



Study of Ambient Air Quality at Newhaven

23 August 2012 – 13 March 2013

Report - AAM/TR/2013/11

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Published by:

Environment Agency Horizon house, Deanery Road Bristol BS1 5AH Tel: 0117 934 4000 Email<u>: enquiries@environmentagency.gov.uk</u> www.environment-agency.gov.uk

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Executive summary

This report provides the results from the study of ambient air quality in the vicinity of Veolia ES South Downs Ltd, in Newhaven. The Environment Agency's Ambient Air Monitoring Team (in National Monitoring Services) carried out the study on behalf of the South East Region, between 23 August 2012 and 13 March 2013 (203 days).

The report presents the measured levels of particulate (PM_{10} and $PM_{2.5}$), sulphur dioxide (SO_2), oxides of nitrogen (NO_X), nitrogen dioxide (NO_2), hydrogen sulphide (H_2S), benzene, 1,3-butadiene, toluene, m&p-xylene and ethylbenzene and compares these levels with the objectives of the UK Air Quality Strategy (AQS), where applicable.

Comparing the collected data from the monitoring at Newhaven with the AQS objectives showed that the monitoring location was subject to concentrations of PM_{10} , $PM_{2.5}$, SO_2 , NO_x , NO_2 , benzene and 1,3-butadiene levels that were likely to meet their respective AQS objectives.

The H_2S and toluene data were compared with their respective World Health Organisation (WHO) guidelines. Toluene was found to be within the specified health and odour limits, whilst H_2S was within health limits but exceeded odour limits for 0.01% of the monitoring period.

The VOCs measured that did not have an AQS objective were compared to Environmental Assessment Levels (EALs), as calculated from the Health and Safety Executive's (HSE) occupational exposure limits, in accordance with the Guidance Note H1. All the VOCs measured were within their respective EALs.

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1 Introduction

The Environment Agency's Ambient Air Monitoring Team (AAM Team), on behalf of the South East Region, carried out a study to investigate ambient air quality in the vicinity of Veolia ES South Downs Ltd, in Newhaven.

The study involved a programme of monitoring carried out between 23 August 2012 and 13 March 2013 (203 days).

During this period the local authority were collecting Particulate and NO_X data at two nearby locations, Denton School and Brightwell. Deposition gauges were also deployed during this period and the data from these monitors is included in this report.

The Ambient Air Monitoring Team's Mobile Monitoring Facility (MMF 3) was used to measure the ambient concentrations of pollutants. The reported pollutants were PM_{10} , $PM_{2.5}$, NO_X , NO_2 , SO_2 , H_2S , benzene, 1,3-butadiene, toluene, ethylbenzene and m&p-xylene.

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 surrounding pollution sources 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 Location

The Ambient Air Monitoring team deployed its mobile monitoring facility (MMF 3) in the car park of the Newhaven Enterprise Centre on Denton Island (Figure 2.1). Veolia ES South Downs Ltd was at a bearing of approximately 350° - 10° from the MMF.

Figure 2.1: Map of monitoring locations





Figure 2.2: Photograph of the Environment Agency MMF at Newhaven.

Figure 2.3: Photograph of local authority monitoring station near Denton School.



3 Monitoring Results

3.1 Meteorology

Wind speed and direction measurements were collected at the MMF site during the study. The sensor was mounted on a mast extending 6m from the top of the MMF trailer giving an overall height above ground of 8m. Where possible the MMF was located over 100m from any buildings of greater or comparable height, so as to reduce any influence that surrounding buildings may have on the wind distribution.

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 August 2012 and 13 March 2013 (203 days) is shown in Figure 3.1.1. The plot shows that over the period the dominant wind direction was between 190° - 360° with wind coming from this sector 72% of the time. Table 3.1.1 shows the wind speed variation during the study period.



Figure 3.1.1: Wind rose for Newhaven

Wind Speed (m/s)	Frequency of wind speed (%)
<0.2	0.65
0.2 - 0.5	3.52
0.5 - 1	10.1
1 - 2	22.9
2 - 3	23.7
3 - 5	32.5
>5	6.58
Total	100.00

Table 3.1.1	Summary	of wind	speed	frequencies.
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A plot of mean wind speed against wind direction is shown in Figure 3.1.2. It can be seen that the maximum mean wind speed was greater than 2.5m/s and came from the wind directions between $20^{\circ} - 70^{\circ}$, $110^{\circ} - 260^{\circ}$ and $340^{\circ} - 360^{\circ}$.

Figure 3.1.2: Wind speed rose at Newhaven



3.2 Particulate (PM₁₀ & PM_{2.5})

Between 23 August 2012 and 13 March 2013 (203 days) airborne $PM_{10} \& PM_{2.5}$ concentrations were measured (at a height of 2m above ground) using a TEOM instrument. Details of the instrumentation and methodology are given in Appendix C. Successful data collection of 5-minute data for $PM_{10} \& PM_{2.5}$ over the period was 99% and 99% respectively.

During the study two Local Authority monitoring stations were also collecting particulate data, one at Denton School and another at a temporary site called Brightwell. A time series plot of 1-hour PM_{10} and $PM_{2.5}$ concentrations for both the MMF and Local Authority monitoring sites is shown in Figure 3.2.1. The Local Authority data sets have not been fully ratified and therefore they will only be used in the directional analysis.

Figure 3.2.1: PM_{10} and $PM_{2.5}$ 1-hour mean concentrations (μ g/m³) at the MMF, Denton School and the Brightwell monitoring sites (— PM_{10} — $PM_{2.5}$).



3.2.1 Comparison with Standards

3.2.1.1 Comparison with Air Quality Strategy (AQS) Objectives

It has been shown that particulate measurements using a TEOM instrument is not equivalent to the reference method for particulate matter and therefore not strictly comparable to the AQS Objectives. This should be taken into consideration when examining data which is close to breaching standards.

 PM_{10} data collected with a TEOM instrument should be adjusted using the Kings College London (KCL) Volatile Correction Model (VCM). The VCM uses FDMS instrument data from sites within 100km distance of the MMF in order to adjust the

 PM_{10} measurements to comply with the reference method, further explanation can be found in Appendix C.

Unratified FDMS data acquired for VCM has been used to correct the PM_{10} data from MMF3. Concentrations that incorporate FDMS data are quoted as $\mu g/m^3$ (as in Figure 3.2.2), where as those that have not been corrected are quoted as $\mu g/m^3$ [TEOM] (as in Figure 3.2.1).

There is not currently a validated correction factor for $PM_{2.5}$ TEOM data and therefore the data is not comparable to the AQS Objective values. However, KCL has developed a VCM for $PM_{2.5}$ that does go some way toward estimating the volatile fraction of the particulate lost on the TEOM. Although not strictly equivalent to the reference method it does give a better estimation of total particulate $PM_{2.5}$ than uncorrected TEOM data and therefore has been used in this study. Further explanation can be found in Appendix C.

The AQS has two objectives for PM_{10} , the first is to limit the annual mean concentration to $40\mu g/m^3$ and the second objective states that the 24-hour mean (midnight – midnight) must not exceed $50\mu g/m^3$ on more than 35 occasions during one year.

The mean PM_{10} concentration over the monitoring period at the MMF was 22.1µg/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 would not be exceeded at the monitoring site.



Figure 3.2.2: 24-hour (midnight-midnight) mean PM_{10} concentrations at the MMF monitoring site.

Figure 3.2.2 shows that for PM_{10} the 24-hour (midnight-midnight) mean concentration was greater than $50\mu g/m^3$ on three occasions during the monitoring period, the

maximum concentration being $67.1\mu g/m^3$. If the assumption is made that the conditions during the monitoring period were representative of a typical year, then the AQS for 24-hours (midnight-midnight) mean PM₁₀ concentrations would not be exceeded at the monitoring site.

The AQS objective for $PM_{2.5}$, limits the annual mean concentration to $25\mu g/m^3$. The mean $PM_{2.5}$ concentration over the monitoring period was $15.2\mu g/m^3$ TEOM. If the assumption is made that the conditions during the monitoring period were 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 Comparison with Air Quality Index

In the United Kingdom a daily Air Quality Index has been developed. The system uses an index numbered 1-10 (low – high pollution), divided into four bands to provide more detail on a daily basis about air pollution levels to the general population and those at higher risk from air pollution.

Figure 3.2.3 looks retrospectively at the daily PM_{10} concentrations in relation to the Air Quality Index banding. The Figure shows that there were three days during the monitoring period where PM_{10} 24-hour concentrations were in the moderate banding of the Air Quality Index.



Figure 3.2.3: PM₁₀ AQI Pie Chart

Figure 3.2.4 looks retrospectively at the daily $PM_{2.5}$ concentrations in relation to the Air Quality Index banding. The Figure shows that there were two days during the monitoring period where $PM_{2.5}$ 24-hour concentrations were in the moderate banding of the Air Quality Index.

Figure 3.2.4: PM_{2.5} AQI Pie Chart



3.2.3 Detailed Consideration of PM₁₀ Pollution Events at the MMF

The periods where PM_{10} 15-minute concentrations (ug/m³TEOM) 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, although not exceeding the AQS objective, were individually considered and the association between recorded PM_{10} levels and the wind direction and wind speed at that time examined. The results are summarised in Table 3.2.1.

Pollution Event	Date	Time	Maximum 15-Minute Concentration (µg/m³)	Wind Direction (degrees)	Wind Speed (m/s)
1	7 Sep 2012	07:00	147	28	0.5
2	24 Oct 2012	14:30	113	71	2.9
3	9 Feb 2013	05:30	256	356	1.9
4	26 Feb 2013	08:00	120	52	3.8
5	12 Mar 2013	08:45	164	24	6.8

Table 3.2.1 Summary of PM₁₀ pollution events

Table 3.3.1 shows that high levels of PM_{10} were recorded at the monitoring site when the wind was coming from between 356° - 71° , at wind speeds of 0.5 - 6.8 m/s. The pollution events occurred between 05:30 - 14:30.

