



Study of Ambient Air Quality at Silverdale

15 January 2019 and 25 June 2019

(AAM/TR/2019/12)

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Executive Summary

This report provides the results of a study to investigate ambient air quality in Silverdale. 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.

The study was carried out by the Environment Agency's Ambient Air Monitoring (AAM) Team, on behalf of the West Midlands Area. This monitoring campaign follows on from an ambient air monitoring study that was carried out in 2017 by the Ambient Air Monitoring Team (AAM/TR/2018/04).

The study involved a monitoring campaign carried out between the 28 February 2019 and 25 June 2019 (118 days). A mobile monitoring facility (MMF) was deployed, containing equipment capable of measuring concentrations of particulate matter (PM₁₀ & PM_{2.5}), hydrogen sulphide (H₂S), methane (CH₄), oxides of nitrogen (NO_x), benzene, toluene, m&p-xylene and ethylbenzene. Wind speed, wind direction, temperature and pressure measurements were also collected.

In addition to the MMF monitoring, three additional methane (CH₄) monitors were set up at three separate monitoring locations, to the north, east and west of the MMF monitoring site. Monitoring was carried out at these locations between the 15 April 2019 and 25 June 2019 (72 days).

The MMF was originally sited at a different monitoring location between the 15 January 2019 and 12 February 2019 (28 days), but the Environment Agency were required to move from this location.

Comparing the collected data from the monitoring at Silverdale with the AQS objectives showed that the monitoring location was subject to concentrations of PM₁₀, PM_{2.5}, NO₂ and benzene that were expected to meet their respective AQS objectives.

Toluene data was compared with the respective World Health Organisation (WHO) guidelines. Toluene was found to be within the specified health and odour limits.

Hydrogen sulphide (H₂S) data was compared with the respective World Health Organisation (WHO) guidelines. H₂S concentrations were within relevant health limits, but exceeded odour limits for 1% of the monitoring period. The MMF was originally sited at a different monitoring location between the 15 January 2019 and 12 February 2019 (28 days). H₂S concentrations were within relevant health limits, but exceeded odour limits for 6% of this shorter 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 Executives (HSE) occupational exposure limits, in accordance with the Guidance Note H1. All the VOCs measured were within their respective EALs.

Comparison of the data with the Defra Air Quality Index showed that levels during the study remained in the low banding of the Air Quality index for NO₂. PM₁₀ and PM_{2.5} daily mean concentrations remained primarily in the low banding of the index. PM₁₀ concentrations were in

the moderate and high bandings for 5% and 2% of the monitoring period respectively. PM_{2.5} concentrations were in the moderate and high banding for 2% and 1% of the monitoring period respectively.

Directional analysis showed that there was a continuous source of CH₄ and H₂S from the direction of Walleys Quarry landfill site and that a build-up of these compounds was seen under conditions of low wind speed and temperature and high pressure.

CH₄ concentrations were measured at lower concentrations at monitoring locations further away from the landfill site, suggesting that these sites were located further from the main source, this was supported by directional analysis showing that the highest CH₄ concentrations were from the direction of the landfill site.

Directional analysis suggests that there is also a relatively continuous NO_x source from the direction of the gas management compound on Walleys Quarry landfill site.

Contents

1 Introduction	5
2 Monitoring Location	6
3 Monitoring Results	8
3.1 Meteorology	8
3.2 Hydrogen Sulphide (H ₂ S)	11
3.2.1 Comparison with WHO Guidelines	11
3.2.2 Comparison with WHO Guidelines (15 January 2019 and 12 February 2019)	13
3.2.3 Directional Analysis	15
3.2.3 Diurnal and Weekday Analysis	20
3.2.4 Conclusion	23
3.3 Methane (CH ₄) at the MMF	24
3.3.1 Directional Analysis	24
3.3.2 Diurnal and Weekday Analysis	29
3.3.3 Conclusion	32
3.4 Methane (CH ₄) at the MMF and standalone sites	33
3.4.1 Directional Analysis	33
3.4.2 Conclusion	38
3.5 Oxides of Nitrogen (NO _x)	39
3.5.1 Comparison with Standards	39
3.5.1.1 Comparison with Air Quality Strategy (AQS) Objectives	39
3.5.1.2 Comparison with Other Standards	40
3.5.2 Comparison with Air Quality Index	41
3.5.3 Directional Analysis	41
3.5.4 Diurnal and Weekday Analysis	44

3.5.5 Conclusion	46	
3.6 BTEX	47	
3.6.1 Comparison with Standards	47	
3.6.1.1 Comparison with Air Quality Strategy (AQS) Objectives	47	
3.6.1.2 Comparison with other relevant standards	48	
3.6.2 Directional Analysis	49	
3.6.3 Conclusion	52	
3.7 Particulate Matter (PM ₁₀ & PM _{2.5})	53	
3.7.1 Comparison with Standards	53	
3.7.1.1 Comparison with Air Quality Strategy (AQS) Objectives	53	
3.7.2 Comparison with Air Quality Index	56	
3.7.3 Directional Analysis	58	
3.7.4 Diurnal and Weekday Analysis	60	
3.7.5 Conclusion	63	
4 Conclusion	64	
5 References	69	
Appendix A	Additional Data (15 January 2019 and 12 February 2019)	70
Appendix B	Mobile Monitoring Facility	73
Appendix C	Quality Assurance and Quality Control	74
Appendix D	Hydrogen Sulphide (H ₂ S)	76
Appendix E	Methane (CH ₄)	78
Appendix F	Oxides of Nitrogen (NO _x)	80
Appendix G	Volatile Organic Compounds (VOCs)	82
Appendix H	Particulate (PM ₁₀ & PM _{2.5})	84
Appendix I	Percentile Analysis	86
Appendix J	Conditional Probability Function (CPF) plots in Openair	89

1 Introduction

This report provides the results of a study to investigate ambient air quality in the vicinity of Walleys Quarry landfill, in Silverdale. The study was carried out by the Environment Agency's Ambient Air Monitoring (AAM) Team, on behalf of the West Midlands Area. This monitoring campaign follows on from an ambient air monitoring study that was carried out in 2017 by the Ambient Air Monitoring Team (AAM/TR/2018/04).

The study involved a monitoring campaign carried out between the 28 February 2019 and 25 June 2019 (118 days). A mobile monitoring facility (MMF) was deployed, containing equipment capable of measuring concentrations of particulate matter (PM₁₀ & PM_{2.5}), hydrogen sulphide (H₂S), methane (CH₄), oxides of nitrogen (NO_x), benzene, toluene, m&p-xylene and ethylbenzene. Wind speed, wind direction, temperature and pressure measurements were also collected.

In addition to the MMF monitoring, three additional methane (CH₄) monitors were set up at three separate monitoring locations, to the north, east and west of the MMF monitoring site. Monitoring was carried out at these locations between the 15 April 2019 and 25 June 2019 (72 days).

The MMF was originally sited at a different monitoring location between the 15 January 2019 and 12 February 2019 (28 days), but the Environment Agency were required to move from this location. The MMF was moved approximately 60m from this original location. This short data set is not included in the main report, with the exception of a comparison of the H₂S concentrations with the WHO guidelines in the H₂S chapter. The short data set monitored between the 15 January 2019 and 12 February 2019 (28 days) is summarised in Appendix A.

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 and WHO guidelines
- 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 Monitoring Location

The ambient air monitoring team deployed a mobile monitoring facility on the grounds of Garners garden centre, Silverdale. Walleys Quarry landfill site was at a bearing of $110^{\circ} - 280^{\circ}$ from the MMF (Figure 2.1), with the gas management compound at a bearing of $160^{\circ} - 170^{\circ}$ and leachate treatment plant at a bearing of $210^{\circ} - 220^{\circ}$.

Three additional CH₄ monitoring locations were established, these monitoring locations are marked on Figure 2.2, alongside historical landfill sites in the area.

During an offsite odour tour carried out by the Environment Agency on the 19 March 2019, five mains gas leaks were identified in the vicinity of Walleys Quarry landfill. The location of the leaks are marked on Figure 2.2. Table 2.1 shows the dates that leak repair works were carried out.

Figure 2.1: Map of Walleys Quarry Landfill Site and MMF location

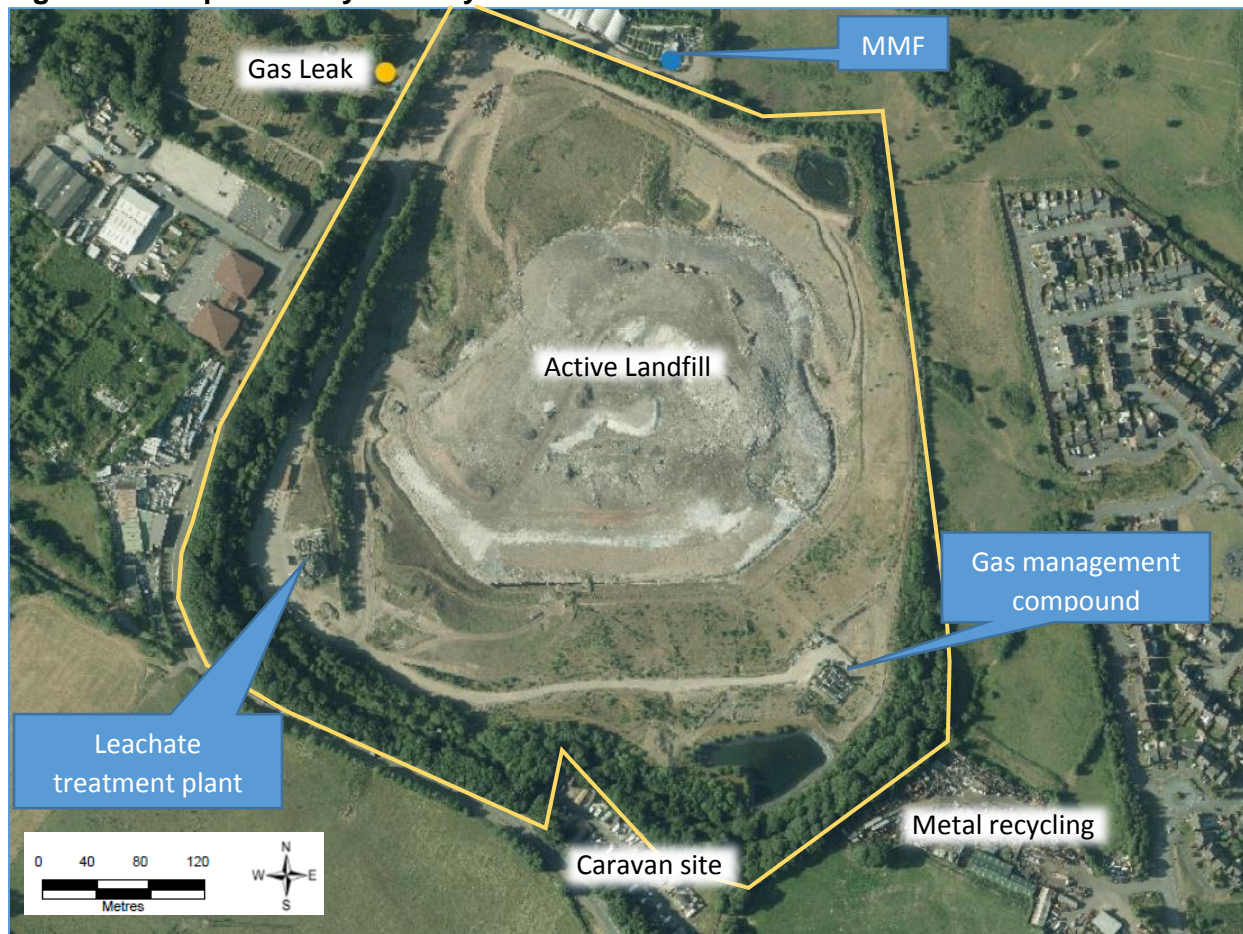


Figure 2.2: Map of CH₄ monitoring locations, gas leaks and historical landfill sites

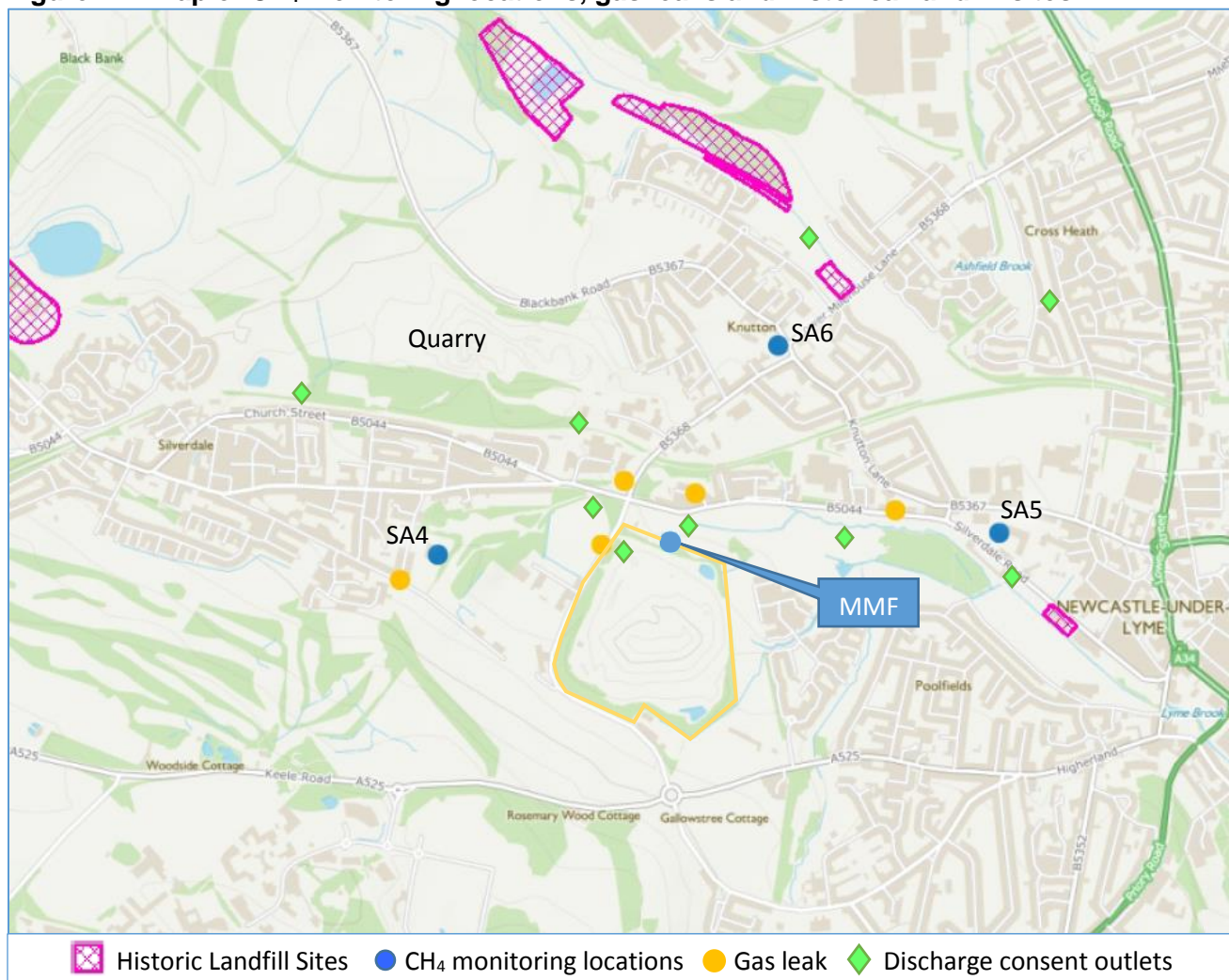


Table 2.1: Details of gas leak repairs

Location of Gas Leak	CH ₄ detected concentration (ppm)	Date repaired	Bearing from MMF (°N)
6 Ellams Place	92.8	20/03/2019	25
Cemetery Road	100	01/05/2019	270
252 Silverdale Road	980	21/05/2019	82
Park Road/Racecourse	5000	21/05/2019	262
Silverdale Road/ Church Lane	50	22/05/2019	325

3 Monitoring Results

This report covers the monitoring results measured between the 28 February 2019 and 25 June 2019 (118 days). Data collected at a separate site between the 15 January 2019 and 12 February 2019 (28 days) is summarised in Appendix A and is not included in the main report, with the exception of a comparison of the H₂S concentrations with the WHO guidelines in the Chapter 3.2.

3.1 Meteorology

Wind speed and direction measurements were collected at the MMF site during the study between the 28 February 2019 and 25 June 2019 (118 days). 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 MMFs are 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. The MMF was located close to a row of trees, with elevated topography causing wind sheltering to the north (Figure 3.1.1), these factors may have had some influence on the metrological conditions.

Figure 3.1.1: MMF monitoring location at Silverdale (looking to the south west)



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.

The frequency distribution of wind direction at different wind speeds between 28 February 2019 and 25 June 2019 (118 days) is shown in Figure 3.1.2. The plot shows that over the period the dominant wind direction was from the north-west and east. Winds from the north were infrequent.

