioxide (SO₂)

Assessment of compliance for SO ₂ ultraviolet fluorescence analyser according to ISO 14956			
MonitorLabs ML 9850B Sulphur Dioxide Analyser			
2000 NCAS for SO ₂ concentrations		15 minute limit value 100ppb	
Measurement performance related to dynamic conditions			
Performance Characteristic	Value	Distribution Type	Standard Uncertainty at 100ppb
Linearity	1% of reading	Rectangular	0.58ppb
Precision	0.5ppb or 1% of reading	Normal	1ppb
Zero Drift	2ppb	Rectangular	0.58ppb
Span Drift	0.5% of reading	Rectangular	0.29ppb
Noise	0.25ppb	Rectangular	0.14ppb
Losses in collection system (i.e. sample lines, filters etc)	10%	Rectangular	5.77ppb
Standard uncertainty of Calibration gas	10%	Rectangular	5.77ppb
Total standard uncertainty			8.3ppb
Total uncertainty for SO₂ (95% confidence)			13.6ppb

Data for the uncertainty analysis was taken from the specifications reported by both the instrument and calibration gas manufacturer's and from the report: 'Quality Assessment of Ambient NO, NO₂ and SO₂ Measurements in European Monitoring Networks', Payrissat M, Gerboles M, Sieja B and De Saeger E (1997).

These instruments are used extensively in the UK automatic monitoring networks and have been designated as equivalent methods for the determination of sulphur dioxide by the USEPA.

Appendix G Percentile Analysis

Appendix G Percentile Analysis

Percentile analysis provides a method of looking at the distribution of concentrations within a data set. Excel calculates percentiles by first sorting the concentrations into ascending order and then ranking each concentration. It then uses the following formula's,

$$r = 1 + \left[\frac{P(n-1)}{100} \right] I + D$$

P = the percentile you want
n = the total number of values
I = the integer part of the ranking
D = the decimal part of the ranking
r = rank

$$p = Y_I + D(Y_{I+1} - Y_I)$$

Y_I = value corresponding to the rank I
p = Value of the required percentile

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to interpolate the value of a particular percentile from the calculated ranking. i.e. it calculates the concentration below which a certain percentage of concentrations fall. For example, at the 95th percentile, 95% of the data will lie below this value and 5% of the data will lie above it.

In order to produce radial percentile roses, the data is first divided into the required wind sectors and then the data in each sector undergoes separate percentile analysis. By calculating the concentration of a pollutant at different percentiles for different wind sectors, you are able to visually examine the distribution of pollutant concentrations at a particular monitoring site. This in turn will provide information on the source that may be influencing levels at the monitoring site.

By separating the data into various wind sectors, it allows you to assess which wind directions are having the greatest influence on pollutant concentrations at the monitoring site. By calculating the average concentration for every wind sector you can produce a 'mean pollution rose', where the influence on pollutant concentrations from a particular wind sector is seen as a bias on a radial plot. This type of analysis is very effective at visually highlighting the wind sectors where there are significant sources of a given pollutant. By breaking each wind sector down into a number of different percentiles it can be seen whether biases are present in all of the percentiles or just certain ones, which can tell you whether a source is affecting the monitoring site relatively continuously or just intermittently. For example, a bias that is observed in all of the percentiles (Figure 1) suggests that the source in that particular wind sector is emitting relatively continuously as it is influencing a large percentage of the data. Whilst a bias that is only observed in the higher percentiles (Figure 2) suggests that the source is intermittent as it only affects a small percentage of the data, i.e. it doesn't affect concentrations at the monitoring site every time the wind is coming from this direction. Occasionally, a bias is observed in the lower percentiles that is not evident in the higher percentiles (Figure 3). This suggests that the source is relatively continuous, as it is affecting a large percentage of the data, but it also tells you that the source is not causing appreciably high concentrations at the monitoring site.

Figure 1. shows a bias between 280° – 300° that is evident in all of the percentiles.