3.2.4 Directional Analysis

A radial plot of mean PM₁₀ and PM_{2.5} concentrations (μ g/m³ TEOM) against wind direction, recorded at MMF3 are shown in Figure 3.2.5. The highest average PM₁₀ concentration are seen for wind sectors 20°, 50° - 90° with average concentrations >20 μ g/m³TEOM. Elevated PM_{2.5} concentrations can be seen for wind direction 300° - 320° and 350° - 110° with average concentrations >10 μ g/m³TEOM.

Figure 3.2.5: PM₁₀ and PM_{2.5} Pollution Rose at the MMF



Figure 3.2.6 shows the mean particulate pollution roses for the MMF and the two Local Authority monitoring sites overlaying a map of Newhaven. The plot shows that the highest levels of PM_{10} were recorded at the Brightwell Local Authority site, which was located very close to New Road and therefore heavily influenced by traffic emissions. The $PM_{2.5}$ roses for the MMF site and Denton School are very similar, with biases in the same wind sectors. This suggests that they are both being influenced by distant sources. The PM_{10} roses for the MMF site and Denton School also show some similarity, but there is an obvious source between $0^{\circ} - 110^{\circ}$ in the MMF that is not seen in the Denton School Rose. This suggests that there is a local source of PM_{10} at a bearing of $0^{\circ} - 110^{\circ}$ that affects levels at the MMF site but does not noticeably influence levels at Denton School.

Figure 3.2.6: PM_{10} pollution roses at the MMF and Local Authority monitoring sites overlaying a map of Newhaven (Scale: $45\mu g/m^3$, $PM_{10} = PM_{2.5}$).



An array of plots showing the contribution to PM_{10} and $PM_{2.5}$ loading (μ g/m³ TEOM) at the monitoring site for different percentiles are shown in Figures 3.2.7 and 3.2.8 respectively. An explanation of percentile analysis is given in Appendix H.





Figure 3.2.7 shows elevated PM_{10} concentrations in the higher percentiles for wind directions between 0° - 100° , suggesting there is an intermittent source(s) of PM_{10} in this wind sector, that gives rise to occasional elevated PM_{10} concentrations.



Figure 3.2.8: PM_{2.5} Percentile Rose at the MMF site

Figure 3.2.8 shows elevated $PM_{2.5}$ concentrations in the higher percentiles for wind directions between 50° - 70°, 130° - 160° and at 280°, suggesting that there are intermittent sources of $PM_{2.5}$ in these wind sectors that give rise to occasional elevated $PM_{2.5}$ concentrations.

3.2.5 Wind Speed Variation

Figures 3.2.9 shows the variation in PM_{10} and $PM_{2.5}$ concentrations ($\mu g/m^3$) with wind speed, seen for varying wind directions at the MMF. The plots show that the highest PM_{10} levels were observed at higher wind speeds from the North North East of the monitoring site. Whereas, the highest $PM_{2.5}$ levels were observed at low wind speeds, i.e. poor dispersion conditions. This suggests that the highest levels of PM_{10} were likely the result of fugitive emissions, such as wind-blown dust, whilst the highest levels of $PM_{2.5}$ were likely the result of low level combustion sources, such as traffic emissions.





Figures 3.2.10 shows the variation in PM_{10} concentrations ($\mu g/m^3$) with wind speed, seen for varying wind directions the MMF and two Local Authority monitoring locations overlaying a map of Newhaven.

The plot shows that the high concentrations of PM_{10} observed in the MMF plot are not seen at the same levels at the Brightwell monitoring location. This may indicate that the source is closer to the MMF site or that there is a physical barrier between the source and the Brightwell monitoring site.

Figure 3.2.10: PM_{10} polar plots at the MMF and Local Authority monitoring sites overlaying a map of Newhaven



3.2.6 Diurnal and weekday Analysis

Consideration of the diurnal distribution of concentration levels can provide further useful information about the sources contributing to the ambient levels in each sector. Pollutants generated from everyday traffic on the roads typically take the form of a double peak pattern, where the peaks correspond to the morning and afternoon/evening rush hours. Emissions from activities on site, meanwhile, are usually characterised by a single peak spanning the hours of the working day or operations on site. Figure 3.2.11 shows diurnal variation of average PM_{10} and $PM_{2.5}$ concentrations for each 45° wind direction sector at the MMF site.

The Figure shows that the plots for the wind sector $0^{\circ} - 90^{\circ}$ both show that PM_{10} concentrations rise during the working day. The rise in $PM_{2.5}$ concentration in these plots is much lower than the rise in PM_{10} , suggesting that although traffic emissions are affecting the monitoring site when the wind is coming from these wind directions, there is also evidence of fugitive dust emissions, such as resuspension.





Figures 3.2.12 shows the variation of average PM_{10} concentrations for each 45° wind direction at the MMF for weekdays, Saturdays and Sundays.

The plots for the wind sector $0^{\circ} - 90^{\circ}$ both show increased PM₁₀ concentrations between the hours 06:00 – 18:00 on Monday – Fridays. Further suggesting that the MMF monitoring site is being influenced by PM₁₀ levels arising from local site activities.





3.2.7 Deposition Monitoring

During the monitoring period six Frisbee gauge monitors were deployed at various locations around Newhaven (see Figure 3.2.13) to measure deposited dust. A series of fortnightly samples were collected between the 12 September 2012 – 19 December 2012 (see Table 3.2.2).

The Frisbee gauge allows for a dust deposition rate to be calculated for each sample, which is a calculation of the mass of dust deposited per unit area, over a known

period. There are no statutory UK or European Community standards for the control of nuisance dust, however, in the UK a 'custom and practice' guideline of 200mg/m²/day is generally used as an indicator of actionable dust nuisance. Further details of the instrumentation and methodology are given in Appendix I.



Figure 3.2.13: Map of Frisbee Gauge Monitoring Locations

Table 3.2.2 Sampling Periods for each of the monitoring sites	Table 3.2.2	Sampling	Periods	for each	of the	monitoring	sites
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Compling Site				Start Date			
Sampling Site	12-Sep-13	26-Sep-13	10-Oct-13	25-Oct-13	07-Nov-13	21-Nov-13	05-Dec-13
Enterprise Centre (Denton Island)	14 Days	14 Days	14 Days	13 Days	14 Days	14 Days	14 Days
Guitar Shop (Estate Rd)	14 Days	14 Days	14 Days	13 Days	14 Days	14 Days	14 Days
Denton School	14 Days	14 Days	14 Days	13 Days	14 Days	14 Days	14 Days
Heighton Crescent	Х	14 Days	14 Days	13 Days	14 Days	14 Days	14 Days
Kings Avenue	Х	14 Days	14 Days	13 Days	14 Days	14 Days	14 Days
St Leonards Close	Х	Х	Х	Х	7 Days	14 Days	14 Days

Dust deposition rates are calculated from the deposited mass collected on each Frisbee gauge sample. However, the results showed that insufficient mass was deposited on all but three of the samples and therefore deposition rates can only be calculated for these three samples.

Table 3.2.3 shows the calculated dust deposition rates for the Frisbee gauges at each of the monitoring sites. Where no value is presented this indicates that insufficient material was collected for a viable sample to be reliably measured and the deposition rate calculated.

Compling Site				Start Date			
Sampling Sile	12-Sep-13	26-Sep-13	10-Oct-13	25-Oct-13	07-Nov-13	21-Nov-13	05-Dec-13
Enterprise Centre (Denton Island)							
Guitar Shop (Estate Rd)		54.3	51.7				
Denton School			39.5				
Heighton Crescent	Х						
Kings Avenue	Х						
St Leonards Close	Х	Х	Х	Х			

Table 3.2.3 Calculated Dust Deposition Rates (mg/m²/day)

The table shows that all of the samples had deposition rates well below the custom and practice nuisance dust guideline of 200mg/m²/day.

Each of the dust samples collected were analysed under a microscope to identify the material fragments collected. The results of the analysis are shown in Table 3.2.4. The materials apparent in each sample are highlighted in yellow.

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Material Present		De	ent	on	isla	anc	k		Gu	itar	SI	hop)	1	De	nto	on \$	Sc	hoc	h		ł	Hei Cre	gh sc	ton enf	l		Ki	ng'	s A	ve	nue	÷		Stl	Leo Cl	ona	ard' Ə	's
	1	2	3	4	5	6	7	1	2	3 4	4 {	5 6	6 7	1	2	3	4	5	6	7	1	2	3	4	5	6	7 1	2	2 3	8 4	5	6	7	1	2	3	4	5 (6
Carbonaceous Material																													T				Γ					Т	
Fine Particulate Matter																													T										
Vegetable Fibres																																							
Coloured Textile Fibres																					- 1								T									T	

Table 3.2.4 List of deposited material in each Frisbee sample

The Table shows that every sample contained carbonaceous material, fine particulate matter and vegetable fibres. Insect fragments, glass fibres and grey fragments were each only found in one of the samples.

The three samples where sufficient mass was collected were also analysed for metals (see Table 3.2.5). Only iron (Fe) and aluminium (AI) are consistently found above detection limits. Copper (Cu) and Lithium (Li) are both found above detection levels in sample one from the guitar shop monitoring site and Zinc (Zn) is found above detection limits in sample two from the guitar shop monitoring site.

Wood (positive lignin test) Insect Fragments

Black fragments (Paint, Rubber, plastic or foam)

Glass Fibres Glass shards Coloured Fibres (plastic) Brick Dust

Metalic fragment Grey fragment (paint)

Metals	Guitar Shop	Guitar Shop	Denton School
(mg/Kg)	Sample 1	Sample 2	Sample 2
Al	9230	9810	5910
В	<6490	<6830	<8930
Ba	<649	<683	<893
Ca	<64900	<68300	<89300
Cd	<325	<341	<446
Cr	<325	<341	<446
Cu	692	<341	<446
Fe	30400	33700	11300
К	<6490	<6830	<8930
Mg	<19500	<20500	<26800
Mn	<649	<683	<893
Na	<130000	<137000	<179000
Ni	<649	<683	<893
Pb	<13000	<13700	<17900
Sr	<1300	<1370	<1790
Zn	<649	777	<893
Li	9480	<6830	<8930

Table 3.2.5 Results of Metal Analysis

3.2.8 Conclusions

Comparison of the PM_{10} data with the AQS objective for the 24-hour (midnight-midnight) mean indicated that the current standard would not be exceeded at the monitoring site.