Figure 3.1.2: Wind Rose (%)

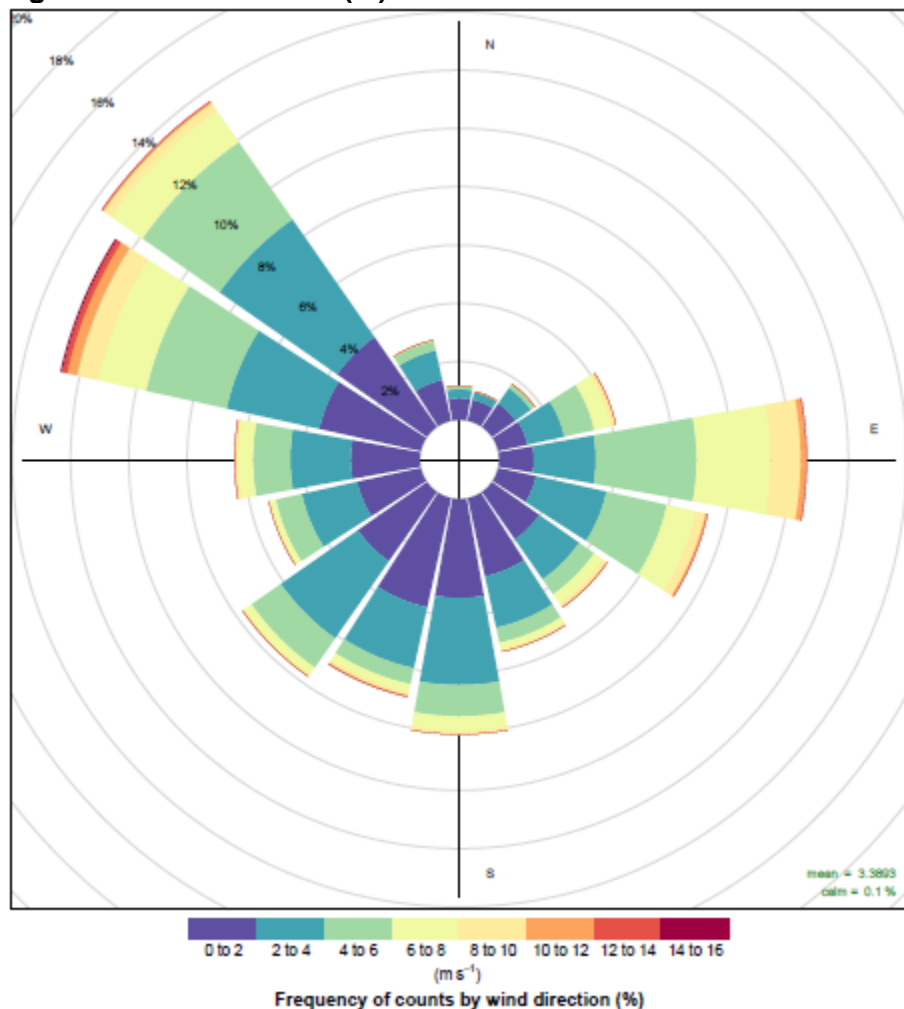


Figure 3.1.3 shows that the most prevalent wind speeds were less than 5m.s^{-1} between $300^\circ - 310^\circ$. The wind speed frequencies for all wind directions are summarised in Table 3.1.1.

Figure 3.1.3: Polar plot of wind speed frequency (from 5-minute values)

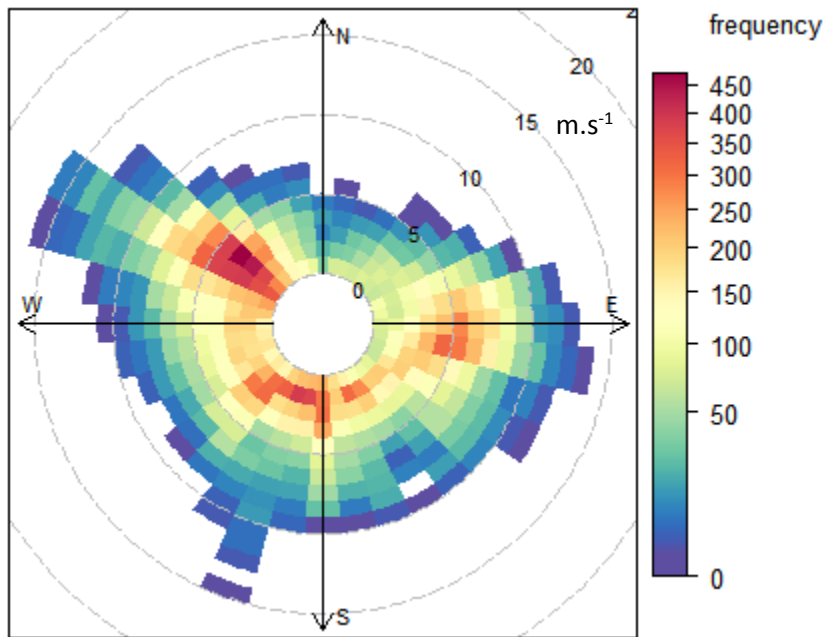


Table 3.1.1 Summary of wind speed frequencies for all wind directions

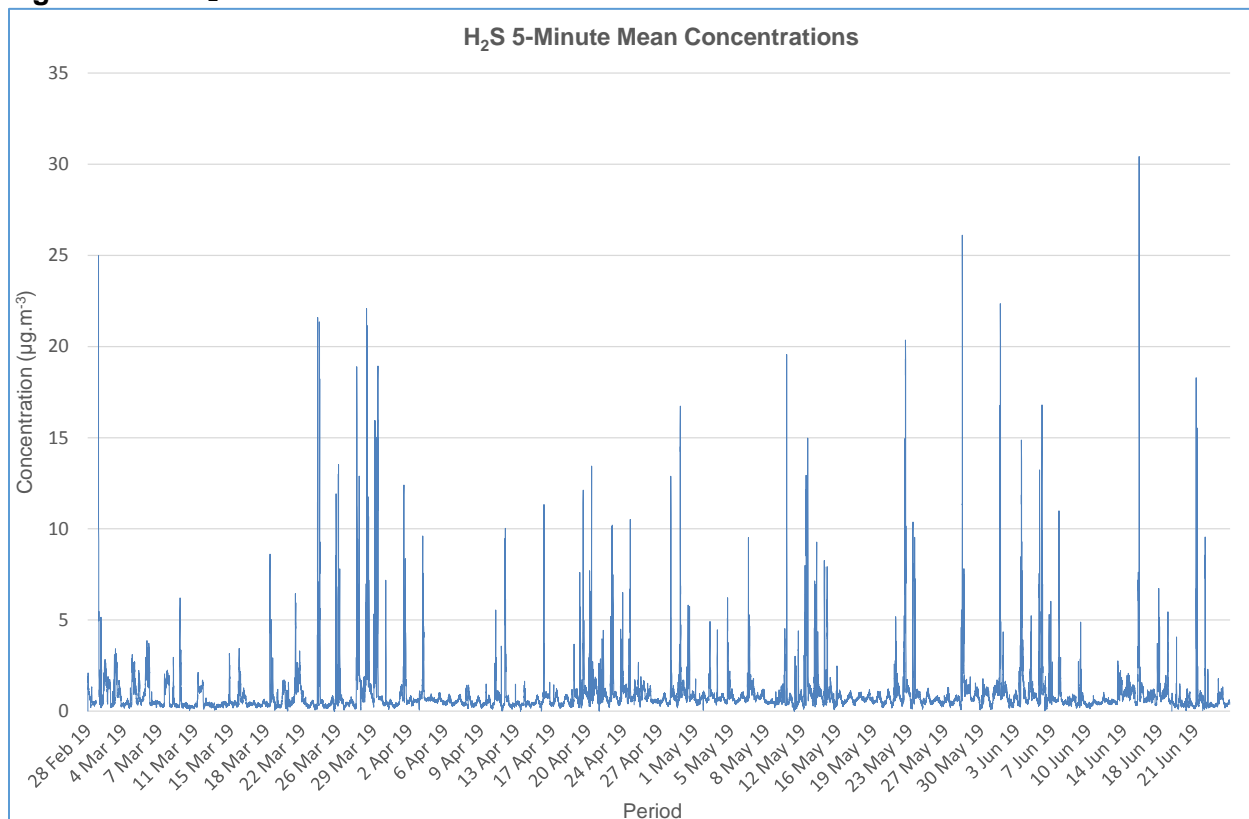
Wind Speed (m.s ⁻¹)	Frequency of wind speed (%)
<0.2	0.7
0.2 - 0.5	3.6
0.5 - 1	8.8
1 - 2	19.3
2 - 3	18.3
3 - 5	25.9
>5	23.4
Total	100

3.2 Hydrogen Sulphide (H₂S)

Between 28 February 2019 and 25 June 2019 (118 days) airborne H₂S concentrations were measured at a height of 2m above ground. Details of the instrumentation and methodology are given in Appendix D. Successful data collection for the monitoring period was 99%.

A time series plot of 5-minute mean concentrations of H₂S over the monitoring period is shown in Figure 3.2.1. The mean concentration over the monitoring period was 1.0µg.m⁻³. The maximum 5-minute mean concentration was 30.4µg.m⁻³.

Figure 3.2.1: H₂S 5-minute mean concentrations

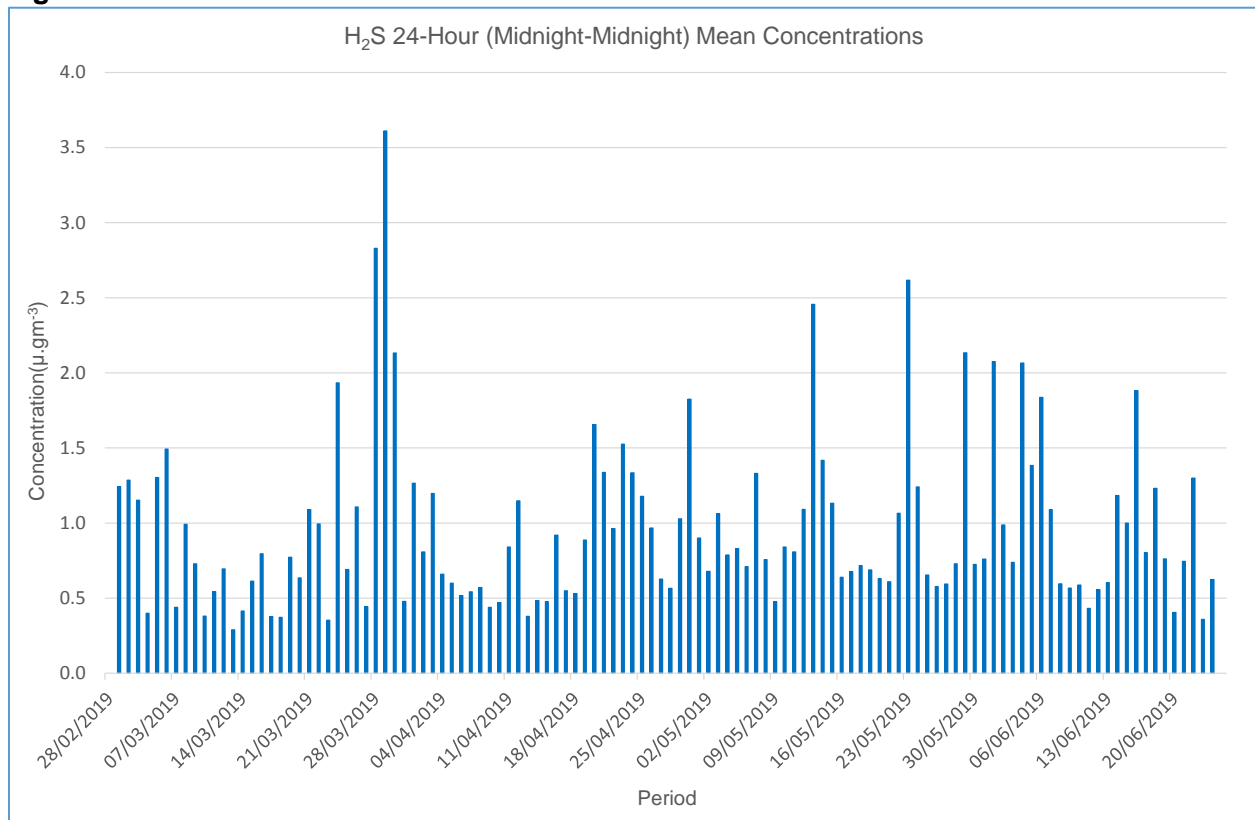


3.2.1 Comparison with WHO Guidelines

The World Health Organisation (WHO) guidelines for Europe (2000) have set a 24-hour guidance limit of 150µg.m⁻³ for H₂S in the context of human health.

A time series plot of 24-hour mean H₂S concentrations at the monitoring site is shown in Figure 3.2.2. The highest recorded 24-hour mean was 3.6µg.m⁻³, which is considerably lower than the 150µg.m⁻³ limit set as a guideline by WHO, in the context of human health.

Figure 3.2.2: H₂S 24-hour mean concentrations



The WHO guidelines have also set a 30-minute mean H₂S guide level of 7µg.m⁻³ above which substantial complaints about odour annoyance can be expected.

A time series plot of 30-minute mean H₂S concentrations measured over the period is shown in Figure 3.2.3.

The highest recorded 30-minute mean during the monitoring period was 19.1µg.m⁻³. There were 67 occasions during the monitoring period, on 26 separate days, where a 30-minute mean value exceeded the WHO guide level of 7µg.m⁻³.

Table 3.2.1 looks at the monthly 30-minute mean H₂S concentrations above 7µg.m⁻³ and shows that the percentage of H₂S concentrations above the WHO guideline were similar for each month, ranging from 0.6 – 1.8%.

Substantial complaints due to odour nuisance from H₂S could be expected for 1% of the total monitoring period, based on the WHO guideline alone, however this does not take in to account the subjective nature of odour complaints.