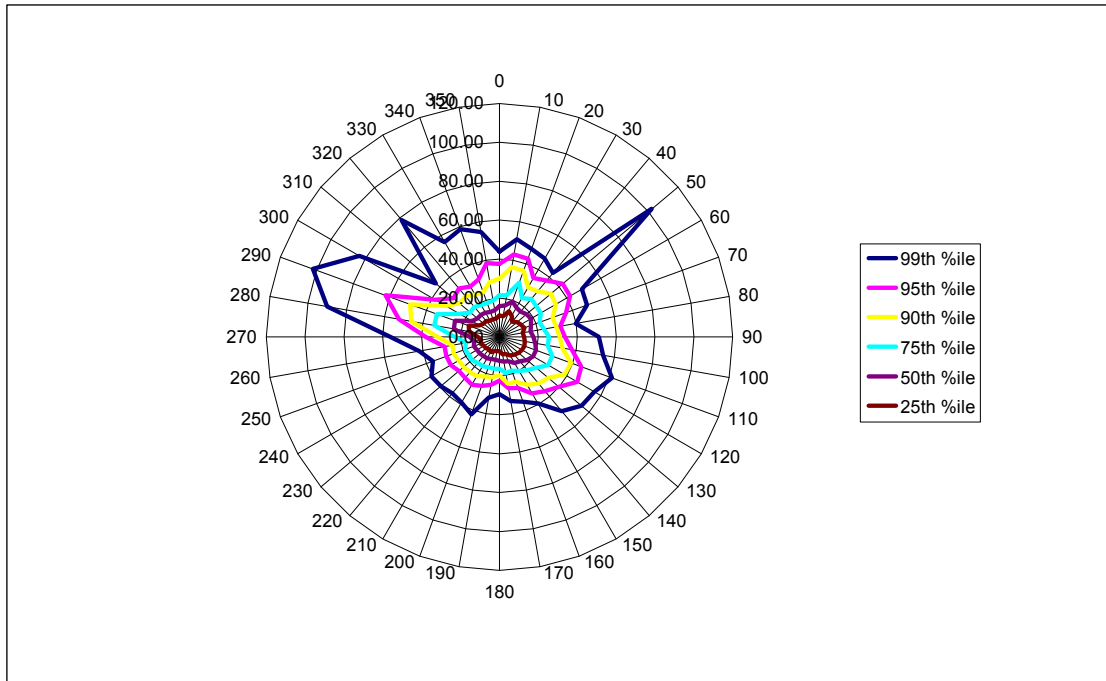
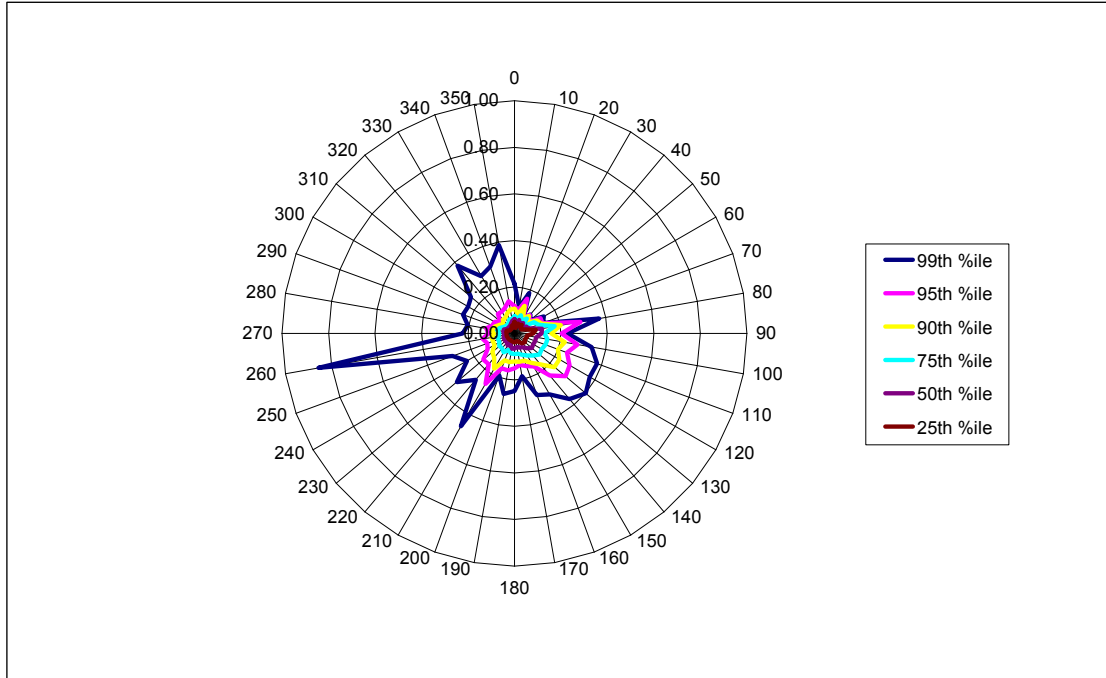


Figure 2. shows a bias at 260° that is only evident in the 99th percentile.



Appendix G Percentile Analysis

Figure 3. shows a bias between 20° – 50° that is only evident in the lower percentiles.