The mean PM_{10} concentration over the monitoring period was $22.1\mu g/m^3$. 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 $40\mu g/m^3$ would not be exceeded at the monitoring site.

The mean $PM_{2.5}$ concentration over the monitoring period was $15.2\mu g/m^3$ TEOM. 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 $25\mu g/m^3$ would not be exceeded at the monitoring site.

Pollution rose analysis indicates that the highest average PM_{10} concentrations measured at the MMF were from a wind direction of 20° and between 50° - 90°. The highest $PM_{2.5}$ concentrations measured at the MMF were from a wind direction between 300° - 320° and 350° - 110°.

Percentile rose analysis suggested that there is an intermittent PM_{10} and source(s) between 340° - 350° and intermittent PM2.5 sources between 50° - 70°, 130° - 160° and 280°.

Diurnal and weekday analysis suggest that the MMF site is being influenced by PM_{10} levels arising from local site activities.

3.3 Sulphur Dioxide (SO₂)

Between 23 August 2012 and 13 March 2013 (203 days) airborne concentrations of SO_2 were measured at a height of 2m above ground. Details of the instrumentation and methodology are given in Appendix D. Successful data collection over the period was 99%.

3.3.1 Comparison with Standards

3.3.1.1 Comparison with Air Quality Strategy (AQS) Objectives

The AQS objective states that the limit of $266\mu g/m^3$ (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 3.3.1.



Figure 3.3.1: SO₂ 15-minute mean concentrations at the MMF monitoring site.

The plot shows that the measured 15-minute mean was never greater than $266\mu g/m^3$ during the monitoring period, the maximum concentration being $26.9\mu g/m^3$. 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 SO_2 states that a limit of $350\mu g/m^3$ (132ppb) must not be exceeded more than 24 times during one year. A time series plots for 1-hour mean concentrations of SO_2 is shown in Figure 3.3.2.



Figure 3.3.2: SO₂ 1-hour mean concentrations at the MMF monitoring site.

The plot shows that the measured 1-hour mean was not greater than $350\mu g/m^3$ during the monitoring period, the maximum concentration being $24.2\mu g/m^3$. 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 $125\mu g/m^3$ (47ppb) must not be exceeded on more than three occasions during one year. A time series plot for 24-hour (midnight – midnight) mean concentrations of SO₂ is shown in Figure 3.3.3.





The plot indicates that over the monitoring period no 24-hour mean concentrations were recorded that exceeded the AQS objective, the maximum concentration being $9.39\mu g/m^3$. 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.

3.3.1.2 Comparison with other relevant standards

The AQS has introduced an annual mean limit of $20\mu g/m^3$ (8ppb) in an effort to protect vegetation and ecosystems. The mean SO₂ concentration over the monitoring period was $1.94\mu g/m^3$ which is below the $20\mu g/m^3$ limit.

3.3.2 Comparison with Air Quality Index

In the United Kingdom a daily Air Quality Index has been developed. The system uses an index numbered 1-10 (low – high pollution), divided into four bands to provide more detail on a daily basis about air pollution levels to the general population and those at higher risk from air pollution.

Figure 3.3.4 looks retrospectively at the daily SO_2 concentrations in relation to the Air Quality Index banding. The Figure shows that during the monitoring period the SO_2 15-minute concentrations remained in the low banding of the Air Quality Index.

Environment Agency Ambient Air Monitoring Team

Figure 3.3.4: SO₂ AQI Pie Chart



Index	10	9	8	7	6	5	4	3	2	1
Band	Very High	High	High	High	Moderate	Moderate	Moderate	Low	Low	Low
μg/m ³	1064+	887 - 1063	709 - 886	532 - 708	443 - 531	355 - 442	266 - 354	177 - 265	89 - 176	0 - 88
	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100.0%

3.3.3 Detailed Consideration of SO₂ Pollution Events

Periods when SO_2 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 SO_2 have been identified from the 15-minute mean concentrations. These 'pollution events', although not all 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 SO_2 at the monitoring site. The results of the pollution event analysis are summarised in Tables 3.3.1.

Pollution Event	Date	Time	Maximum 15- Minute Concentration (µg/m ³)	Wind Direction (degrees)	Wind Speed (m/s)
1	9 Sep 2012	09:15	23.2	139	1.8
2	23 Oct 2012	02:45	19.2	346	2.2
3	23 Oct 2012	23:00	26.9	15	1.6
4	11 Dec 2012	14:15	15.5	3	3.0
5	20 Feb 2013	12:45	16.8	53	5.2

Table 3.3.1 Summary of SO₂ pollution events

Table 3.3.1 shows that when higher levels of SO_2 were recorded at the monitoring site, the wind was coming from between 3° - 53°, 139° and 346°. The episodes occurred at wind speeds between 1.6 - 5.2m/s, and between the hours of 23:00 - 14:15.

3.3.4 Directional Analysis

A radial plot of mean SO₂ concentrations (μ g/m³) against wind direction is shown in Figure 3.3.5. The plot shows that the highest average SO₂ concentrations were measured at the monitoring site when the wind was coming from between 50° – 60°, 140° – 150° and 330°, where average levels were greater than 2.5 μ g/m³.





Figures 3.3.6 shows an array of plots showing the contribution to SO_2 loading at the monitoring site for different percentiles. The plots show that the contribution from the sources between $50^{\circ} - 60^{\circ}$, $140^{\circ} - 150^{\circ}$ and 330° are evident in all of the percentiles, suggesting that there are relatively continuous sources of SO_2 in these wind sectors.





3.3.5 Wind Speed Variation

Figures 3.3.7 shows the variation in SO₂ concentrations (μ g/m³) with wind speed, seen for varying wind directions at the MMF. The plots show that the highest SO₂ levels were observed from wind directions between 305° - 340°, where levels increase with increasing wind speed. This suggests that there is a stack source of SO₂ in this wind sector, where the plume is grounded during high wind speeds, i.e. greatest mechanical mixing. There are also high levels at lower wind speeds between 45° – 70° and 100° - 160°.

3.3.6 Diurnal and Weekday Analysis

Consideration of the diurnal distribution of concentration levels can provide further useful information about the sources contributing to the ambient levels in each sector. Pollutants generated from everyday traffic on the roads typically take the form of a double peak pattern, where the peaks correspond to the morning and afternoon/evening rush hours. Emissions from activities on site, meanwhile, are usually characterised by a single peak spanning the hours of the working day or operations on site.

Figure 3.3.8 shows diurnal and weekday variation of average SO_2 concentrations for each wind direction at the MMF site.





Figure 3.3.8: SO₂ Diurnal and Weekday Annulus Plot at the MMF site



The diurnal plot shows that SO_2 levels were highest around the middle of the day in the wind directions between $30^{\circ} - 175^{\circ}$, with levels increasing again during the night between $115^{\circ} - 145^{\circ}$. Levels are also highest around the middle of the day for the wind directions between $300^{\circ} - 355^{\circ}$, but levels remain elevated into the early evening. This suggests that the site is being influenced by stack sources of SO_2 , where the plume is being brought to ground at the times of greatest solar and mechanical mixing.

The weekday plot shows that the source(s) between $300^{\circ} - 360^{\circ}$ is highest during the week, especially on Tuesdays, Wednesdays and Thursdays. The source(s) between $25^{\circ} - 85^{\circ}$ is highest on Wednesdays and Thursdays and the source(s) between $115^{\circ} - 170^{\circ}$ is highest on Wednesdays.

3.3.7 Conclusions

Comparison of the SO_2 data with the AQS objective for the 15-minute, 1- hour and 24-hour (midnight-midnight) mean concentrations indicated that air quality would comply with all of these objectives.

Pollution rose analysis indicates that the highest average SO_2 concentrations measured were from a wind direction of $50^\circ - 60^\circ$, $140^\circ - 150^\circ$ and 330° .

Percentile rose analysis suggests the sources of SO_2 in these wind sectors are relatively continuous, and commonly cause high levels at the monitoring site.

Wind speed variation and diurnal analysis suggest that the site is being influenced by stack sources of SO_2 .

3.4 Oxides of Nitrogen (NO_X)

Between 23 August 2012 and 13 March 2013 (203 days) airborne NO_x and NO_2 concentrations were measured at a height of 2m above ground. Details of the instrumentation and methodology are given in Appendix E. Successful data collection at the MMF was 99%.

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 oxidation 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 at the MMF and Denton School monitoring sites is shown in Figures 3.4.1. The plot shows that NO_X concentrations remained predominantly below 150µg/m³ with discrete excursions above this level. The average NO_X concentration over the period at the MMF was 26.9µg/m³.



Figure 3.4.1: NO_x 15-minute mean concentrations at the MMF

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 NO_2 concentration is more important from a human

health stand point. NO_2 is the constituent of NO_X that is harmful to health and consequently a National Air Quality Strategy Objective exists for NO_2 levels. NO_2 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 $200\mu g/m^3$ (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 MMF monitoring site is shown in Figure 3.4.2.



Figure 3.4.2: NO₂ 1-hour mean concentrations at the MMF monitoring site.

The plot shows that the 1-hour NO_2 concentrations were never greater than $200\mu g/m^3$, the maximum concentration being $77.8\mu g/m^3$. If the assumption is made that the conditions during the monitoring period were representative of a typical year, then the AQS for 1-hour NO_2 mean concentrations would not be exceeded at the monitoring site.

The annual objective states that a concentration value of $40\mu g/m^3$ (21ppb) must not be exceeded in one year. The average NO₂ concentration during the monitoring period was 16.9µg/m³. If the assumption is made that conditions during the monitoring period were representative of a typical year, then the results would indicate that the annual AQS objective for NO₂ would not be exceeded with the emission rates that existed during the monitoring period.

3.4.2 Comparison with Air Quality Index

In the United Kingdom a daily Air Quality Index has been developed. The system uses an index numbered 1-10 (low – high pollution), divided into four bands to provide more detail on a daily basis about air pollution levels to the general population and those at higher risk from air pollution.