Figure 3.2.3: H₂S 30-minute mean concentrations

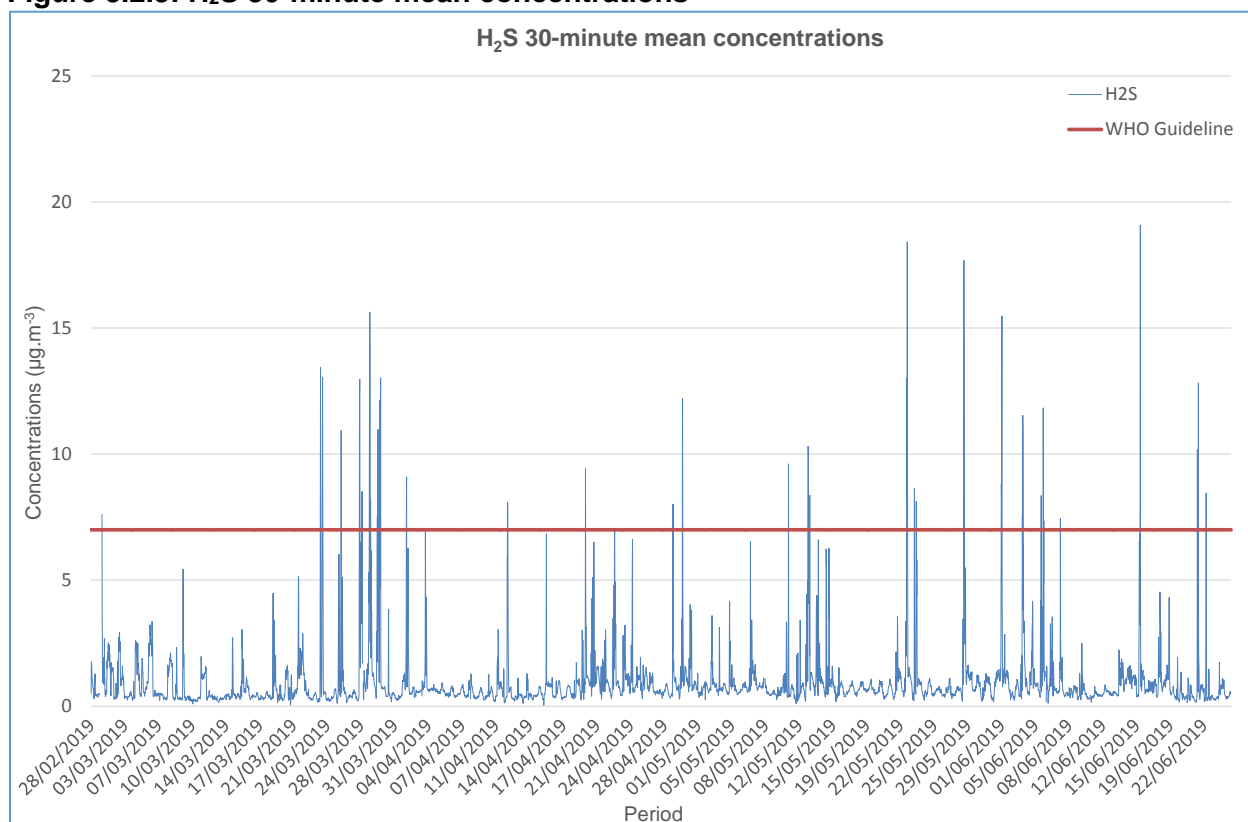


Table 3.2.1 Monthly 30-minute H₂S data

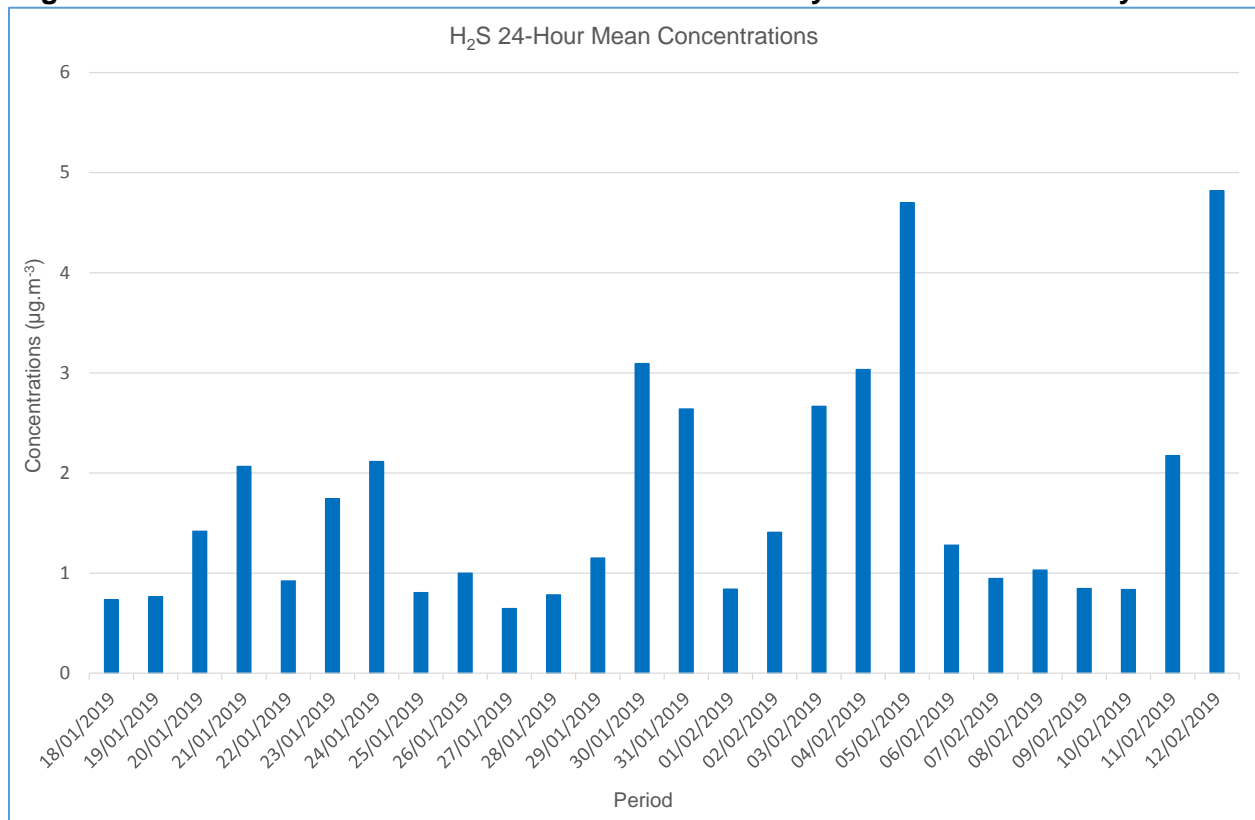
Month	Percentage of Data above WHO odour threshold 7µg.m ⁻³ (%)	Maximum 30-minute mean concentration (µg.m ⁻³)	Mean (µg.m ⁻³)
Mar	1.8	15.6	1.0
Apr	0.6	12.2	0.9
May	1.0	18.4	1.0
Jun	1.5	19.1	1.0

3.2.2 Comparison with WHO Guidelines (15 January 2019 and 12 February 2019)

The MMF was originally sited at a different monitoring location between the 15 January 2019 and 12 February 2019 (28 days), this short data set is summarised in Appendix A.

A time series plot of 24-hour mean H₂S concentrations between the 15 January 2019 and 12 February 2019 (28 days) at the original monitoring location is shown in Figure 3.2.4. The highest recorded 24-hour mean was 4.8µg.m⁻³, which is considerably lower than the 150µg.m⁻³ limit set as a guideline by WHO, in the context of human health.

Figure 3.2.4: H₂S 24-hour mean concentrations 15 January 2019 and 12 February 2019



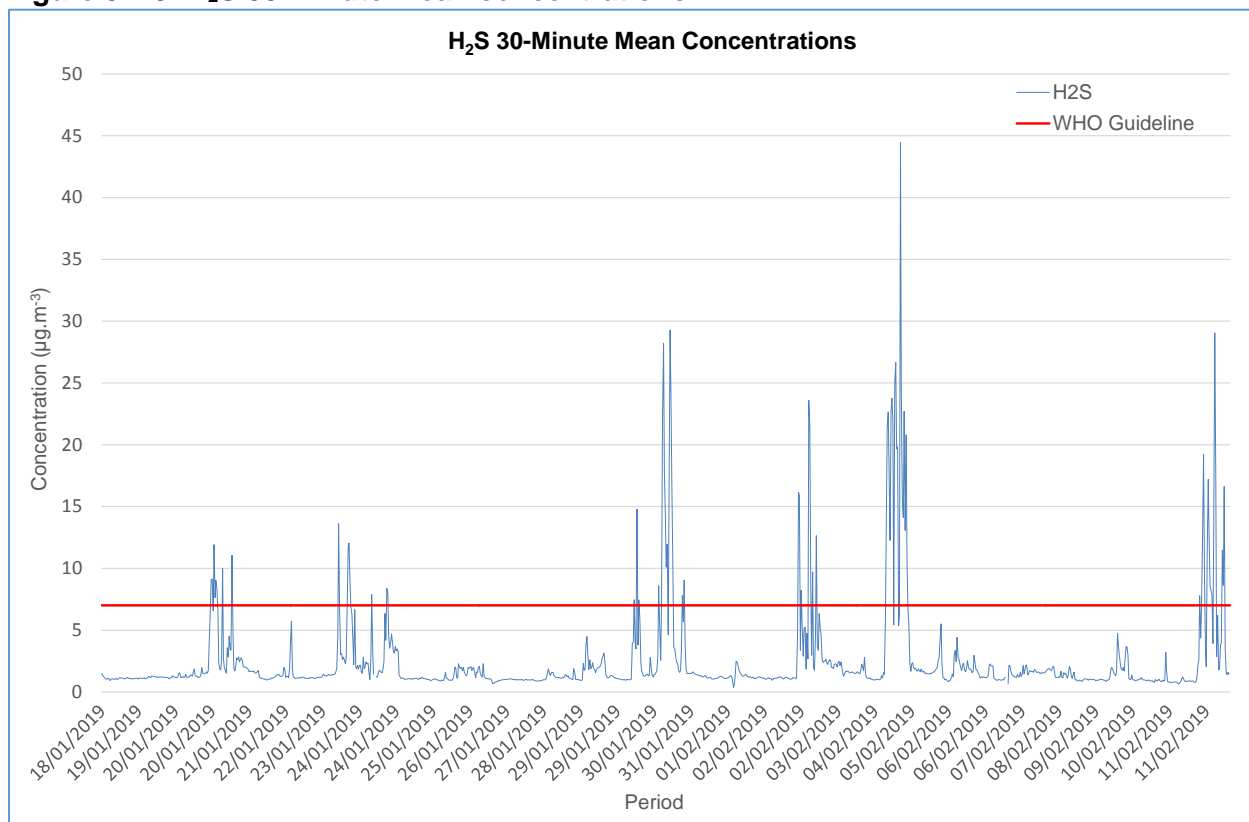
The WHO guidelines have set a 30-minute mean H₂S guide level of 7µg.m⁻³ above which substantial complaints about odour annoyance can be expected.

A time series plot of 30-minute mean H₂S concentrations measured between 15 January 2019 and 12 February 2019 (28 days) is shown in Figure 3.2.5.

The highest recorded 30-minute mean between 15 January 2019 and 12 February 2019 (28 days) was 44.5µg.m⁻³. There were 76 occasions during this short monitoring period, on 12 separate days where the 30-minute mean value exceeded the WHO guide value of 7µg.m⁻³.

Substantial complaints due to odour nuisance from H₂S could be expected for ~6% of the first monitoring period, based on the WHO guideline. The monitoring period between the 15 January 2019 and 12 February 2019 (28 days) saw higher H₂S concentrations than those seen for the longer monitoring period at the second monitoring location between 28 February 2019 and 25 June 2019 (118 days).

Figure 3.2.5: H₂S 30-minute mean concentrations



3.2.3 Directional Analysis

A polar frequency plot showing the mean H₂S concentrations for varying wind speeds and wind directions over the monitoring period is shown in figure 3.2.6. The plot shows that for wind speeds up to 1m.s⁻¹, higher H₂S concentrations can be seen for all wind directions. This suggests that at lower wind speeds, where there is less mixing of air, that there is a build-up of H₂S concentration and the true direction of the H₂S source is unclear. Higher mean H₂S concentrations are seen for wind directions 120° – 210° for all wind speeds, suggesting a relatively continuous H₂S source from the direction of Walleys Quarry landfill site.

Radial plots of mean H₂S concentrations (µg.m⁻³) against wind direction are shown in Figure 3.2.7, the data has been plotted for wind speeds <1m.s⁻¹ and >1m.s⁻¹.

Figure 3.2.6: H₂S polar frequency rose

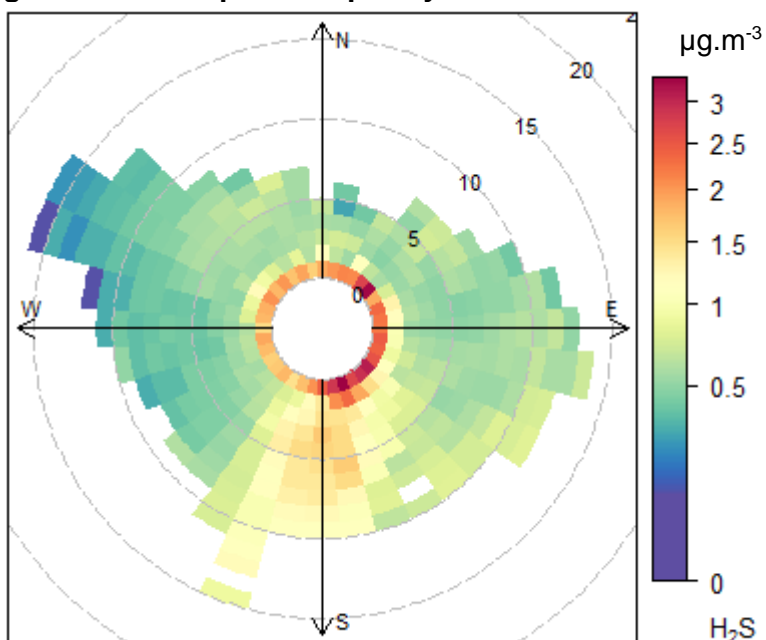
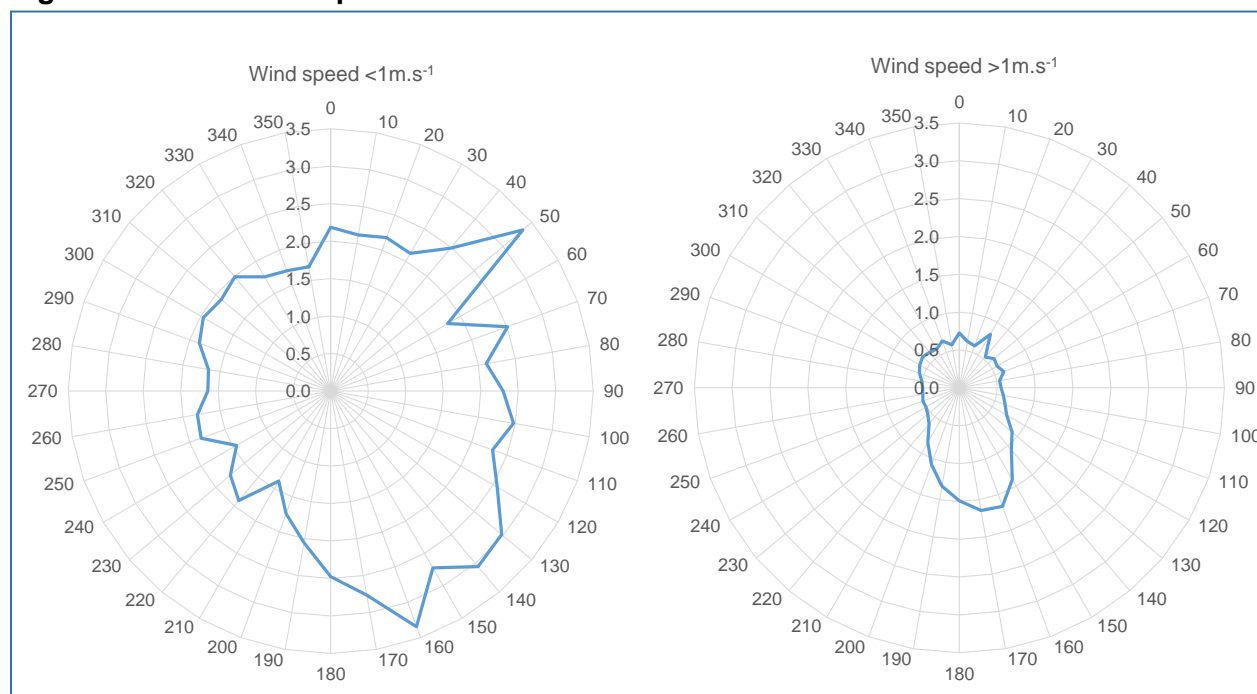


Figure 3.2.7: H₂S mean pollution rose

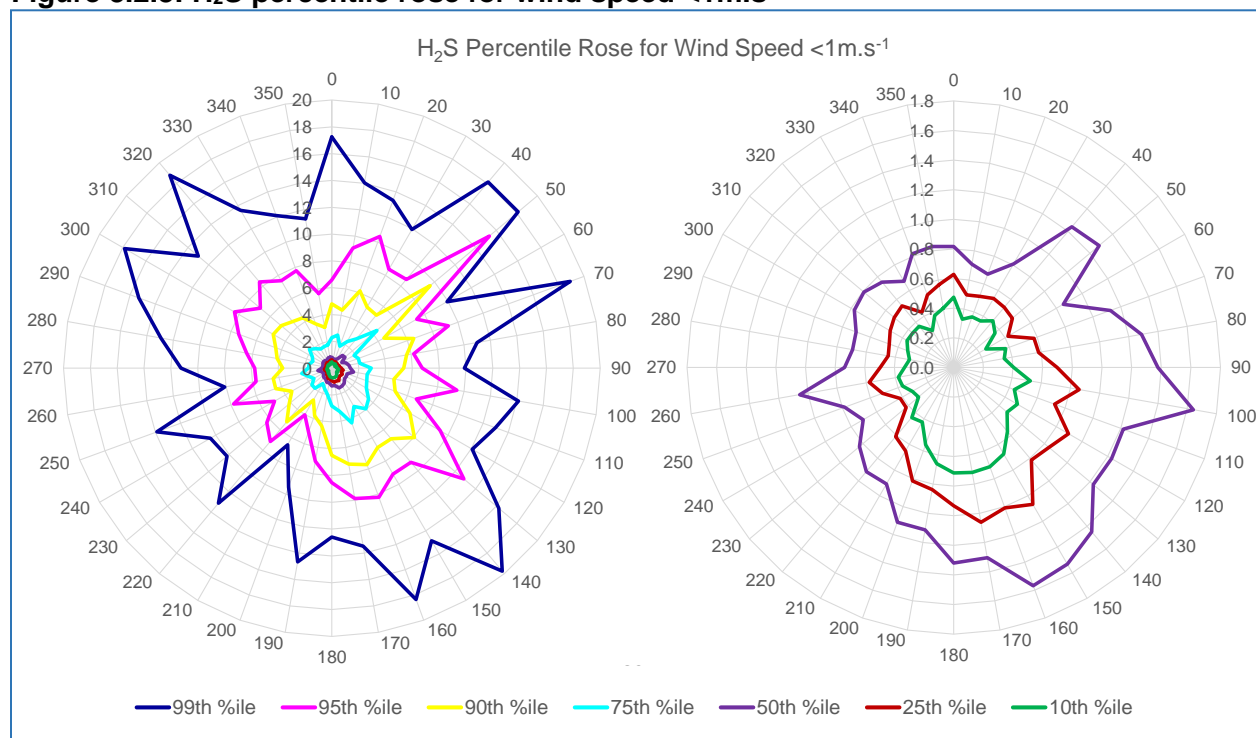


The plot of mean H₂S concentrations for wind speeds <1m.s⁻¹ shows that the highest concentrations came from the wind sector 50°, from the direction of a Silverdale sewage pumping station discharge point, and 120° - 150°, from the direction of Walleys Quarry landfill site, with mean concentrations >2.5µg.m⁻³.

The plot of mean H₂S concentrations for wind speeds >1m.s⁻¹ shows that the highest concentrations came from the wind sector 140° – 200° from the direction of Walleys Quarry landfill site, with mean concentrations >1µg.m⁻³.

An array of plots showing the contribution to H₂S loading (µg.m⁻³) at the monitoring site for different percentiles, where wind speeds were <1m.s⁻¹ and >1m.s⁻¹ are shown in Figure 3.2.8 and Figure 3.2.9 respectively. An explanation of percentile analysis is given in Appendix I.

Figure 3.2.8: H₂S percentile rose for wind speed <1m.s⁻¹



Both Figure 3.2.8 and 3.2.9 show the contribution from the source(s) between 120° - 200° (the direction of the landfill site) affect all the percentiles, which indicates that the source(s) is relatively continuous and commonly affects H₂S concentrations at the monitoring site. There are also elevations in the 99th percentile for wind directions 300°, 360°, 30°, 50° and 70°.

Figure 3.2.10 shows the variation in H₂S concentrations with pressure. The plots show that the highest H₂S concentrations were seen under conditions of higher pressure. Elevated H₂S concentrations were seen under low and high pressure between 150° – 190° from the direction of Walleys Quarry landfill site, further confirming a continuous H₂S source from this wind direction.