Figure 3.4.3 looks retrospectively at the daily NO_2 concentrations in relation to the Air Quality Index banding. The Figure shows that during the monitoring period the NO_2 1-hour concentrations remained in the low banding of the Air Quality Index.



Figure 3.4.3: NO₂ AQI Pie Chart

3.4.3 Detailed consideration of NO_X pollution events

Periods when 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', although not exceeding the AQS objectives, 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 the monitoring site. The results of the pollution event analysis are summarised in Table 3.4.1.

Pollution Event	Date	Time	Maximum 15- Minute Concentration (µg/m ³)	Wind Direction (degrees)	Wind Speed (m/s)
1	7 Sep 2012	07:00	214	28	0.5
2	6 Nov 2012	08:45	364	337	0.5
3	12 Dec 2012	22:30	247	116	2.6
4	19 Dec 2012	14:45	324	116	3.3
5	21 Jan 2013	07:45	223	109	0.2

Table 3.4.1 Summary of NO _x pollution events at the MMF site

Table 3.4.1 shows that elevated NO_X concentrations were observed when the wind was coming from between 337° - 116°. The pollution episodes occurred between the hours of 07:00 – 22:30. Three of the events occurred at very low wind speeds, i.e. poor dispersion conditions and occurred between the hours 07:00 – 08:45 suggesting that they may be the result of traffic emissions. The other two events occurred at much higher wind speeds but both occurred when the wind was coming from 116°.

3.4.4 Directional Analysis

A radial plot of mean NO_X concentrations (μ g/m³) against wind direction is shown in Figures 3.4.4. The plot shows that the highest average NO_X concentrations were measured at the monitoring site when the wind was coming from between 60° - 120° and 310°, where average levels are greater than 40 μ g/m³.

Figure 3.4.4: NO_X Pollution Rose



Figure 3.4.5 shows an array of plots showing the contribution to NO_X loading at the monitoring site for different percentiles. The plots show that the contribution from the sources between 60° - 120° and 310° are evident in all of the percentiles, suggesting that there are relatively continuous sources in these wind directions.




3.4.5 Wind Speed Variation

Figures 3.4.6 shows the variation in NO₂ concentrations (μ g/m³) with wind speed, seen for varying wind directions at the MMF. The plot shows that the highest NO_x levels were observed at low wind speeds from wind directions between 310° – 135°. This suggests that poor dispersion conditions and low level sources, such as traffic emissions are responsible. Elevated concentrations at slightly higher wind speeds may indicate the presence of additional more elevated sources.

3.4.6 Diurnal and Weekday Analysis

Consideration of the diurnal distribution of concentration levels can provide further useful information about the sources contributing to the ambient levels in each sector. Pollutants generated from everyday traffic on the roads typically take the form of a double peak pattern, where the peaks correspond to the morning and afternoon/evening rush hours. Emissions from activities on site, meanwhile, are usually characterised by a single peak spanning the hours of the working day or operations on site.

Figure 3.4.7 shows diurnal and weekday variation of average NO_X concentrations for each wind direction at the MMF site.

Figure 3.4.6: NO_X Polar Plot at the MMF Site



Figure 3.4.7: NO_X Diurnal and Weekday Annulus Plot at the MMF site



The diurnal plot shows that NO_X levels were highest around the morning rush hour in the wind directions between 50° – 115°, with levels being higher in the evening rush hour between 75° - 125°. This suggests that traffic emissions are the dominant source of NO_X at the MMF site.

The weekday plot shows that the source(s) between $40^{\circ} - 125^{\circ}$ is highest during the week, with levels particularly high on Thursdays.

3.4.7 Conclusions

Comparison of the NO_2 data with the AQS objective for the 1-hour mean concentrations indicated that air quality at the monitoring site would comply with this objective under current emissions.

The mean NO₂ concentrations over the monitoring period was $16.9\mu g/m^3$. 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.

Pollution rose analysis indicates that the highest average NO_X concentrations were measured at the monitoring site when the wind was coming from 60° - 120° and 310°.

Percentile analysis suggested that these sources between were relatively continuous.

Wind speed variation and diurnal analysis suggest that the dominant source of NO_X at the MMF site was traffic emissions.

3.5 Hydrogen Sulphide (H₂S)

Between 23 August 2012 and 13 March 2013 (203 days) airborne H_2S concentrations 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 monitoring period was 99%.

The time series plot of 15-minute concentrations of H_2S over the period is shown in Figure 3.5.1. The plot shows that H_2S concentrations remained below $2\mu g/m^3$ for the majority of the data recorded with occasional peaks above this value. The average concentration over the period was $0.71\mu g/m^3$.



Figure 3.5.1: H₂S 15-minute mean concentrations at the MMF monitoring site.

3.5.1 Comparison with WHO Guidelines

A time series plot of 24-hour mean H_2S concentrations is shown in Figure 3.5.2. This data can be compared directly with the relevant WHO Guideline for Europe 2000. The highest recorded 24-hour mean was $2.24\mu g/m^3$ which is comfortably less than the $150\mu g/m^3$ limit set as a guideline by WHO, in the context of human health.

Figure 3.5.2: H_2S 24-hour (midnight – midnight) mean concentrations at the MMF monitoring site.



A time series plot of 30-minute average H_2S concentrations measured over the period is shown in Figure 3.5.3. This data also allows direct comparison with the WHO Guidelines for Europe 1987, which have set a guide level of $7\mu g/m^3$ above which substantial complaints about odour annoyance can be expected. The highest recorded 30-minute mean was $7.37\mu g/m^3$ and complaints due to odour nuisance from H_2S could be expected during 0.01% of the monitoring period.



Figure 3.5.3: H₂S 30-minute mean concentrations at the MMF monitoring site.

3.5.2 Detailed consideration of H₂S pollution events

Periods where H_2S concentrations increased significantly above the average level have been considered as separate 'pollution events'. The five highest levels of H_2S , have been identified from the 15-minute mean concentrations. 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 H_2S at the monitoring site.

The results of the pollution event analysis are summarised in Table 3.5.1.

Pollution Event	Date	Time	Maximum 15- Minute Concentration (μg/m³)	Wind Direction (degrees)	Wind Speed (m/s)
1	23 Sep 2012	13:15	9.59	34	3.5
2	6 Nov 2012	08:45	5.26	337	0.5
3	19 Dec 2012	14:45	4.17	116	3.3
4	15 Feb 2013	23:00	4.76	260	0.4
5	7 Mar 2013	09:15	4.61	79	2.0

3.5.1 Table Summary of H₂S pollution events

Table 3.5.1 shows that elevated concentrations of H_2S were seen for wind directions between 260° - 116°. The highest H_2S levels were recorded at wind speeds ranging from 0.4 – 3.5 m/s and occurred between the hours of 08:45 - 23:00.

3.5.3 Directional Analysis

A radial plot of mean H_2S concentrations ($\mu g/m^3$) against wind direction is shown in Figure 3.5.4. The plot shows that the highest average H_2S concentrations were measured at the monitoring site when the wind was coming from between 350° - 130° and 310°, where average levels are greater than 0.80 $\mu g/m^3$.

Figure 3.5.4: H₂S Pollution Rose



An array of plots showing the contribution to H_2S loading at the monitoring site for different percentiles are shown in Figure 3.5.5. The plots show that the contribution from the sources between 350° - 130° and 310° affect all the percentiles, which indicates that the sources are relatively continuous and commonly affect H_2S concentrations at the monitoring site.





3.5.4 Wind Speed Variation

Figures 3.5.6 shows the variation in H₂S concentrations (μ g/m³) with wind speed, seen for varying wind directions at the MMF. The plot shows that the highest H₂S levels were observed at relatively high wind speeds from wind directions between 5° - 50°. The plot also shows that like NO_X, H₂S levels are elevated at low wind speeds from wind directions between 310° - 135°. This suggests that poor dispersion conditions and low level sources, such as traffic emissions are responsible.

3.5.5 Diurnal and Weekday Analysis

Consideration of the diurnal distribution of concentration levels can provide further useful information about the sources contributing to the ambient levels in each sector. Pollutants generated from everyday traffic on the roads typically take the form of a double peak pattern, where the peaks correspond to the morning and afternoon/evening rush hours. Emissions from activities on site, meanwhile, are usually characterised by a single peak spanning the hours of the working day or operations on site.

Figure 3.5.7 shows diurnal and weekday variation of average H_2S concentrations for each wind direction at the MMF site.

Figure 3.5.6: H₂S Polar Plot at the MMF Site



Figure 3.5.7: H₂S Diurnal and Weekday Annulus Plot at the MMF site



The diurnal plot shows that H_2S levels were highest around the morning rush hour in the wind directions between 20° – 120°, with levels being higher in the evening rush hour between 90° - 135°. This suggests that traffic emissions are the dominant source of NO_X at the MMF site. There is also a slight rise around midday in the wind directions between 30° – 75°, which may indicate a stack source of H_2S .

The weekday plot shows that the source(s) between $35^{\circ} - 130^{\circ}$ is highest during the week, with levels particularly high on Thursdays. There is also evidence of source between $0^{\circ} - 70^{\circ}$ that also emits on Sundays.

3.5.6 Conclusions

Comparison of the H_2S data with the WHO guidelines for human health of $150\mu g/m^3$, as 24-hour mean concentrations, indicated that the air quality at the monitoring site is within these guidelines.

Comparison of the H_2S data with the WHO guidelines for odour annoyance of $7\mu g/m^3$, as 30-minute mean concentrations, indicated that odour complaints could be expected for 0.01% of the monitoring study.

Pollution rose analysis indicates that the highest average H_2S concentrations were measured at the monitoring site when the wind was coming from between 350° - 130° and 310°.

Percentile analysis suggested that these sources are relatively continuous.

Wind speed variation and diurnal analysis suggest that there is a stack source of H_2S in the wind sector 5° – 50°.

3.6 VOCs

Between 24 August 2012 and 13 March 2013 (202 days) airborne VOC concentrations were measured at a height of 2m above ground. The main VOCs monitored were benzene, 1,3-butadiene, toluene, ethylbenzene and m&p-xylene. Details of the instrumentation and methodology are given in Appendix G. The successful data collection over the monitoring period C_2 - C_5 GC was 72% and for the C_6 - C_{10} GC it was 70%.

3.6.1 Comparison with Standards

3.6.1.1 Comparison with Air Quality Strategy (AQS) objectives

The two VOCs included in the AQS are benzene and 1,3-butadiene. Time series plots for each of these VOCs are shown in Figures 3.6.1 and 3.6.2.

The AQS objective for benzene is expressed as an annual mean and is currently set at $5ug/m^3$ (1.5ppb). The mean benzene concentration over the monitoring period was at 2.51ug/m³, which is 50% of the AQS annual mean objective. If the monitoring period is taken to be representative of annual emissions and dispersion then benzene concentrations at the site will fall within the AQS objective.

The AQS objective for 1,3-butadiene is expressed as a running annual mean (RAM) and is currently set at 2.25ug/m³ (1ppb). The mean 1,3-butadiene concentration over the monitoring period was 0.22ug/m³, which is 10% of the AQS annual mean objective. If the monitoring period is taken to be representative of annual emissions and dispersion then 1,3-butadiene concentrations at the monitoring site will fall within the AQS objective.



Figure 3.6.1: Benzene 30-Minute Mean Concentrations



Figure 3.6.2: 1,3-Butadiene 30-Minute Mean Concentrations

3.6.1.2 Comparison with other relevant standards

The other VOCs measured do not have an AQS objective and have therefore been compared with Environmental Assessment Levels (EALs) derived from Occupational Exposure Limits (OELs) taken from the Health and Safety Executives (HSE) publication, Occupational Exposure Limits 2002, using the calculations provided in Guidance Note H1 (Table 3.6.1).

Table 3.6.1 Comparison of the mean concentrations over the monitoring period with

 EALs derived from the HSE occupational exposure limits.

VOC	Long-term OEL (8hr-TWA)	Long-term EAL (annual mean)	Mean over monitoring period
Toluene	191 mg/m ³	1910ug/m ³	2.18ug/m ³
Ethylbenzene	441 mg/m ³	4410ug/m ³	0.64ug/m ³
Xylenes	220 mg/m ³	2200ug/m ³	1.82ug/m ³

Toluene also has two World Health Organisation (WHO) guidelines. The guideline for human health is 0.26mg/m^3 as a weekly average. The maximum weekly average over the period was $3.70 \mu \text{g/m}^3$ (0.004mg/m^3), below the human health guideline. The other guideline is for odour annoyance and is set at 1mg/m^3 over a 30-minute mean. The highest 30-minute mean over the monitoring period was $206 \mu \text{g/m}^3$ (0.21mg/m^3). Therefore, toluene should not have caused odour annoyance in the vicinity of the monitoring site.

3.6.2 Detailed consideration of Benzene and 1,3-Butadiene pollution events

Periods where benzene and 1,3-butadiene concentrations increased significantly above the average level have been considered as separate 'pollution events'. The five highest levels of benzene and 1,3-butadiene, have been identified from the 30-minute mean concentrations. 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 benzene at the monitoring site.

The results of the pollution event analysis are summarised in Tables 3.6.2 and 3.6.3.

Pollution Event	Date	Time	Maximum 30- Minute Concentration (μg/m ³)	Wind Direction (degrees)	Wind Speed (m/s)
1	28 Oct 2012	07:30	14.1	246	0.4
2	11 Nov 2012	17:30	10.9	296	0.2
3	29 Nov 2012	17:30	10.2	321	0.8
4	12 Dec 2012	08:30	9.06	310	1.3
5	19 Feb 2013	19:00	8.82	277	0.7

3.6.2 Table Summary of benzene pollution events

Table 3.6.2 shows that elevated concentrations of benzene were seen for wind directions between 246° - 321° . The highest benzene levels were recorded at wind speeds ranging from 0.2 - 1.3 m/s and occurred during the hours of 07:30 - 19:00. The table shows that the events occurred at low wind speeds, i.e. poor dispersion conditions.

Pollution Event	Date	Time	Maximum 30- Minute Concentration (µg/m ³)	Wind Direction (degrees)	Wind Speed (m/s)
1	10 Nov 2012	19:00	2.07	262	1.8
2	11 Nov 2012	18:00	2.09	314	0.6
3	30 Nov 2012	18:00	2.32	307	0.5
4	18 Dec 2012	18:00	2.26	294	0.4
5	3 Mar 2013	11:30	1.91	89	3.9

3.6.3 Table Summary of 1,3-butadiene pollution events

Table 3.6.3 shows that elevated concentrations of 1,3-butadiene were seen for wind directions between 262 - 314° and 89° . The highest 1,3-butadiene levels were recorded at wind speeds ranging from 0.4 - 3.9 m/s and occurred during the hours of 11:30 -19:00. The table shows that three of the five events occurred at 18:00 and at low wind speeds, i.e. poor dispersion conditions.

3.6.3 Directional Analysis

Radial plots of mean concentrations (ug/m³) against wind and percentile breakdowns against wind direction are shown for benzene, 1,3-butadiene, toluene, m&p-xylene and ethylbenzene in Figures 3.6.3 - 3.6.12.

A radial plot of mean benzene concentrations (μ g/m³) against wind direction is shown in Figures 3.6.3. The plot shows that the highest average benzene concentrations were measured at the monitoring site when the wind was coming from between 280° - 140°, where average levels are greater than 2.50 μ g/m³.



Figure 3.6.3: Benzene Pollution Rose

A radial plot of mean 1,3-butadiene concentrations (μ g/m³) against wind direction is shown in Figures 3.6.4. The plot shows that the highest average 1,3-butadiene concentrations were measured at the monitoring site when the wind was coming from between 50° - 90°, 110° - 140° and 270° - 340°, where average levels are greater than 0.20 μ g/m³.



Figure 3.6.4: 1,3-Butadiene Pollution Rose

A radial plot of mean toluene concentrations (μ g/m³) against wind direction is shown in Figures 3.6.5. The plot shows that the highest average toluene concentrations were measured at the monitoring site when the wind was coming from between 290° - 340°, 0° - 80° and 110° - 120°, where average levels are greater than 2.50 μ g/m³.

Figure 3.6.5: Toluene Pollution Rose



A radial plot of mean m&p-xylene concentrations (μ g/m³) against wind direction is shown in Figures 3.6.6. The plot shows that the highest average xylene concentrations were measured at the monitoring site when the wind was coming from between 10° - 70°, 110° - 120°, 300° and 320°, where average levels are greater than 2.0 μ g/m³.



Figure 3.6.6: m&p-Xylene Pollution Rose

A radial plot of mean ethylbenzene concentrations (μ g/m³) against wind direction is shown in Figures 3.6.7. The plot shows that the highest average ethylbenzene concentrations were measured at the monitoring site when the wind was coming from between 10° - 50°, 210°, 230° and 250°, where average levels are greater than 0.80µg/m³.

An array of plots showing the contribution to benzene loading at the monitoring site for different percentiles are shown in Figure 3.6.8. The plots show that the contribution from the sources between 280° - 140° can be seen to affect each of the percentile plots suggesting that these sources are continuous and commonly affect benzene concentrations at the monitoring site when the wind is from these directions.



Figure 3.6.7: Ethylbenzene Pollution Rose

Figure 3.6.8: Benzene Percentile Rose



An array of plots showing the contribution to 1,3-butadiene loading at the monitoring site for different percentiles are shown in Figure 3.6.9. The plots show that the contribution from the source(s) between 270° - 340° can be seen to affect each of the percentile plots suggesting that this source(s) is continuous and commonly affects

1,3-butadiene concentrations at the monitoring site when the wind is from these directions. Contribution from the sources between 50° - 90° and 110° - 140° were more evident in the lower percentiles. This indicates that the sources in these wind sectors are relatively continuous, but do not cause appreciably high concentrations of 1,3-butadiene at the monitoring site.



Figure 3.6.9: 1,3-Butadiene Percentile Rose

An array of plots showing the contribution to toluene loading at the monitoring site for different percentiles are shown in Figure 3.6.10. The plots show that the contribution from the sources between 290° - 340°, 0° - 80° and 110° - 120° can be seen to affect each of the percentile plots suggesting that these sources are continuous and commonly affect toluene concentrations at the monitoring site when the wind is from these wind sectors.

An array of plots showing the contribution to m&p-xylene loading at the monitoring site for different percentiles are shown in Figure 3.6.11. The plots show that the contribution from the sources between $10^{\circ} - 70^{\circ}$, $110^{\circ} - 120^{\circ}$, 300° and 320° can be seen to affect each of the percentile plots suggesting that these sources are continuous and commonly affect xylene concentrations at the monitoring site when the wind is from these directions.



Figure 3.6.10: Toluene Percentile Rose





An array of plots showing the contribution to ethylbenzene loading at the monitoring site for different percentiles are shown in Figure 3.6.12. Contribution from the sources between 10° - 50°, 210°, 230° and 250° can be seen to affect each of the percentile plots suggesting that these sources are continuous and commonly affect ethylbenzene concentrations at the monitoring site when the wind is from these directions.



Figure 3.6.12: Ethylbenzene Percentile Rose

3.6.4 Wind Speed Variation

Figures 3.6.13 shows the variation in VOC concentrations (μ g/m³) with wind speed, seen for varying wind directions at the MMF. The plots show that the highest benzene, toluene, m&p-xylene and ethylbenzene levels were observed at relatively high wind speeds from wind directions between 5° – 35°. This suggests there is a stack source of these VOCs in this wind sector. All of the VOCs also show increased concentrations at very low wind speeds, i.e. poor dispersion conditions, which is likely to be the result of traffic emissions. Benzene, 1,3-butadiene and ethylbenzene all showed the presence of additional significant sources.

3.6.5 Diurnal and Weekday Analysis

Consideration of the diurnal distribution of concentration levels can provide further useful information about the sources contributing to the ambient levels in each sector. Pollutants generated from everyday traffic on the roads typically take the form of a double peak pattern, where the peaks correspond to the morning and afternoon/evening rush hours. Emissions from activities on site, meanwhile, are





usually characterised by a single peak spanning the hours of the working day or operations on site.