Figure 3.2.9: H₂S percentile rose for wind speed >1m.s⁻¹

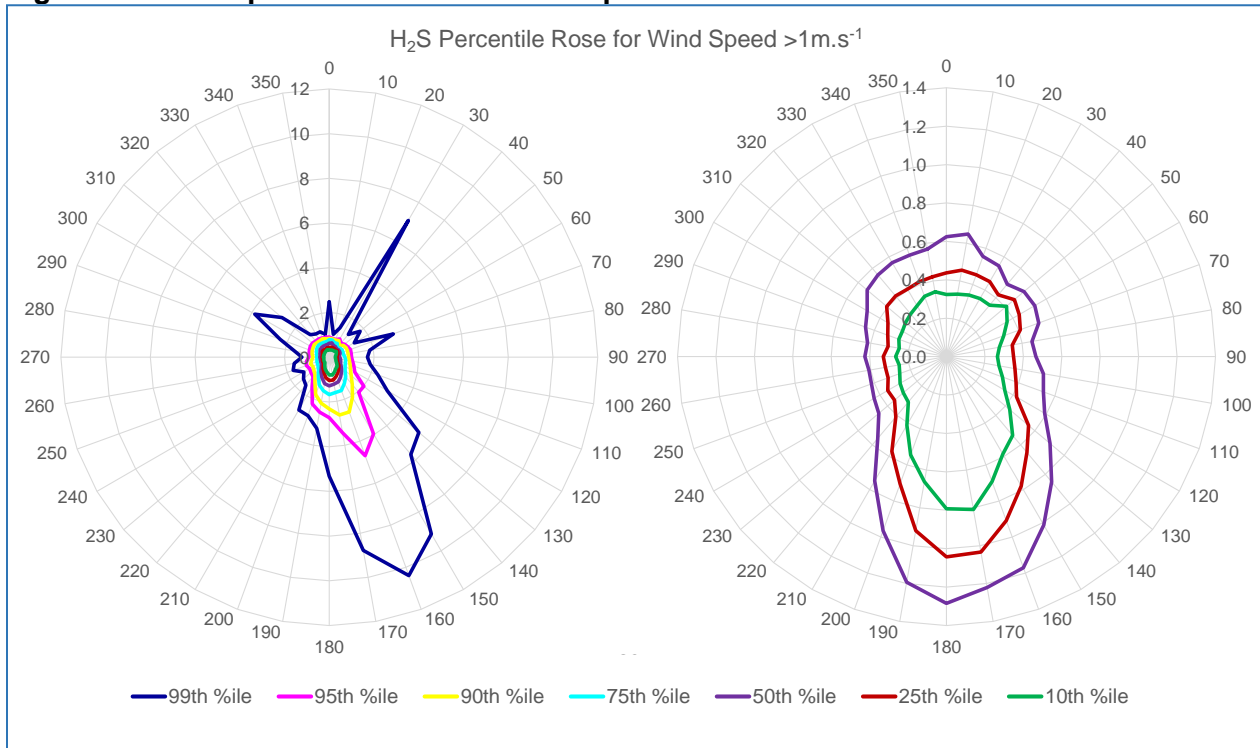


Figure 3.2.10: H₂S polar plot against pressure

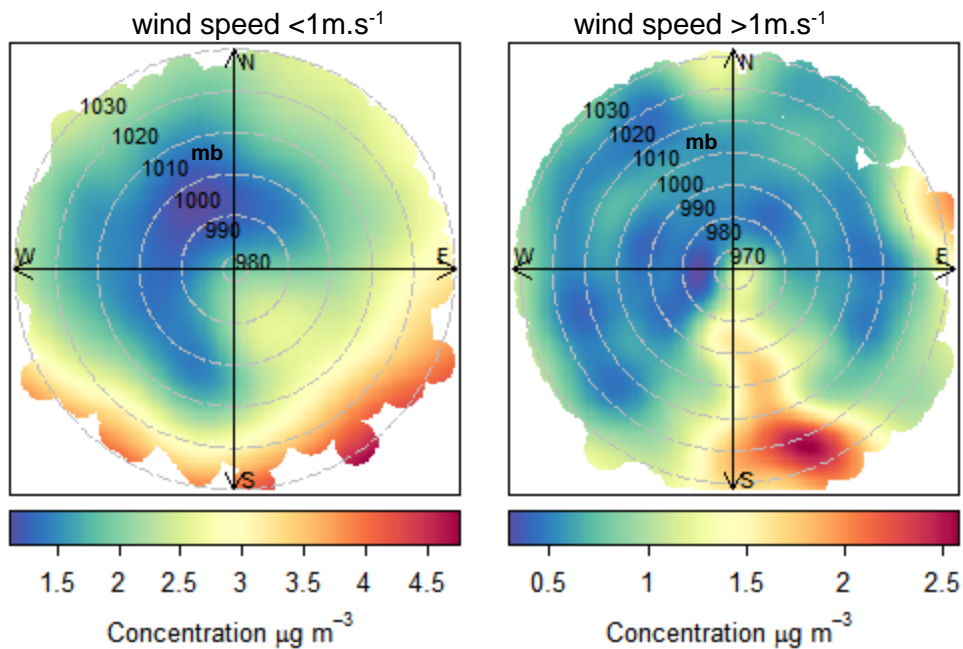


Figure 3.2.11 shows the variation in H₂S concentrations with temperature. The plots show that the highest H₂S concentrations were seen at lower temperatures.

Figure 3.2.11: H₂S polar plot against temperature

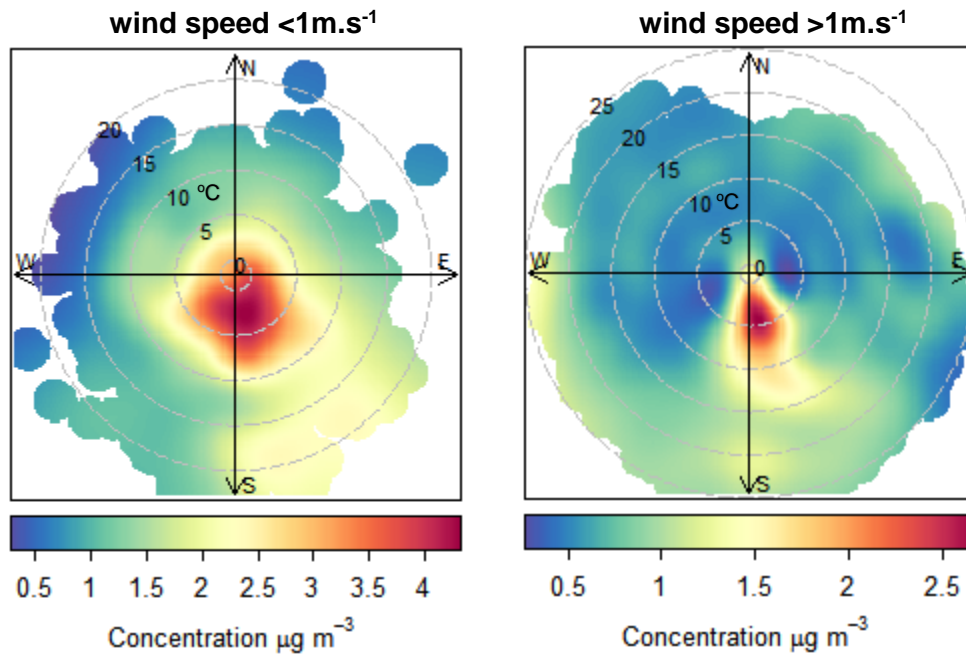
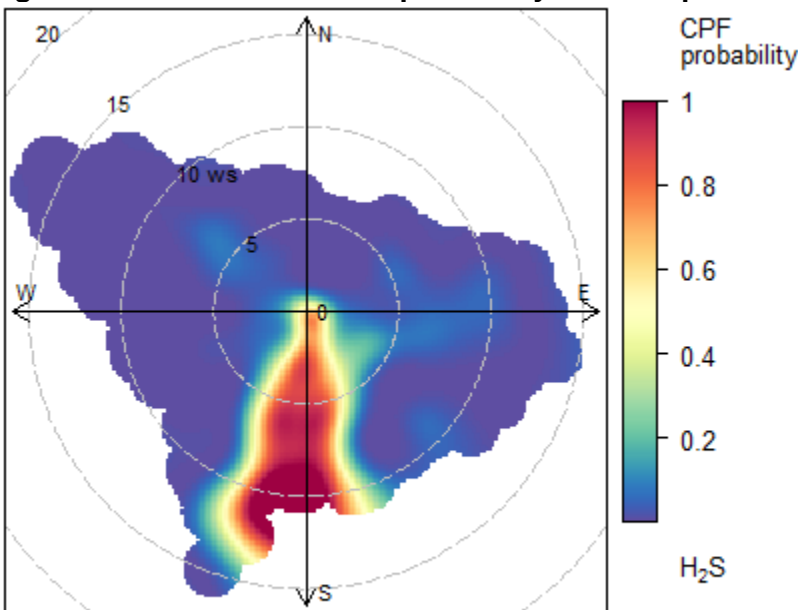


Figure 3.2.12 shows a conditional probability function plot for H₂S concentrations >75th percentile. The plot calculates the probability that H₂S concentrations would be greater than the 75th percentile value ($0.9\mu\text{g.m}^{-3}$) for a particular wind speed and wind direction. Further information about this method can be found in Appendix J.

Figure 3.2.12:H₂S conditional probability function plot for concentrations >75th percentile



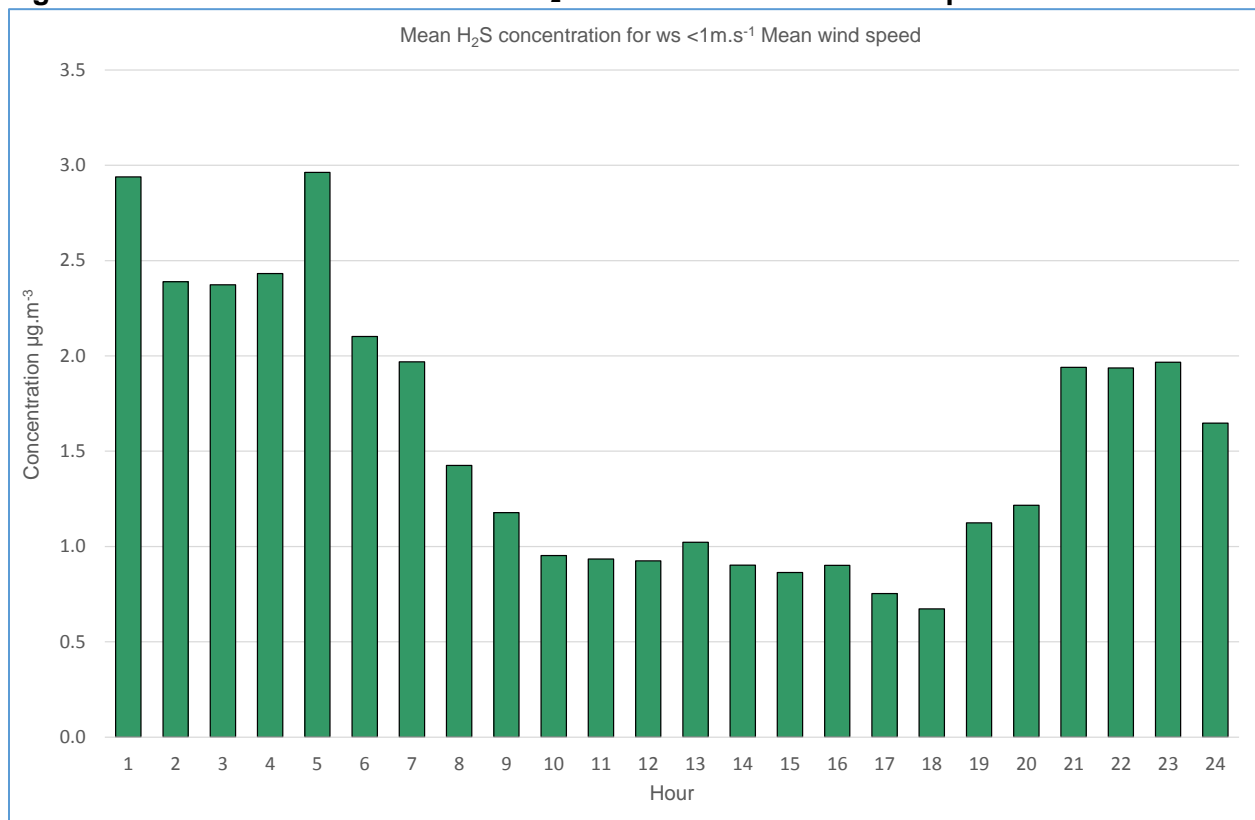
CPF at the 75th Percentile ($=0.9\mu\text{g.m}^{-3}$)

Figure 3.2.12 shows that high concentrations (greater than the 75th percentile of all observations) are likely to occur between 160° – 210° from the direction of Walleys Quarry landfill site, with very low conditional probabilities of these concentrations being experienced for other wind directions.

3.2.3 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. Figure 3.2.13 shows diurnal variation of mean H₂S concentrations for data where wind speeds were <1m.s⁻¹.

Figure 3.2.13: Diurnal trends in mean H₂S concentrations for wind speeds <1m.s⁻¹

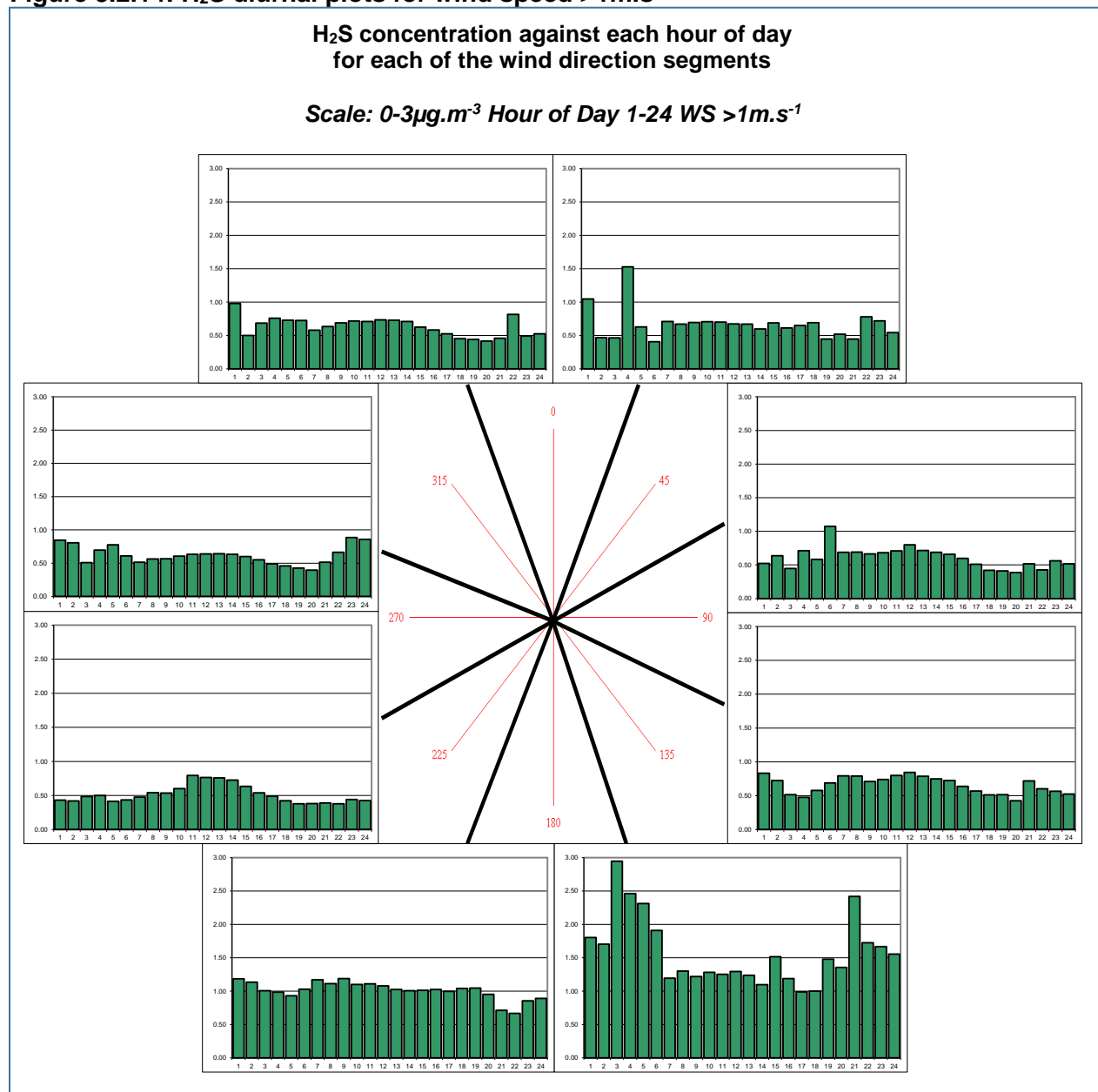


As well as seeing elevated H₂S concentrations for all wind directions at low wind speeds (Figure 3.2.6) Figure 3.2.13 shows us that there is a diurnal profile with higher H₂S concentrations seen overnight.

Figure 3.2.14 shows diurnal variation of mean H₂S concentrations for each 45° wind direction sector at the MMF site for data where wind speeds were >1m.s⁻¹.

At wind speeds >1m.s⁻¹, the build-up of H₂S overnight is not apparent, with the exception of wind sector 180° – 135° from the direction of Walleys Quarry landfill.