Figure 3.6.14 shows diurnal and weekday variation of average VOC concentrations for each wind direction at the MMF site.



0.2

0.1

X1.3.butadiene

Figure 3.6.14: VOC Polar Plots at the MMF Site

s

0.2

0.1

X1.3.butadiene

Saturda

s



The diurnal plots show that the highest levels of both benzene and 1,3-butadiene are observed in the wind directions between $260^{\circ} - 340^{\circ}$ during the early evening. The highest levels of toluene, m&p-xylene were from the wind directions between $10^{\circ} - 45^{\circ}$ in the early afternoon, whilst ethylbenzene was highest at night in the wind directions between $170^{\circ} - 220^{\circ}$.

The weekday plots show that the highest levels of benzene, toluene, xylene and ethylbenzene were observed in the wind directions between $70^{\circ} - 100^{\circ}$ on a Friday nights/Saturday early mornings. 1,3-butadiene was highest in the wind sector $90^{\circ} - 340^{\circ}$, with levels elevated during most nights, including Saturdays and Sundays.

3.6.6 Conclusions

Comparison of the benzene data with its AQS objective indicated that if the monitoring period was representative of a typical year then the standard was unlikely to be exceeded at the monitoring site.

Comparison of the 1,3-butadiene data with its AQS objective indicated that if the monitoring period was representative of a typical year then the standard was unlikely to be exceeded at the monitoring site.

The other VOCs measured do not have AQS objectives and were therefore compared with their HSE Occupational Exposure Limits. The results showed that the toluene, m&p-xylene, and ethylbenzene concentrations were well within their respective EALs.

Toluene has WHO guidelines for both human health and odour annoyance and neither was exceeded at the monitoring site.

Directional analysis indicates that there were sources of VOC coming from between 270° - 140° .

Wind speed variation and diurnal analysis suggest that there is a stack source of benzene, toluene, xylene and ethylbenzene in the wind directions between $5^{\circ} - 35^{\circ}$.

4 Conclusions

Comparing the collected data from the monitoring at Newhaven with the AQS objectives showed that the monitoring location was subject to concentrations of PM_{10} , $PM_{2.5}$, SO_2 , NO_2 , benzene and 1,3-butadiene levels that were likely to meet their respective AQS objectives.

The VOCs measured that did not have an AQS objective were compared to Environmental Assessment Levels (EALs), as calculated from the Health and Safety Executives (HSE) occupational exposure limits, in accordance with the Guidance Note H1. All the VOCs measured were within their respective EALs.

The H_2S and toluene data were compared with their respective World Health Organisation (WHO) guidelines. Toluene was found to be within the specified health and odour limits, whilst H_2S was within health limits but exceeded odour limits for 0.01% of the monitoring period.

Time series plots for the pollutants monitored are shown in Figures 4.1 and 4.2.

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 4.3-4.5 summarises the extent of likely compliance, where appropriate, with other relevant standards. A projected compliance ratio \leq 1 indicates compliance, whilst a value >1 indicates non-compliance.

Table 4.6 summarises the results from the mean pollution roses, where wind directions showing a significant bias for a particular pollutant are shaded in red.

Pollutant	Averaging Time	AQS	Standard	Maximum Concentration (ug/m³)	Permitted Exceedance (A)	Measured Exceedance* (B)	Projected Compliance Ratio (B/A)
PM ₁₀	24-hr (midnight- midnight)	2000	50µg/m³	67.1 μg/m ³	35/year	5/year	0.14
SO ₂	15-min 1-hr 24-hr (midnight- midnight)	2000 2000 2000	266µg/m ³ 350µg/m ³ 125µg/m ³	26.9 µg/m ³ 24.2 µg/m ³ 9.39 µg/m ³	35/year 24/year 3/year	0/year 0/year 0/year	0.09 0.00 0.00
NO ₂	1-hr	2000	200µg/m³	77.8 μg/m ³	18/year	0/year	0.00

Table 4.1 Impact summary fo	r short- term air	quality objectives.
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* Extrapolated from effective monitoring period

Pollutant	Averaging Time	AQS	Standard (A)	Measurement* (B)	Projected Compliance Ratio (B/A)
PM ₁₀	Year	2000	40 μg/m ³	22.1 μg/m ³	0.55
PM _{2.5}	Year	2007	25 μg/m³	15.2 μg/m³	0.61
NO ₂	Year	2000	40 μg/m ³	16.9 μg/m³	0.42
Benzene	Year	Addendum 2003	5 μg/m³	2.51µg/m³	0.50
1,3-Butadiene	Year	2000	2.25 μg/m ³	0.22 μg/m ³	0.10

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

Extrapolated from effective monitoring period

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

Pollutant	Averaging Time	Standard	Standard (A)	Measurement* (B)	Projected Compliance Ratio (B/A)
SO ₂	Year	2000 AQS	20 μg/m ³	1.94 μg/m³	0.10
NOx	Year	2000 AQS	30 μg/m ³	26.9 μg/m³	0.90

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

• Extrapolated from effective monitoring period

Table 4.4 Impact summary of H_2S and Toluene compliance with the WHO guidelines for Europe 2000.

Pollutant	Averaging Time	Guidance Limit	Percentage of Time Exceeding the Guidance Limit				
H ₂ S	24hr (midnight- midnight)	150µg/m³	0				
	30-Minute	7μg/m³	0.01				
Toluene	Weekly average	0.26mg/m ³	0				
	30-Minute	1mg/m ³	0				

Table 4.5 Impact summary of VOC compliance with their EALs

Pollutant	Averaging Time	Standard	Standard (A)	Measurement* (B)	Projected Compliance Ratio (B/A)
Toluene	Year	Long-term EAL	1910ug/m ³	2.18ug/m ³	0.00
Ethylbenzene	Year	Long-term EAL	4410ug/m ³	0.64ug/m ³	0.00
Xylenes	Year	Long-term EAL	2200ug/m ³	1.82ug/m ³	0.00

* Extrapolated from effective monitoring period

		Wind Direction (Degrees)																
	10	20	30	40	50	60	70	80	06	100	110	120	130	140	150	160	170	180
PM ₁₀																		
PM _{2.5}																		
SO ₂																		
NO _X																		
H₂S																		
Benzene																		
1,3-Butadiene																		
Toluene																		
Xylene																		
Ethylbenzene																		

Table 4.6Summary of mean pollution roses. The bearing of Veolia ES SouthDowns Ltdfrom the monitoring site is shaded in yellow.

	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																		
NOx																		
H₂S																		
Benzene																		
1,3-Butadiene																		
Toluene																		
Xylene																		
Ethylbenzene																		



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Figure 4.2 Organic Time Series for the MMF monitoring site in Newhaven (30-minute mean concentrations)

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Period

5 References

- 1. Department for Environment, Food and Rural Affairs (July 2007), *The Air Quality Strategy for England, Scotland, Wales and Northern Ireland,* (HMSO)
- 2. World Health Organisation (2000), WHO Air Quality Guidelines for Europe

Appendix A Mobile Monitoring Facility

National Monitoring Services carries out ambient air monitoring on behalf of Environment Agency regions using Mobile Monitoring Facilities (MMFs). These facilities allow us to carry out flexible, short-term studies examining the impact of specific EPR permitted installations 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 Newhaven study was MMF3. The pollutants that can be measured using MMF3 are:

- particles (PM₁₀ & PM_{2.5})
- nitrogen dioxide
- sulphur dioxide
- carbon monoxide
- hydrogen sulphide
- Methane
- VOCs

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 5 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

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 Location	-	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.
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})

Airborne particulate matter can be found in a wide range of particle sizes (nm-um) 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 10µm. PM_{2.5} is defined as particulate matter with an aerodynamic diameter less than 2.5 µm. The description of PM₁₀ and PM_{2.5} is restricted to its physical characteristic and no particular chemical composition is implied. In the case of PM₁₀ The size-selective samplers used are designed to collect 50% of 10µm aerodynamic diameter particles, more than 95% of 5µm particles, and less than 5% of 20µm particles; for PM_{2.5} a similar distribution is used with 2-5µm as the centre point . 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 7µm are deposited in the nose and throat, and only 20-30% of particles between 1 and 7µm are deposited in the alveoli. However, up to 60% of particles below 0.1µm 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 therefore being transported over longer distances.

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 sulphate, 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 Analyser

The analyser used to measure particulate concentration is a TEOM/FDMS system comprising of a Rupprecht & Patashnick (R&P) series 8500 Filter dynamics measurement system (FDMS) module attached to a R&P Tapered Element Oscillating Microbalance (TEOM) series 1400a ambient particulate monitor. The FDMS system was designed to correct for the loss of semi volatile particles which occurred when using the TEOM system only. The FDMS/TEOM monitor for PM₁₀ and PM_{2.5} has been approved as an equivalent to the European Union gravimetric reference method in the United Kingdom equivalence program.

 PM_{10} and $PM_{2.5}$ fractions were measured using two separate FDMS/TEOM systems with specific PM_{10} and $PM_{2.5}$ filter inlets. 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 ±0.1 litres per minute. The action of the air through the head selects particles of the relevant aerodynamic diameter (less than 10µm for PM_{10} less than 2.5µm for $PM_{2.5}$). The air passes through the FDMS module and continues through the TEOM monitor.

The air sampled from the TEOM inlet passes through a dryer, removing water from the sample, the drying efficiency is monitored by an integrated humidity sensor. The air is then passed through two alternative modes (base sample and purge) switching between the two modes every 6 minutes.

The FDMS unit accounts for both volatile and non volatile PM components with readings being reported as a mass concentration. This is achieved by measuring the volatile portion of the sample separately from the incoming cycle (purge sample). The base cycle allows the dried sample to continue to the TEOM filter. In the purge filter cycle the temperature is lowered to 4°C which removes PM and aerosols from the sample stream.

The base sample and purge air flows alternately pass through the TEOM filter. The filter is kept at a temperature of 30° C to reduce particle loss. The TEOM 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**).

$$\mathbf{m} = \mathbf{k}/f^2$$

Where k is a constant determined during calibration of the instrument. Any mass decrease that is measured in the purged stream over the 6 minute period is automatically added back to the mass measurement obtained from the sample stream to give the total mass concentration.

Mass concentration(MC) = sample MC- purge mass MC

Where the purge MC value is usually negative due to volatilization of mass from the filter. The FDMS/TEOM system is accurate to within $\pm 0.75\%$ for mass measurements and

precision of $\pm 2.5 \ \mu g/m^3$ (1-hour average), $\pm 0.8 \ \mu g/m^3$ (24-hour average). The method computes one-hour running mean of PM mass concentration which updates every six minutes.
Appendix D Sulphur Dioxide (SO₂)

Sulphur dioxide is formed by the oxidation of sulphur and 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 smog's 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.

O₂ Analyser

The analyser used to measure sulphur dioxide was a ML 9850B. The operation of this analyser is based on the measurement of fluorescence from SO_2 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 SO_2 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:

Irradiation $SO_2 + hv_1 \longrightarrow SO_2^*$ Fluorescence $SO_2^* \longrightarrow SO_2 + hv_2$

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

$$I_a = I_o[1 - exp(-ax(SO_2))]$$

Where, I_0 is the UV light intensity, **a** the absorption coefficient of SO₂, **x** the path length, and (SO₂) 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 SO_2 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 SO_2 molecules.

Total uncertainty calculation is made for the SO_2 15 minute 2000 NAQS limit value of 100ppb.

Assessment of compliance for SO ₂ ultraviolet florescence analyser according to ISO			
14956			
MonitorLabs ML 9850B Sulphur Dioxide Analyser			
2000 NAQS for SO ₂ concentrations		15 minute limit value 100ppb	
Measurement performance related to dynamic conditions			nic conditions
Performance	Value	Distributio	Standard Uncertainty at
Characteristic		n Type	100ppb
Linearity	1% of reading	Rectangular	0.58ppb
Precision	0.5ppb or 1% of	Normal	1ppb
	reading		
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	10%	Rectangular	5.77ppb
(i.e. sample lines, filters etc)		-	
Standard uncertainty of	10%	Rectangular	5.77ppb
Calibration gas		-	
Total standard uncertainty			8.3ppb
Total uncertainty for SO (05% confidence)			
13.0 pp			

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, NO_2 and SO_2 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 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 . Typically 90 to 95 percent of NO_x , at the time of emission from an industrial combustion source, is in the form of NO.

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 PM_{10} .

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:

$$NO + O_3 \rightarrow NO_2 + O_2$$

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:

$$NO_2 + hv \rightarrow O^{\bullet} + NO$$

 $O^{\bullet} + O_2 + M \rightarrow O_3 + M$
 $O_3 + NO \rightarrow O_2 + NO_2$

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.

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:

$$NO + O_3 \rightarrow NO_2^* + O_2 \rightarrow NO_2 + O_2 + hv$$

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 NO ₂ chemiluminescence analyser according to ISO 14956			
MonitorLabs ML 9841B Nitrogen Dioxide Analyser			
2000 NAQS for NO ₂ concentrations		1 hour limit value 105ppb	
Measurement performance related to dynamic conditions			
Performance	Value	Distributio	Standard Uncertainty at
Characteristic		n Type	100ppb
Linearity	1% of reading	Rectangular	0.6ppb
Precision	0.5ppb or 1% of	Normal	1ppb
	reading		
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	10%	Rectangular	6ppb
(i.e. sample lines, filters etc)			
Standard uncertainty of	10%	Rectangular	6ppb
Calibration gas			
Total standard uncertainty			8.5ppb
Total uncertainty for NO ₂ (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, NO_2 and SO_2 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 Hydrogen Sulphide (H₂S)

Hydrogen sulphide is formed by the direct combination of the two elements, or by the action of dilute hydrochloric or sulphuric acid on iron sulphide. At normal temperature and pressure it is a gas. It is readily decomposed and highly reactive and will combine rapidly with other elements to form a range of compounds, notably sulphur dioxide.

Sources

Following the introduction of catalytic converters into the manufacture of modern cars, a greater incidence of the characteristic "bad eggs" smell of H_2S has been observed. This is due to the chemical reduction of sulphur dioxide, from a poorly tuned engine, within the catalytic converter. Sulphur compounds are temporarily "stored" in the converter and then released "en masse" during abrupt acceleration or following prolonged periods of high speed driving (e.g. on motorways).

Hydrogen sulphide is not simply a by-product of chemical processes, but can also arise from other sources e.g. decomposition of organic matter such as sewage which in some instances has generated highly toxic, even fatal concentrations.

Health Effects

Hydrogen sulphide is a potent chemical asphyxiant, combining with haemoglobin and with cytochromes and thus rapidly stopping oxygen from access to cellular metabolism (just like gases such as carbon monoxide and hydrogen cyanide). Indeed H_2S is arguably as toxic as hydrogen cyanide HCN.

Hydrogen sulphide is very foul smelling but very quickly paralyses the sense of smell, and can at high levels go on to overcome the victim and eventually cause death. Therefore smell cannot be relied upon to provide warnings of this treacherous gas.

Hydrogen sulphide is also an irritant of mucous membranes including the eyes and respiratory tract.

H₂S analyser

The analyser used to measure hydrogen sulphide is an adapted sulphur dioxide analyser. Gas entering the analyser first passes through a selective scrubber to remove sulphur dioxide, then enters a catalytic converter, where hydrogen sulphide is oxidised to form sulphur dioxide. This secondary gas stream of sulphur dioxide is then sampled and analysed using a standard sulphur dioxide analyser.

The operation of the sulphur dioxide analysers is based on the measurement of fluorescence from SO_2 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 SO_2 molecules in the sampling air, which produce fluorescence that can be measured by a PMT with a secondary UV filter. The equations describing the reactions are:

Irradiation $SO_2 + hv_1 \longrightarrow SO_2^*$ Fluorescence $SO_2^* \longrightarrow SO_2 + hv_2$ The UV light at any point in the system is given by:

$$I_a = I_o[1 - exp(-ax(SO_2))]$$

where I_0 is the UV light intensity, **a** the absorption coefficient of SO₂, **x** the path length, and (SO₂) 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 SO_2 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 SO_2 molecules and by inference hydrogen sulphide molecules.

Appendix G Volatile Organic Compounds (VOCs)

Volatile organic compounds (VOCs) are an important class of air pollutant commonly found in the atmosphere at ground level in urban and industrial areas. The strict definition of a VOC is an organic compound present in the atmosphere as a gas, but which under normal conditions of temperature and pressure would be a liquid or solid. However a more general description is commonly taken in which the term VOC is taken to include all carboncontaining compounds found in the atmosphere, excluding elemental carbon, carbon monoxide, and carbon dioxide.

Sources

Natural biogenic processes can give rise to substantial ambient concentrations of a limited number of organic compounds including isoprene, monoterpenes and methane. Natural sources include emissions from plants, trees, wild animals, natural fires, and anaerobic processes in bogs and marshes. However the contributions resulting from human activities are considerably greater. The major source categories identified include all modes of transport, solvent usage, evaporation during handling, the industrial processes of oil refining and chemicals manufacture, oil and gas production, and agriculture. Table F2.1 lists a number of VOCs, and gives their emission due to motor vehicles and non-motor vehicle sources, extracted from the NAEI 1997. Table H2.1also includes the Photochemical Ozone Creation Potential (POCP), where available, for each VOC.

Environmental Considerations

The presence of VOCs in the atmosphere is of concern because of their role in a number of environmental issues. These include:

- Ground level photochemical ozone formation
- Toxic or carcinogenic human health effects
- Accumulation and persistence in the environment
- Enhancing the global greenhouse effect
- Stratospheric ozone depletion

Ground Level Ozone Formation

Ozone is formed by the reaction of atomic oxygen with molecular oxygen. In the troposphere the only significant source of atomic oxygen is photodissociation of NO_2 which also results in the formation of NO. In the atmosphere NO reacts with ozone, forming molecular oxygen and NO_2 . This series of reactions establishes a dynamic equilibrium with the amount of ozone formed by reaction between molecular and atomic oxygen equal to that removed by reaction with NO. The equilibrium is dependent upon the amount of prevailing sunlight. The 'background' concentration of ozone in the atmosphere in the UK is 20 to 30ppb depending on season.

The primary removal process for VOCs in the troposphere is reaction with OH radicals where the OH radical removes a hydrogen atom from the VOC to leave a VOC radical. The products of the reaction of VOCs with OH radicals can result in the conversion of NO to NO_2 but with no corresponding removal of ozone. As a consequence the set of reactions result in

a net production of ozone, the concentration of ozone being limited by the available VOCs, photochemical dissociation and dry deposition. Maximum hourly concentrations of ozone, observed in the UK, over recent years have been of the order of 100ppb.

However, each VOC can contribute differently to the formation of ozone and other secondary oxidants in the troposphere, both in terms of quantity and time-scale. Concern resulting from the generation of elevated levels of ozone in regions of high population has led to increased priority being placed on controlling those compounds that are oxidised rapidly. The concept of POCP has been introduced to allow the different compounds to be ranked. The POCP scale indicates the relative abilities of VOCs to produce ozone on short timescales (up to 5 days). Ethene (C_2H_4) is the reference compound, for which a POCP value of 100.0 is assigned. A POCP value is defined per unit mass emission. Currently calculated POCP values range from zero for unreactive fully halogenated compounds to about 130 for reactive substituted aromatic compounds.

POCP is a calculated quantity that depends on the use of models and their underlying assumptions. When POCPs are calculated using different atmospheric models, the ratio of POCPs for any given compound may differ appreciably. The POCP values used in this study are taken from Derwent & Jenkin (1991).