Figure 3.2.14: H₂S diurnal plots for wind speed >1m.s⁻¹



A diurnal Openair plot for H₂S, for all wind speeds is shown in Figure 3.2.15. The plot shows that the highest concentrations of H₂S were seen overnight for wind direction 120° – 200° from the direction of Walleys Quarry landfill site.

Figure 3.2.16 shows the variation in H₂S concentrations for each day of the week for all wind directions and wind speeds. The plot shows the highest mean H₂S concentrations seen overnight for wind direction 120° – 200° are shown for Saturday, Sunday, Monday and Wednesday.

Figure 3.2.15 H₂S diurnal polar plot

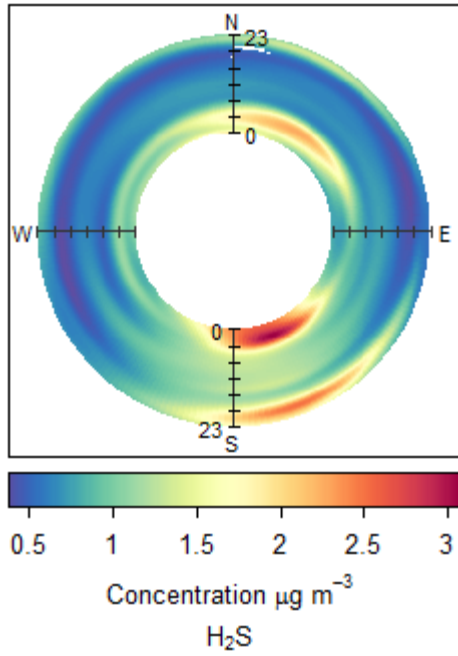
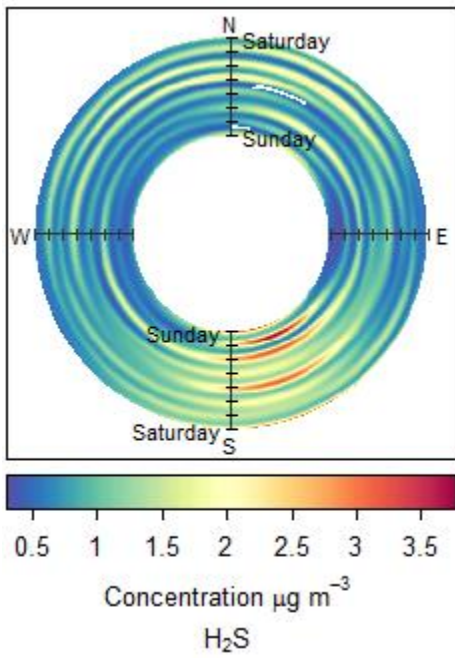


Figure 3.2.16 H₂S weekday polar plot



3.2.4 Conclusion

Comparison of the H₂S data with the WHO guidelines for human health of 150µg.m⁻³, as 24-hour mean concentrations, indicated that the air quality at the monitoring site was within these guidelines.

Comparison of the H₂S data with the WHO guidelines for odour annoyance of 7µg.m⁻³, as 30-minute mean concentrations, indicated that the air quality at the monitoring site exceeded this guideline for around 1% of the monitoring period. The mean H₂S concentration over the monitoring period was 1.0µg.m⁻³.

The MMF was originally sited at a different monitoring location between the 15 January 2019 and 12 February 2019 (28 days) Comparison of the H₂S data with the WHO guidelines for odour annoyance of 7µg.m⁻³, as 30-minute mean concentrations, indicated that over this shorter monitoring period, the air quality at the monitoring site exceeded this guideline for around ~6% of the time, showing that the highest H₂S concentrations were seen in January and February.

Consideration of meteorological conditions suggest that at low wind speeds <1m.s⁻¹ there is poor dispersion and a build-up of H₂S concentrations seen for all wind directions, with the source of H₂S being less clear.

Higher mean H₂S concentrations are seen for wind directions 120° – 210° for all wind speeds, suggesting a relatively continuous H₂S source from the direction of Walleys Quarry landfill site.

Directional analysis indicated that the highest mean H₂S concentrations were measured from wind sectors between 120° – 200° from the direction of Walleys Quarry landfill site. There also appeared to be a source from sector 50° for wind speeds <1m.s⁻¹, from the direction of Silverdale sewage pumping station discharge point.

Percentile rose analysis showed that there was a continuous H₂S source from the direction of Walleys Quarry landfill site and that the source from 50° was an intermittent source seen occasionally at low wind speeds, from the direction of the pumping station.

Consideration of H₂S concentrations against temperature and pressure showed that the highest H₂S concentrations were seen at low temperatures and high wind speeds. Due to the continuous nature of the source from the direction of Walleys Quarry landfill site the H₂S concentrations from these wind directions were higher for a wider range of temperatures and pressures than for other wind directions.

The probability of measuring higher H₂S concentrations (greater than the 75th percentile of all observations) was much more probable from wind directions 160° – 210°, from the direction of the landfill site.

Consideration of the diurnal variation of H₂S concentrations showed that H₂S concentrations were elevated overnight typically at lower wind speeds, this pattern was also apparent for wind speeds >1m.s⁻¹ for wind sector 135° -180° from the direction of Walleys Quarry landfill site.

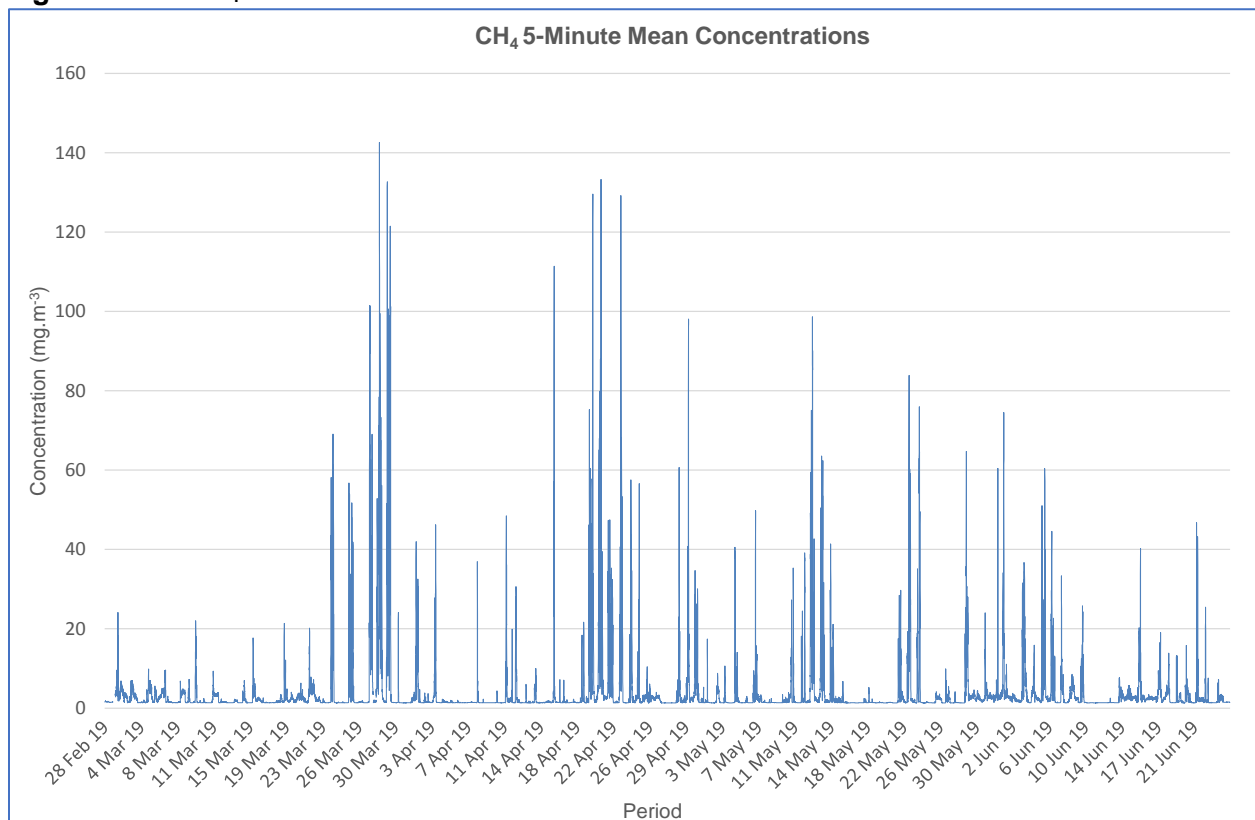
Over the monitoring period the highest mean H₂S concentrations seen overnight for wind direction 120° – 200° were seen for Saturday, Sunday, Monday and Wednesday.

3.3 Methane (CH₄) at the MMF

Between 28 February 2019 and 25 June 2019 (118 days) airborne CH₄ concentrations were measured at a height of 2m above ground. Successful data collection over the monitoring period was 99%. Details of the instrumentation and methodology are given in Appendix E. A time series plot of 5-minute CH₄ concentrations (mg.m⁻³) over the monitoring period is shown in Figure 3.3.1.

The time series plot of 5-minute mean CH₄ concentrations (mg.m⁻³) over the period is shown in Figure 3.3.1.

Figure 3.3.1: CH₄ 5-minute mean concentrations



Methane does not have any associated impacts on human health, with the exception of explosive risk at very high concentrations, its main environmental impact is from its relatively high potential for global warming. The mean concentration over the period was 3.9mg.m⁻³, which is higher than the northern hemisphere background concentration of around 1.21mg.m⁻³, suggesting a localised source.

3.3.1 Directional Analysis

A polar frequency plot showing the mean CH₄ concentrations for varying wind speeds and wind directions over the monitoring period is shown in figure 3.3.2. The plot shows that for wind speeds up to 1m.s⁻¹, higher CH₄ concentrations can be seen for all wind directions. This suggests that at lower wind speeds, where there is less mixing of air, that there is a build-up of CH₄ concentration and the direction of the CH₄ source is unclear. Higher mean CH₄ concentrations are seen for

wind directions $140^{\circ} - 220^{\circ}$ for all wind speeds, suggesting a relatively continuous CH_4 source from the direction of Walleys Quarry landfill site.

Radial plots of mean CH_4 concentrations (mg.m^{-3}) against wind direction are shown in Figure 3.3.3, the data has been plotted for wind speeds $<1\text{m.s}^{-1}$ and $>1\text{m.s}^{-1}$.

Figure 3.3.2: CH_4 polar frequency plot

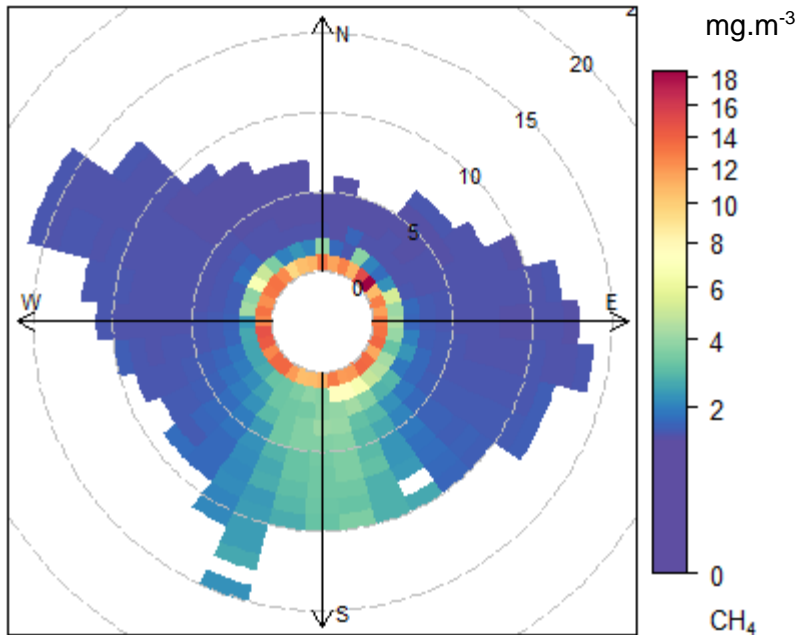
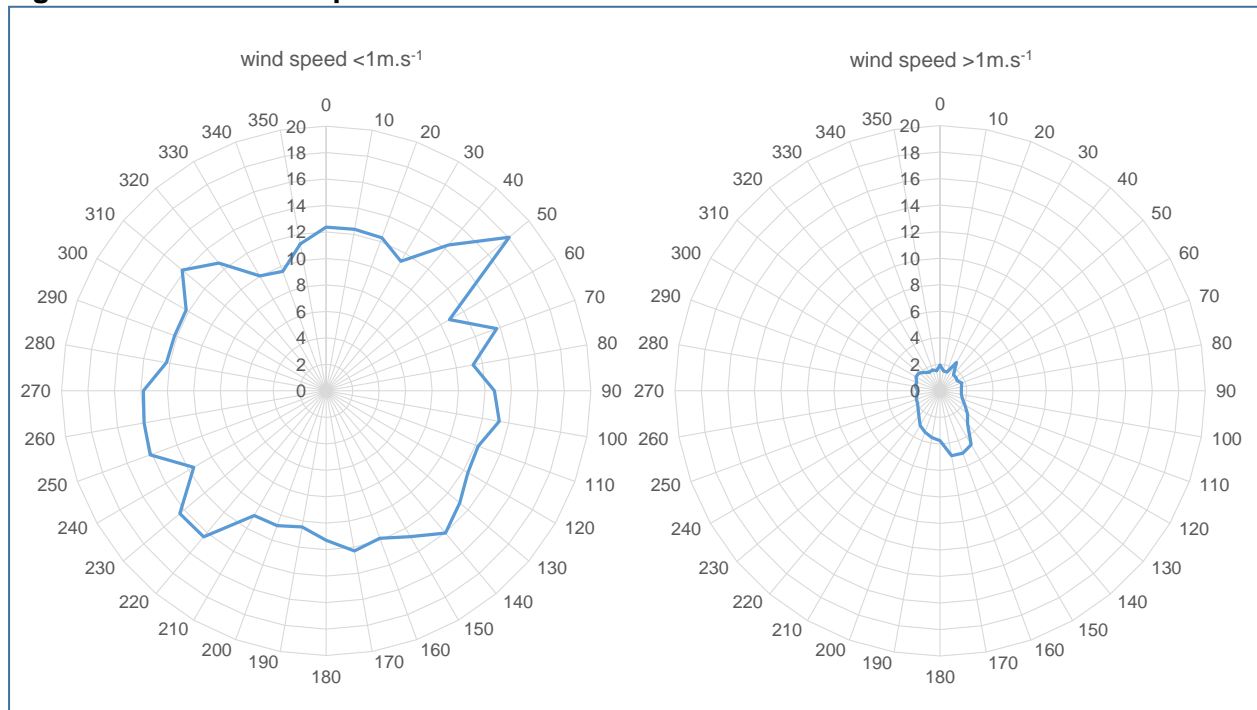


Figure 3.3.3: CH_4 mean pollution rose



The plot of mean CH₄ concentrations for wind speeds <1m.s⁻¹ shows that the concentrations were similar for all wind directions, this could be linked to poor dispersion at these low wind speeds. The highest concentrations came from the wind sector 50°, from the direction of Silverdale sewage pumping station discharge point, with mean concentrations >16mg.m⁻³. This source was also apparent in the H₂S data.

The plot of mean CH₄ concentrations for wind speeds >1m.s⁻¹ shows that the highest concentrations came from the wind sector 30° and 120° – 230° from the direction of Walleys Quarry landfill site, with mean concentrations >2mg.m⁻³.

An array of plots showing the contribution to CH₄ loading (mg.m⁻³) at the monitoring site for different percentiles, where wind speeds were <1m.s⁻¹ is shown in Figures 3.3.4 and for wind speeds >1m.s⁻¹ in Figure 3.3.5.

Figure 3.3.4: CH₄ percentile rose for wind speeds <1m.s⁻¹

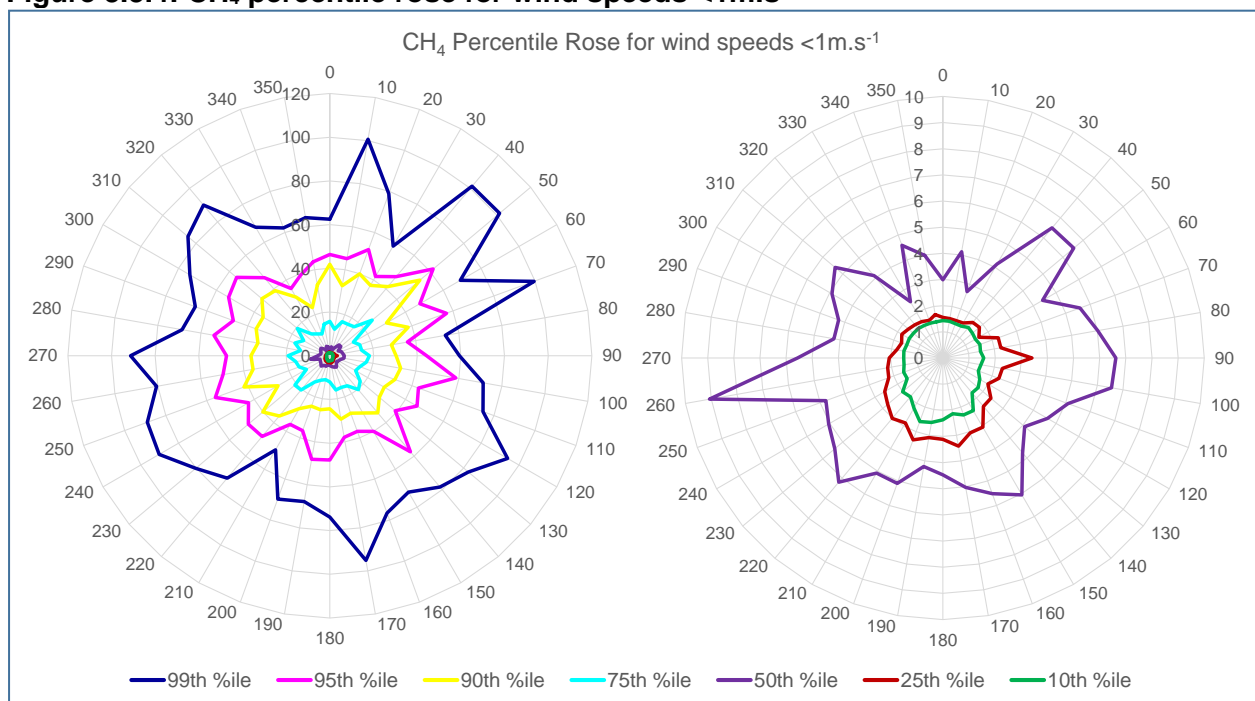


Figure 3.3.4 shows that for CH₄ data measured at low wind speeds <1m.s⁻¹ the contribution from the source(s) at 50° only affect the higher percentiles, which indicates that the source(s) is intermittent.