Measured VOC	Motor Vehicle	Non-Motor Vehicle	Total Emissions	POC
	Emissions	Emissions	(kt/annum)	P
	(kt/Annum)	(kt/annum)	\$	\$\$
	`\$´´	`\$´´	·	
t-2-butene	5.32	1.63	6.95	99
c-2-butene	5.32	1.54	6.86	99
i-Pentane	38.05	23.69	61.74	60
n-Pentane	19.65	67.80	87.45	62
t-2-pentene	3.44	1.14	4.58	95
2-methylpentane	13.94	2.50	16.44	78
3-methylpentane	9.26	1.27	10.52	66
n-hexane	10.20	32.58	42.79	65
cyclohexane	0.00	2.46	2.46	60
n-heptane	3.80	23.04	26.84	77
benzene	24.45	13.33	37.79	33
toluene	63.98	61.11	125.09	77
ethylbenzene	18.54	1.92	20.46	81
(m+p)-xylene	55.50	40.46	95.96	109
o-xylene	22.11	18.46	40.57	83
1,3-butadiene	0.00	5.37	5.37	*
Isoprene	0.00	0.05	0.05	*
Styrene	0.00	4.86	4.86	8
1,2,4-trimethylbenzene	13.48	9.55	23.03	132
1,3,5-trimethylbenzene	4.33	3.51	7.84	135

Table G2.1VOC Emission Data and POCPs

\$ Data from the National Atmospheric Emission Inventory 1997

\$\$ Data from The categorisation of Volatile Organic Compounds EA Report No.

- DoE/HMIP/RR/95/009
- * Data not supplied

Table H2.1 Data for a range of VOCs. The emission source strengths have been extracted from the NAEI for 1997 and are listed by motor vehicle and non-motor vehicle sources. The Photochemical Ozone Creation Potential (POCP) has been taken from The Categorisation of Volatile Organic Compounds, EA Report DoE/HMIP/RR/95/009.

N.B.

1)The Ozone Depletion Potential of all the listed VOCs is zero because they do not contain any halogen atoms and will all undergo reaction in the troposphere.

2)The Global Warming Potential has not been calculated for any of the listed VOCs in Table.

Toxic and Carcinogenic Health Effects

Organic compounds may have important impacts on human health through direct mechanisms in addition to their indirect impacts. Some organic compounds affect the human senses through their odour, some others exert a narcotic effect and certain species are toxic. Concern is particularly expressed about those organic compounds that could induce cancer in the human population: the human genotoxic carcinogens. A wide range of other chemicals are also coming under scrutiny in this context. The most prominent organic compounds that belong to the air toxic category, and are widely distributed in the ambient atmosphere are benzene and 1,3-butadiene.

Accumulation and Persistence

There is an important class of organic compounds, the semi-volatile VOCs which, because of their molecular size and complexity, tend to become adsorbed onto the surface of suspended particulate matter. In this form they undergo long-range transport and may be removed in rain remote from their point of original emission. Once deposited in rain, they may reevaporate back into the atmosphere and begin the cycle all over again. Ultimately this material may be recycled through the atmosphere before reaching its more permanent sink in the colder aquatic environments in polar regions. Biological accumulation in these sensitive environments can lead to toxic levels in human foodstuffs in areas exceeding remote from the point of original emission. Compounds associated with biological accumulation include polychlorinated biphenyls (PCB), phthalic acid and its derivatives.

Global Greenhouse Effect

Some of the longer-lived organic compounds accumulate in the troposphere, or may have the potential to do so. If any of these compounds can absorb solar or terrestrial infrared radiation, then they may contribute to the enhanced greenhouse effect. Such compounds would be classed as radiatively active gases and their relative effectiveness can be expressed through their Global Warming Potential (GWP). The GWP of a substance is a measure of the extra amount of heat that is trapped in the atmosphere when 1kg of the substance is released instantaneously into it, relative to the case when 1kg of carbon dioxide is released. Many organic compounds are not themselves radiatively active gases, but they do have the property of potentially being able to perturb the global distributions of other radiatively active gases. If they exhibit this property, then they can be classed as secondary greenhouse gases and indirect GWPs may be defined for them. Organic compounds can behave as secondary greenhouse gases by reacting to produce ozone in the troposphere (ozone is an important greenhouse gas) or increasing or decreasing the troposphere 'OH distribution and hence perturbating the distribution of methane.

GWPs are calculated using computer models which incorporate the radiative heat balance of the atmosphere and the chemical kinetics of the substance. GWP values are published by the World Meteorological Organisation (1995).

Stratospheric Ozone Depletion

Some organic compounds do not react with OH in the troposphere due to the lack of available hydrogen atoms in the molecules. As a result they are relatively unreactive in the troposphere and can enter the stratosphere. The organic compounds may be fully substituted halogenated compounds. The primary reaction the compounds undergo is photolysis which releases the halogens into the stratosphere. The halogen atoms become involved in an ozone-destroying reaction where the halogen acts as a catalyst for the destruction of ozone. A large number of ozone molecules can be destroyed by each halogen atom before the halogen atom is removed from the stratosphere. An examples of the result of the destruction of startospheric ozone is the formation of the Antarctic 'ozone hole'. Many chlorinated solvents and refrigerants, and bromine-containing fire retardants and fire extinguishers have been identified as containing organic compounds that may lead to stratospheric ozone layer depletion.

The extent to which VOCs can contribute to depletion of ozone in the stratosphere is usually expressed in terms of Ozone Depletion Potentials (ODPs). An ODP is a calculated quantity. To find the ODP for a particular compound, properties of that compound are put into a mathematical model. The model calculates the rate and height at which the compound interacts with other atmospheric constituents in the presence of sunlight, to initiate chains of reactions that destroy stratospheric ozone. The ozone depletion arising from an instantaneous release of the compound is calculated for the whole of the life of the compound in the atmosphere. The depletion of stratospheric ozone calculated for the compound is then expressed as a fraction of the depletion calculated for CFC-11 (trichlorofluoromethane) which is given an ODP of 1.0.

ODP is only associated with compounds containing the halogens fluorine, chlorine, bromine and iodine; consequently the majority of VOCs are ascribed a zero ODP.

ODP values are published by the World Meteorological Organisation (1994).

Monitoring Methodology

The VOCs were monitored using a Syntech GC955 POCP analyser. The POCP analyser consists of two GCs, the C₂-C₅ VOCs were trapped and resolved on one of the GCs and the C₆-C₁₀ VOCs were trapped and resolved on the second. A computer built into the C₂-C₅ GC controlled both of the GCs.

C ₂ -C ₅ :		
Carrier Gas	-	Nitrogen
Dryer	-	Perma Pure Nafion dryer
Column	-	Al ₂ O ₃ /Na ₂ SO ₄ PLOT
Detector	-	FID (the fuel gases, hydrogen and air, were supplied by generators). PID (10.6eV)

C ₆ -C ₁₀ :		
Carrier Gas	-	Nitrogen
Column	-	EPA 624 equivalent
Detector	-	FID
		PID (10.6eV)

The BTEX analyser was calibrated fortnightly with a gas standard supplied by National Physics Laboratory (NPL).

Appendix H 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 formulas,



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.





Figure 3 - shows a bias between $20^{\circ} - 50^{\circ}$ that is only evident in the lower percentiles.

Appendix I Nuisance Dust

Nuisance dust is an inherent problem associated with many different industries including construction work, quarries, mines, landfills, intensive farming and waste transfer sites. It most routinely manifests as the soiling of cars, window ledges, etc.

Unfortunately, there are no statutory UK or European Community standards for the control of nuisance dust. However, in the UK a practical guideline of 200mg/m²/day is generally used as an indicator of actionable dust nuisance. Public perception of dust nuisance can also be influenced by the colour and density of the dust, which is not measured by deposition gauges as they only measure the mass of the dust deposited.

One important factor is the distance between the source and the receptor. Particles are subject to aerodynamic and gravitational effects, which determine the distance they will travel. Large particles generally settle out quite close to the site, whereas fine particles can travel great distances. For example, particles with diameters >50 µm tend to be deposited quickly, whereas particles of diameter <10 µm have an extremely small deposition rate in comparison (DoE, 1995). A pilot sampling survey can be used to provide some information on how particulates vary with distance. In some instances, computer modelling can also be valuable in this respect. Large particles (>30 µm) responsible for most dust annovance mostly deposit within 100 m of the source (the source is not usually located at the waste facility boundary.) Intermediate-sized particles (10-30 µm) are likely to travel up to 200-500 m. Smaller particles (<10 µm) can travel up to 1 km from the source, although very small particles can travel much further (DETR, 2000a). Government guidance for air guality review and assessment (DETR, 2000c) around quarries, stockpiles and landfill sites suggests that such sources are likely to add about 3 µg/m³ to the annual mean background concentration of receptors within 200-400 m of the sources (M17).

The most widely used deposition gauge is the dry Frisbee (with foam insert) gauge. A wet Frisbee gauge is available that is coated with liquid paraffin, instead of using the foam insert, but this sticky coating is reported to cause a number of problems and therefore the dry Frisbee gauge is preferable.



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The Frisbee Gauge (Figure B1) has been found to have superior collecting efficiency and aerodynamic characteristics that make it suitable for short-term sampling periods of about a week. The plastic (or preferably aluminium) inverted Frisbee (diameter 235 mm) is mounted horizontally on a pole 1.75 m above the ground. A hole at the centre of the Frisbee allows rainwater to drain through a spacer tube and into a polythene bottle (1litre capacity). At the end of the sampling period, the Frisbee and collection bottle are transported to the laboratory and the deposited matter on the collection surface and the insoluble matter in the bottle are quantitatively removed and separated by gentle vacuum filtration; petroleum ether (15 ml) is used to loosen the particles if liquid paraffin was added. After drying, the deposited matter is determined gravimetrically and expressed as mg m⁻² d⁻¹:

A∫ CVsdt

A= the area of the gauge opening	C= particle concentration
Vs = the particle settling velocity	t= time

References

- 1. Protocol for using the dry Frisbee (with foam insert) dust deposit gauge, H.W. Vallack, Stockholm Environment Institute, February 1995.
- Monitoring of particulate matter in ambient air around waste facilities, Technical guidance document (Monitoring) M17, Environment Agency, March 2004.
- 3. Airborne particulate matter in the United Kingdom, Third Report of the Quality of Urban Air Review Group, May 1996.