Figure 3.3.5 shows that for CH₄ data measured at wind speeds >1m.s⁻¹ the contribution from the source(s) between 120° - 200° (the direction of the landfill site) affect all the percentiles, which indicates that the source(s) is relatively continuous and commonly affects CH₄ concentrations at the monitoring site. There are also elevations in the 99th percentile for wind directions 280° – 310°, 360°, 30° and 70°, which were also seen in the H₂S data. The higher 5-minute concentrations that contributed to these spikes occurred at wind speeds <2m.s⁻¹

Figure 3.3.5: CH₄ percentile rose for wind speeds > 1m.s⁻¹

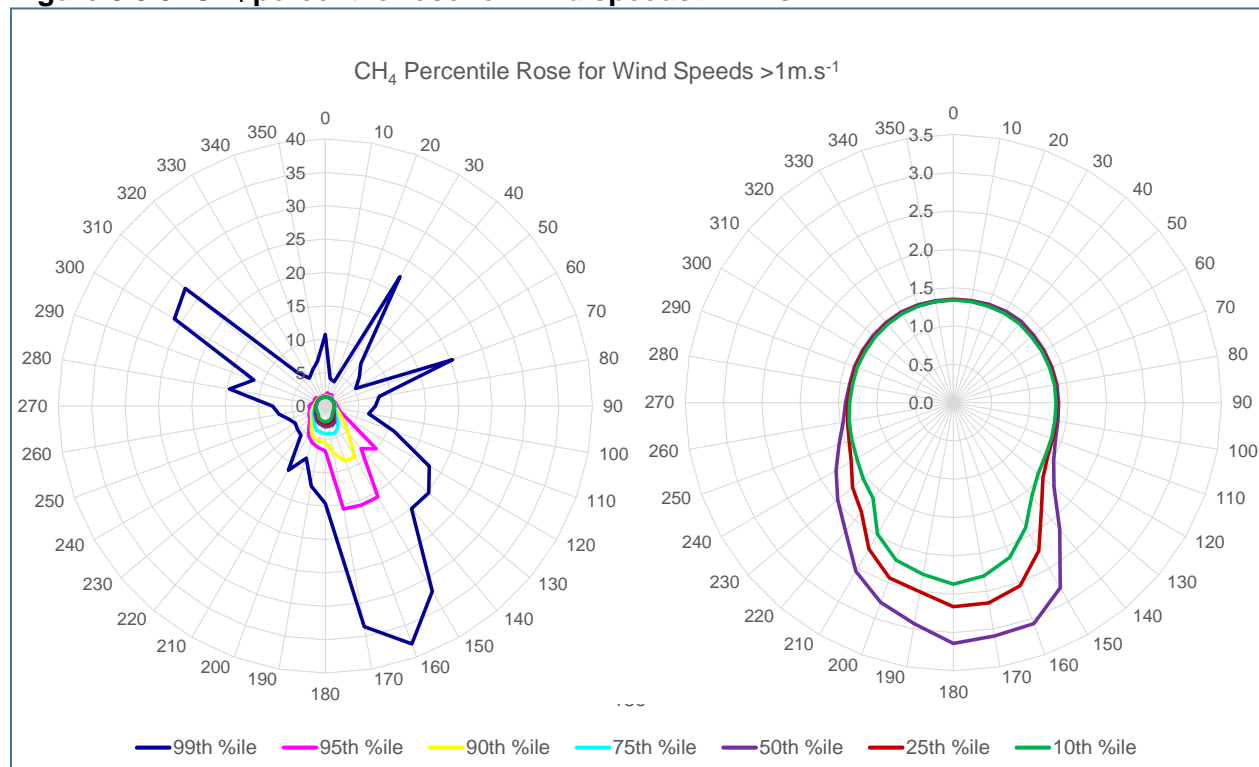


Figure 3.3.6 shows the variation in CH₄ concentrations with pressure. The plots show that the highest CH₄ concentrations were seen under conditions of higher pressure. Elevated CH₄ concentrations were seen under low and high pressure between 140° – 190° from the direction of Walleys Quarry landfill site, further confirming a continuous CH₄ source from this wind direction.

Figure 3.3.6: CH₄ polar plot against pressure

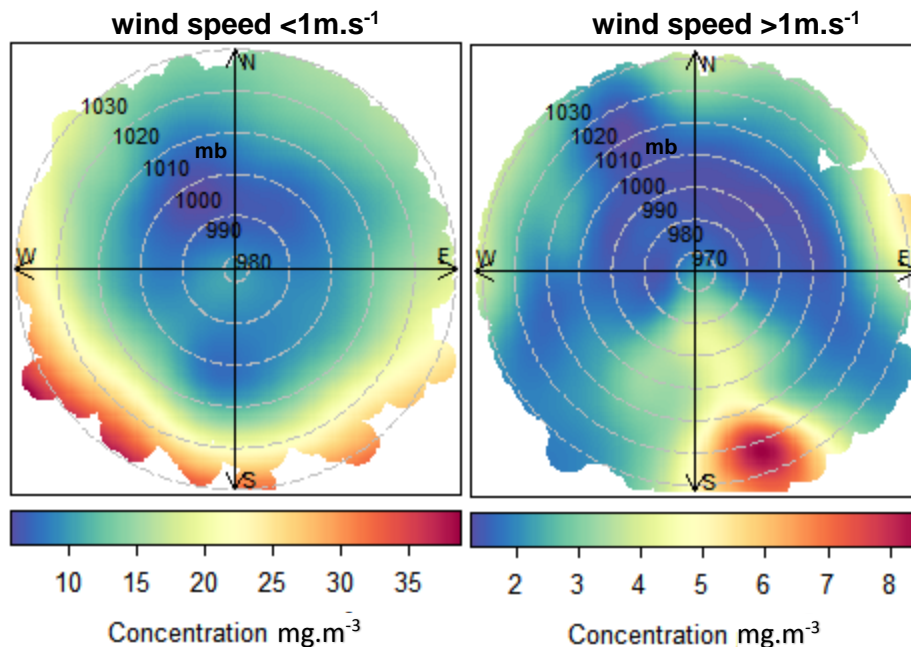


Figure 3.3.7 shows the variation in CH₄ concentrations with temperature. The plots show that the highest CH₄ concentrations were seen at lower temperatures.

Figure 3.3.7: CH₄ polar plot against temperature

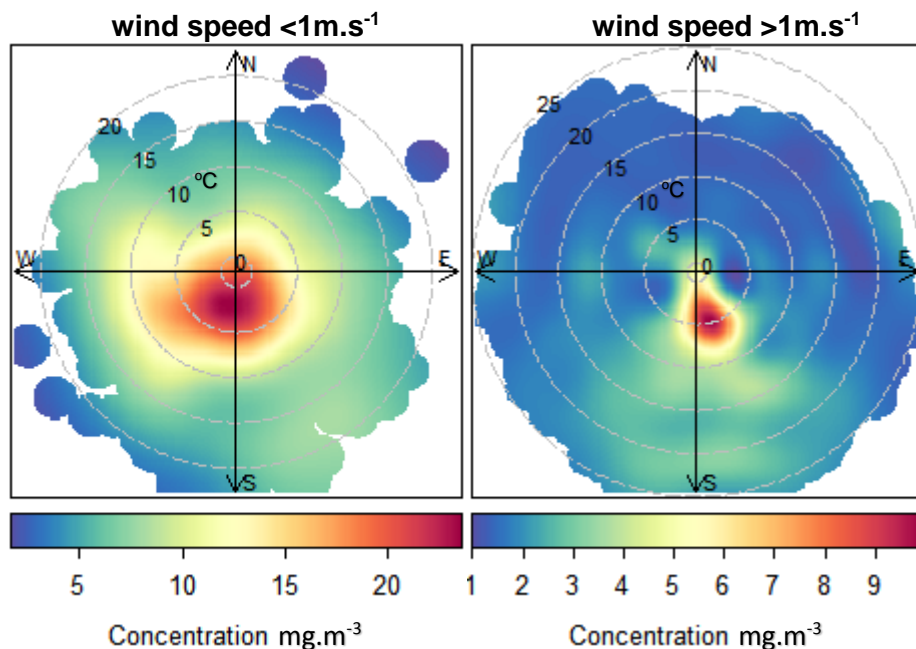
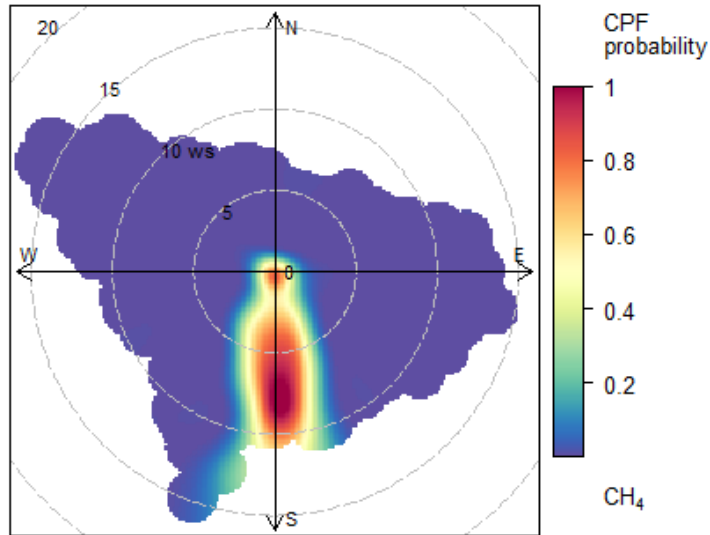


Figure 3.3.8 shows a conditional probability function plot for CH₄ concentrations >75th percentile. The plot calculates the probability that CH₄ concentrations would be greater than the 75th percentile value (2.7mg.m⁻³) for a particular wind speed and wind direction. Further information about this method can be found in Appendix J.

Figure 3.3.8 shows that high concentrations (greater than the 75th percentile of all observations) are more likely to occur between 160° – 200° from the direction of Walleys Quarry landfill site, with very low probabilities of these concentrations being experienced for other wind directions.

Figure 3.3.8: CH₄ conditional probability function plot for concentrations >75th percentile (2.7 mg.m⁻³)

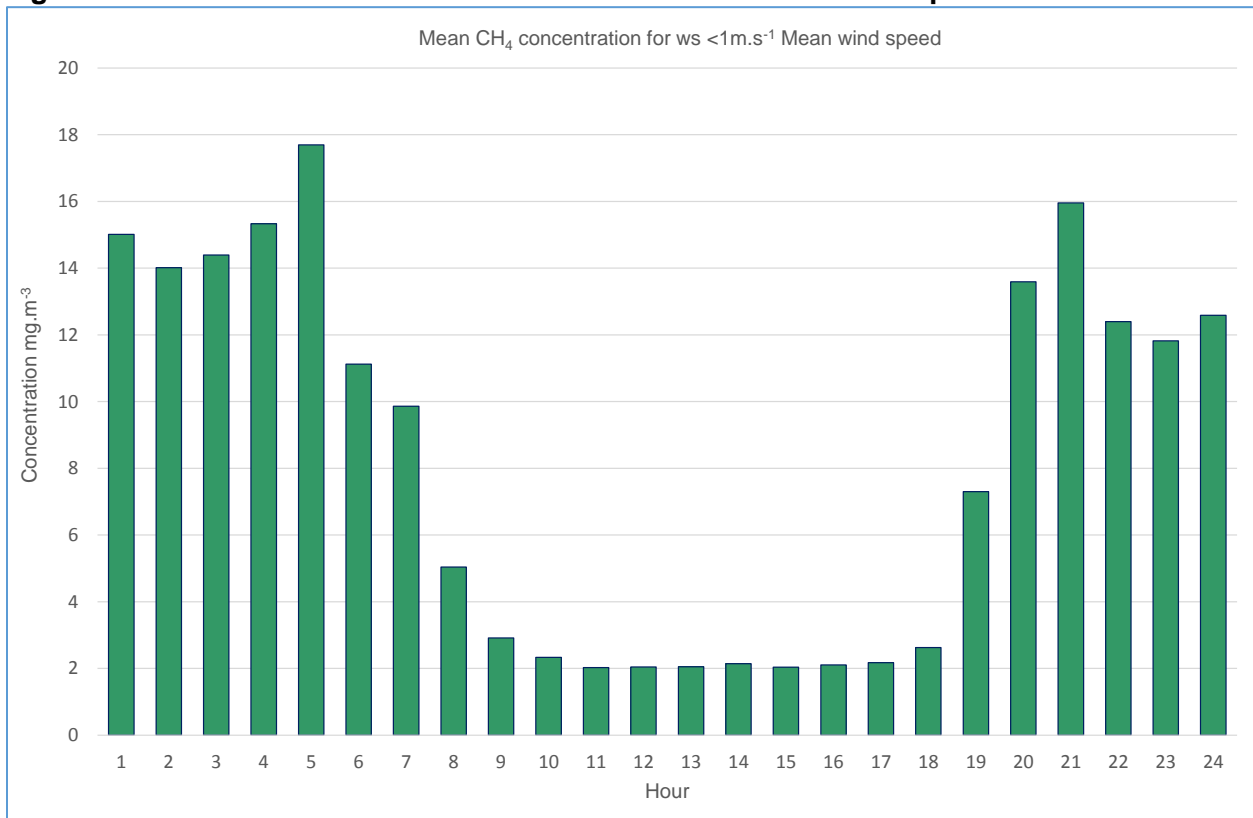


CPF at the 75th Percentile (=2.7mg.m⁻³)

3.3.2 Diurnal and Weekday Analysis

Figure 3.3.9 shows diurnal variation of mean CH₄ concentrations for wind speeds <1m.s⁻¹.

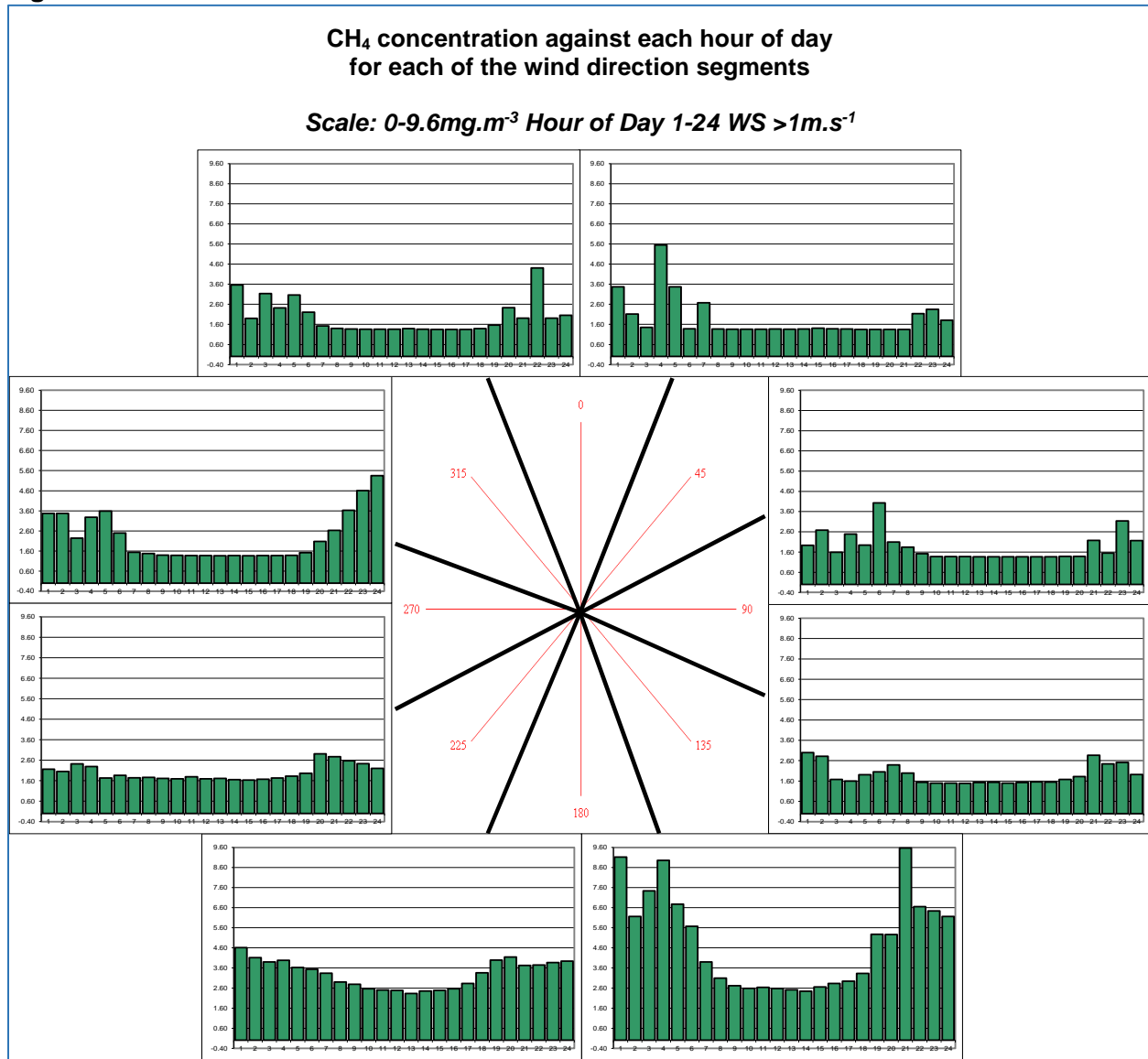
Figure 3.3.9: Diurnal trends in mean CH₄ concentrations for wind speeds <1 m.s-1



As well as seeing elevated CH₄ concentrations for all wind directions at low wind speeds, Figure 3.3.9 shows us that there is a diurnal profile with higher CH₄ concentrations seen overnight.

Figure 3.3.10 shows diurnal variation of mean CH₄ concentrations for each 45° wind direction sector at the MMF site for wind speeds >1m.s⁻¹. The plots show the highest CH₄ concentrations are seen from the direction of Walleyes Quarry landfill site overnight.

Figure 3.3.10: Diurnal trends in mean CH₄ concentrations



A diurnal Openair plot for CH₄, for all wind speeds is shown in Figure 3.2.11. The plot shows that the highest concentrations of CH₄ were seen overnight for wind direction 120° – 200° from the direction of Walleyes Quarry landfill site and 340° – 70°.

Figure 3.3.11 CH₄ diurnal polar plot

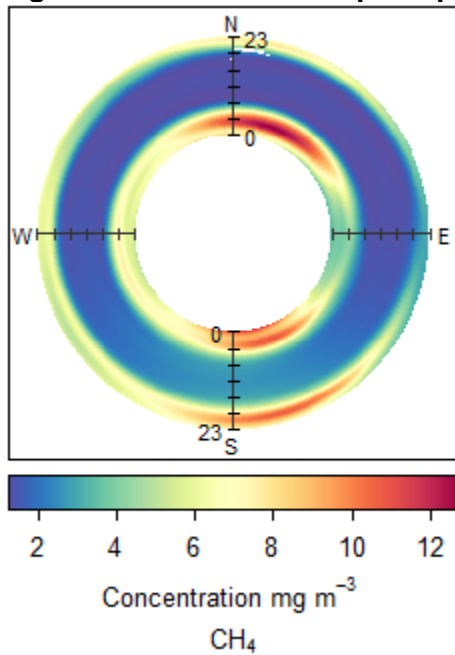
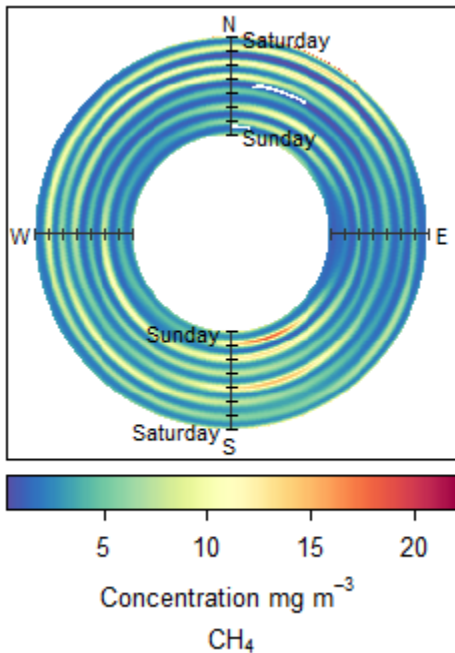


Figure 3.2.12 shows the variation in CH₄ concentrations for each day of the week for all wind directions and wind speeds. The plot shows the highest mean CH₄ concentrations seen overnight for wind direction 120° – 200° are shown for Sunday, Monday and Wednesday.

Figure 3.3.12 CH₄ diurnal polar plot



3.3.3 Conclusion

The mean CH₄ concentration over the period was 3.9mg.m⁻³, which is higher than the northern hemisphere background concentration of around 1.21mg.m⁻³, suggesting a localised source.

Consideration of meteorological conditions suggest that at low wind speeds <1m.s⁻¹ there is poor dispersion and a build-up of CH₄ concentrations seen for all wind directions, with the source of CH₄ being less clear.

Higher mean CH₄ concentrations are seen for wind directions 120° – 210° for all wind speeds, suggesting a relatively continuous CH₄ source from the direction of Walleys Quarry landfill site.

Directional analysis indicated that the highest mean CH₄ concentrations were measured from wind sectors between 30° and 120° – 200° from the direction of Walleys Quarry landfill site. There also appeared to be a source from sector 50° for wind speeds <1m.s⁻¹, from the direction of Silverdale sewage pumping station discharge point.

Percentile rose analysis showed that there was a continuous CH₄ source from the direction of Walleys Quarry landfill site and that the source from 50° was an intermittent source seen on some occasions of low wind speeds.

Consideration of CH₄ concentrations against temperature and pressure showed that the highest CH₄ concentrations were seen at low temperatures and high wind speeds. Due to the continuous nature of the source from the direction of Walleys Quarry landfill site the CH₄ concentrations from these wind directions were higher for a wider range of temperatures and pressures than for other wind directions.

The probability of measuring higher CH₄ concentrations (greater than the 75th percentile of all observations) was much more probable from wind directions 160° – 210°, from the direction of the landfill site.

Consideration of the diurnal variation of CH₄ concentrations showed that CH₄ concentrations were elevated overnight, this pattern was also apparent for wind speeds >1m.s⁻¹ for wind sector 135° - 180° from the direction of Walleys Quarry landfill site.

Over the monitoring period the highest mean CH₄ concentrations seen overnight for wind direction 120° – 200° were seen for, Sunday, Monday and Wednesday.

3.4 Methane (CH₄) at the MMF and standalone sites

In addition to the MMF monitoring, another three methane (CH₄) monitors were set up at three separate monitoring locations, to the north, east and west of the MMF monitoring site. This was to help confirm the sources contributing to elevated CH₄ concentrations and to map the extent of the impact. Monitoring was carried out at these locations for a shorter period between the 15 April 2019 and 25 June 2019 (72 days). The location of the monitors is marked on Figure 2.2.

A summary of the data sets is shown in table 3.4.1 and a time series plot of 5-minute mean concentrations of CH₄ over the monitoring period for the four monitoring locations, including the MMF, is shown in Figure 3.4.1.

Table 3.4.1: CH₄ data summary

	SA6	SA5	SA4	MMF
Mean	1.4	1.8	1.5	4.0
Maximum	13.0	35.2	44.4	133.3
75%ile	1.4	1.4	1.4	2.8
Median	1.3	1.3	1.3	1.6
25%ile	1.3	1.3	1.3	1.4
Minimum	1.3	1.3	1.3	1.3

Table 3.4.1 and Figure 3.4.1 show that the highest CH₄ concentrations were measured at the MMF monitoring site, which was located closest to Walleys Quarry landfill site. The MMF location measured many more CH₄ events above background concentrations than at the standalone sites. The standalone site which saw the higher number of elevated CH₄ concentrations was SA5, which was to the north east of the landfill site, and would have received a higher frequency of wind from the direction of the landfill than the other standalone sites.

3.4.1 Directional Analysis

Figure 3.4.2 shows the CH₄ polar frequency plots for the four monitoring locations, showing CH₄ concentrations for varying wind speeds and wind directions over the monitoring period. The plots have been overlaid on a map to help identify the main CH₄ sources. The plots show varying scales with the highest concentrations seen at the location of the MMF. All concentrations for each plot are representative of a single location over the monitoring period.

Figure 3.4.2 shows that at all monitoring locations the highest CH₄ concentrations are seen at low wind speeds <1m.s⁻¹. The plots also show that for all four monitoring locations, the strongest CH₄ signal comes from the direction of Walleys Quarry landfill site.

Figure 3.4.3 Shows the radial plots of mean CH₄ concentrations (mg.m⁻³) against wind direction, for wind speeds >1m.s⁻¹ at all of the monitoring locations overlying a map. Each of the plots is set to a scale of 5mg.m⁻³. The plots clearly show that the highest concentrations were measured at the MMF monitoring location and that the highest mean concentrations, for all four monitoring locations, came from the direction of Walleyes landfill site.

Figure 3.4.4 shows conditional probability function plots for CH₄ concentrations >75th percentile, for all four monitoring locations overlying a map. These plots calculate the probability that the CH₄ concentrations would be greater than the 75th percentile value for a particular wind speed and wind direction. Further information about this method can be found in Appendix J.

Figure 3.4.1: CH₄ 5-minute mean concentrations

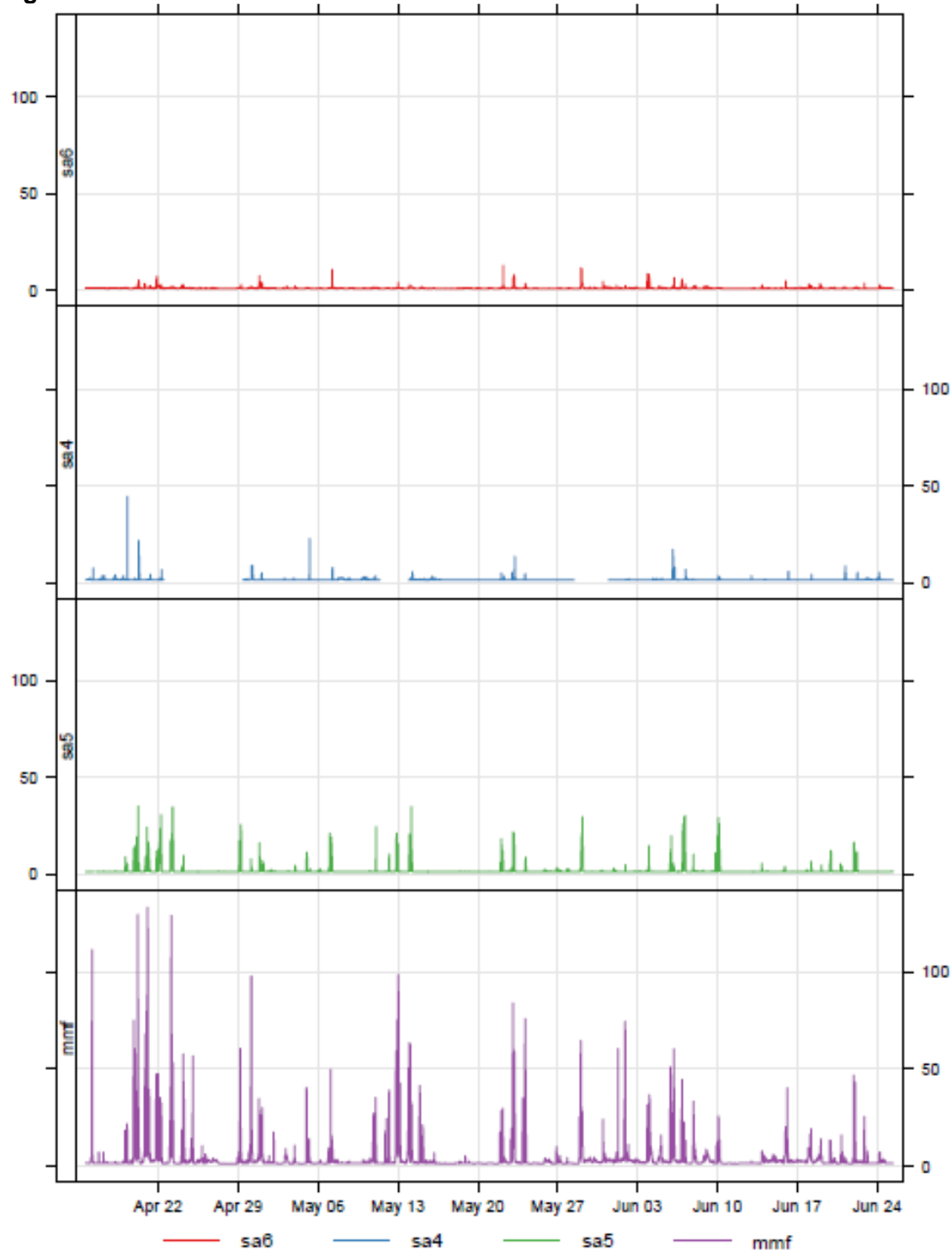


Figure 3.4.2: CH₄ polar frequency plots to varying scales

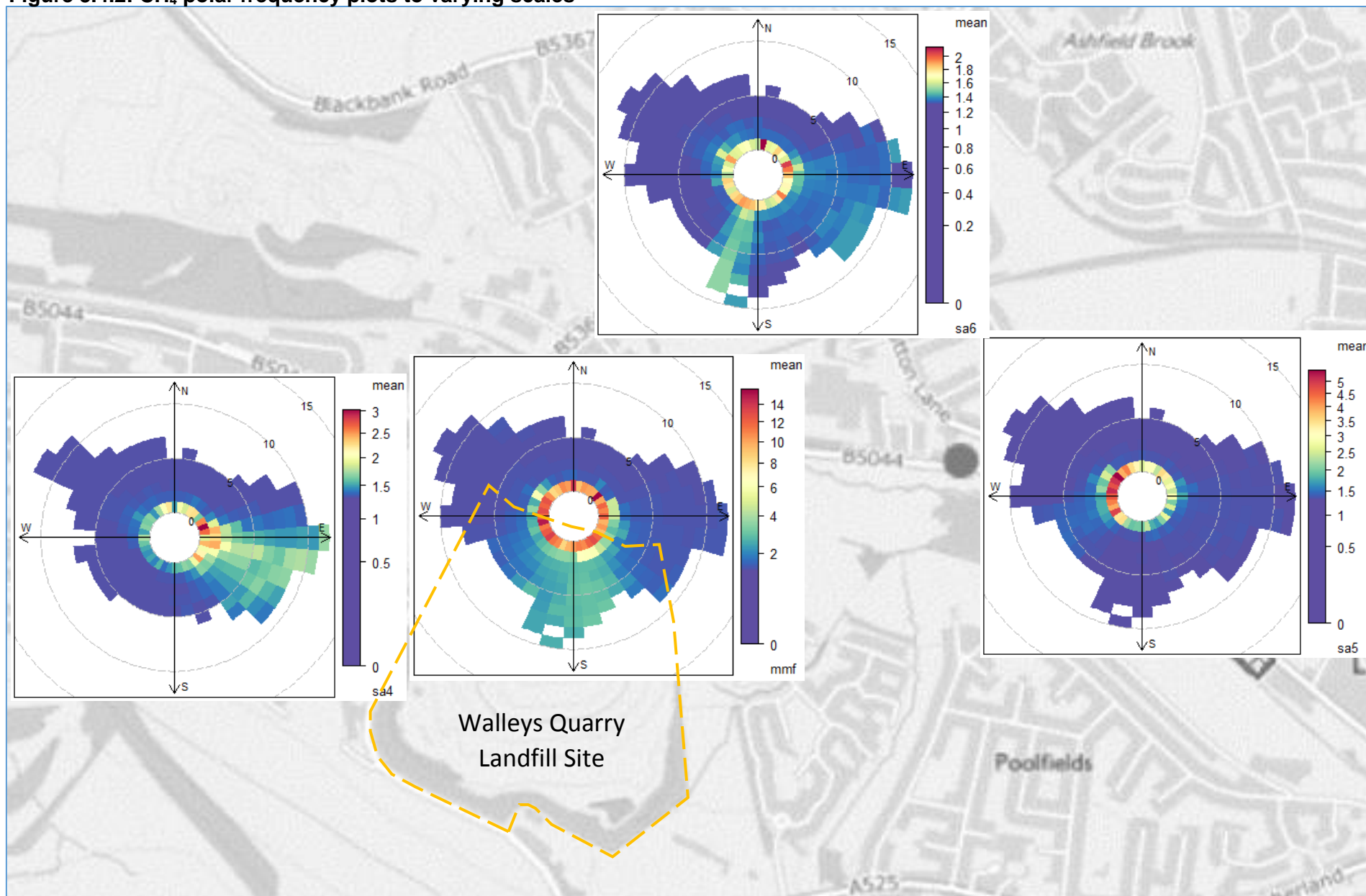


Figure 3.4.3: CH₄ pollution roses for wind speeds >1m.s⁻¹ scale 0-5 mg.m⁻³

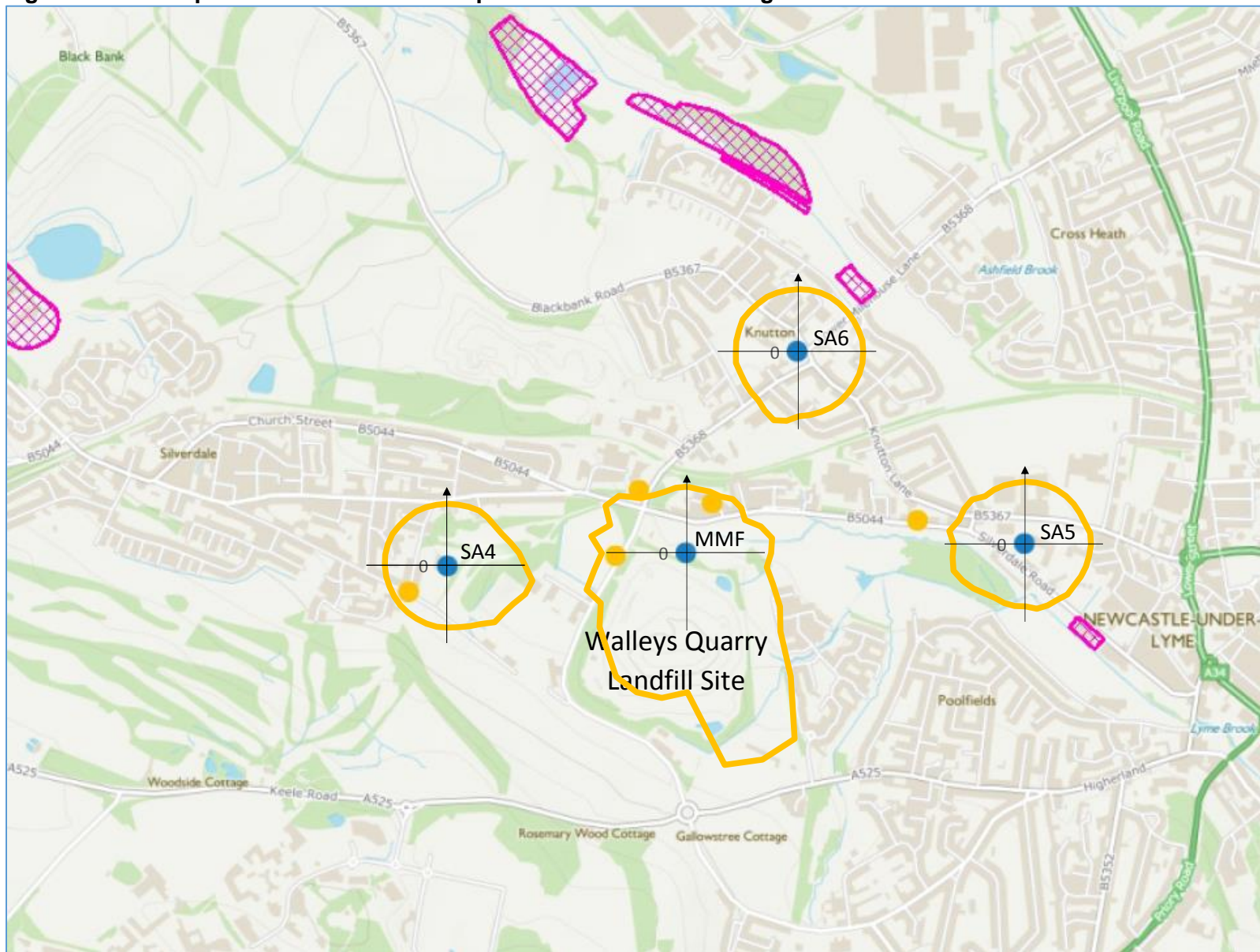


Figure 3.4.4: CH₄ conditional probability function plots for concentrations >75th percentile (mg.m⁻³)



Figure 3.4.4 shows that at all four monitoring locations, high concentrations (greater than the 75th percentile of all observations) came from the direction of Walleys Quarry landfill site, with very low conditional probabilities of these concentrations being experienced for other wind directions.

3.4.2 Conclusion

Consideration of the CH₄ concentrations at the four monitoring locations showed that the highest methane concentrations were measured at the MMF monitoring location, closest to Walleys Quarry landfill site.

Consideration of CH₄ concentrations for varying wind speeds showed that higher CH₄ concentrations were seen at all sites at lower wind speeds <1m.s⁻¹.

All monitoring locations showed elevated CH₄ concentrations when the wind was from the direction of the landfill site.

The probability of measuring high CH₄ concentrations was much greater from the direction of the landfill site.

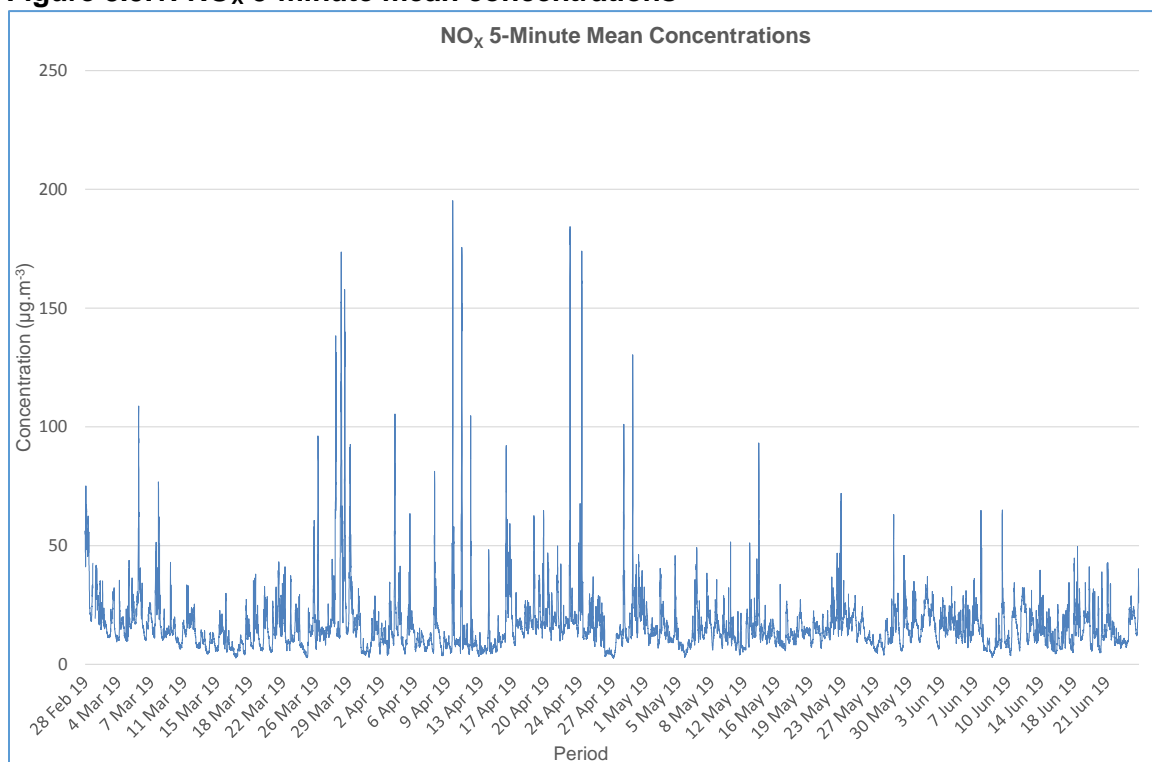
3.5 Oxides of Nitrogen (NO_x)

Between 28 February 2019 and 25 June 2019 (118 days) airborne NO_x and NO₂ concentrations were measured at the MMF monitoring location at a height of 2m above ground. Details of the instrumentation and methodology are given in Appendix F. Successful data collection was 99%.

A consideration of NO_x (NO + NO₂) 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 specific 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 5-minute concentrations of NO_x is shown in Figures 3.5.1. The plot shows that NO_x concentrations remained predominantly below 50µg.m⁻³ with discrete excursions above this level. The mean concentration over the period was 25.1µg.m⁻³.

Figure 3.5.1: NO_x 5-minute mean concentrations



3.5.1 Comparison with Standards

3.5.1.1 Comparison with Air Quality Strategy (AQS) Objectives

A comparison with the AQS objectives set out in the Air Quality Strategy for England, Scotland, Wales and Northern Ireland, has been made in this report, to provide a measure against which

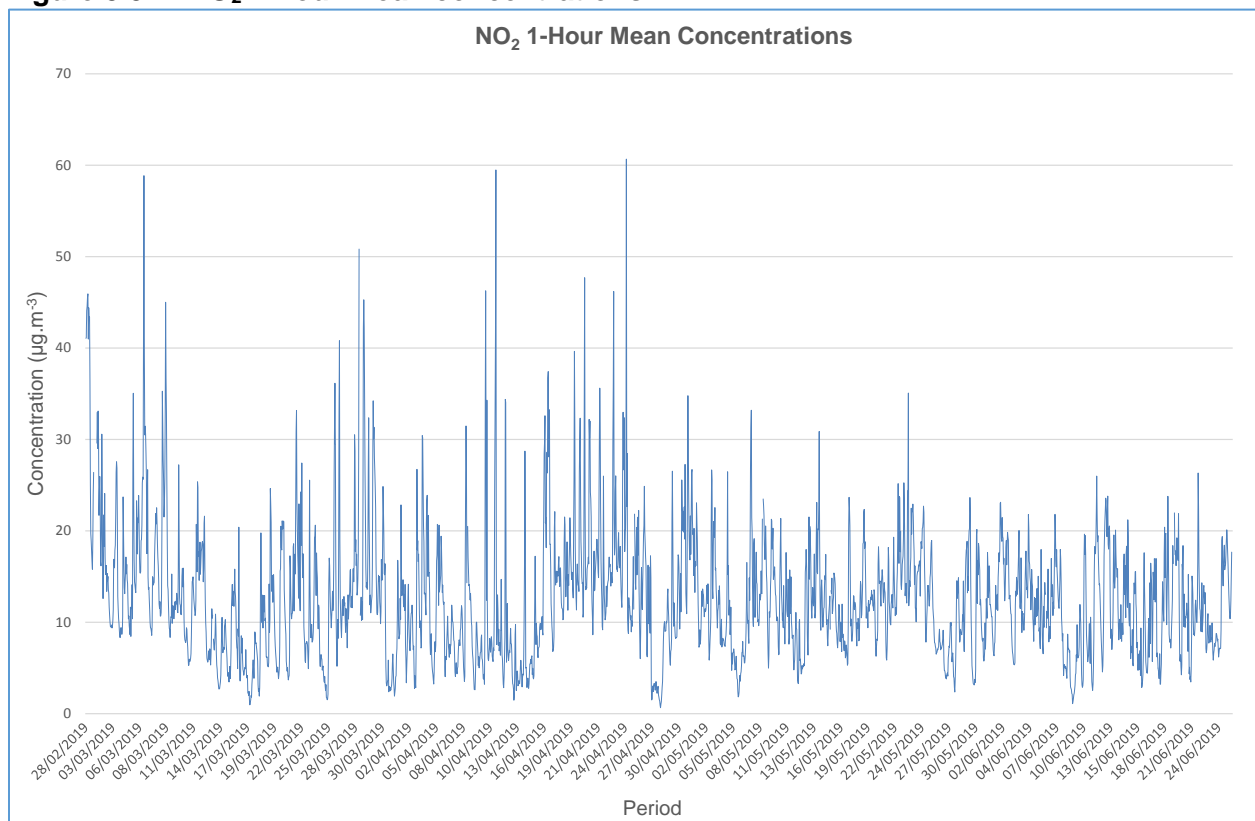
air quality, in the immediate vicinity of sites that we regulate, can help evaluate compliance and quantify the sites environmental impact.

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 NO_2 concentrations. The AQS objectives for the 1-hour mean concentrations states that a value of $200\mu\text{g.m}^{-3}$ (105ppb) must not be exceeded on more than 18 occasions during one year. The annual objective states that the mean concentration of NO_2 over the year must not exceed $40\mu\text{g.m}^{-3}$ (21ppb).

A time series plot of 1-hour concentrations of NO_2 measured at the MMF monitoring site is shown in Figure 3.5.2. The plot shows that the 1-hour NO_2 concentrations were never greater than $200\mu\text{g.m}^{-3}$, the maximum concentration being $60.7\mu\text{g.m}^{-3}$. The mean NO_2 concentration during the monitoring period was $12.6\mu\text{g.m}^{-3}$ which is 32% of the annual objective trigger level.

Figure 3.5.2: NO_2 1-hour mean concentrations



3.5.1.2 Comparison with Other Standards

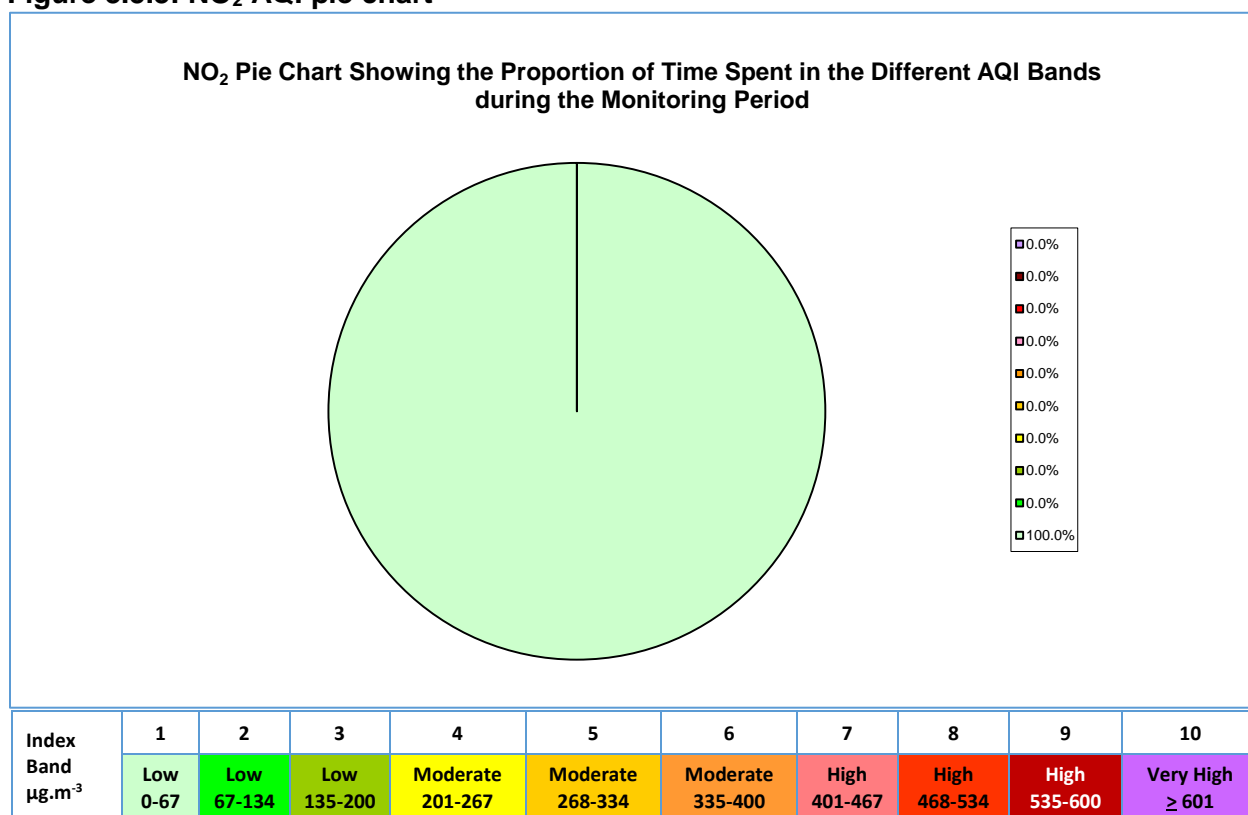
The AQS objective has an annual standard for NO_x of $30\mu\text{g.m}^{-3}$, for the protection of vegetation and ecosystems. The mean NO_x concentration during the monitoring period was $16\mu\text{g.m}^{-3}$, i.e. 53% of the annual standard. However this standard is only relevant if the location meets certain

criteria which are outlined in appendix F. In this instance the monitoring location does not meet these criteria and so the standard does not apply. It is mentioned merely as a point of possible interest, that the levels measured were less than the standard.

3.5.2 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), 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 3.5.3 looks at the hourly mean NO₂ concentrations in relation to the Air Quality Index banding.

Figure 3.5.3: NO₂ AQI pie chart

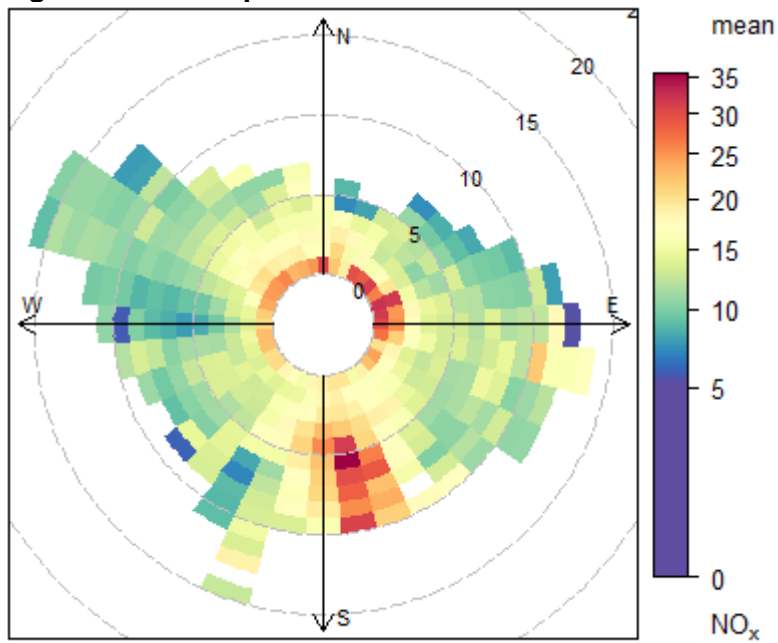


Comparison of the hourly mean NO₂ concentrations with the Air Quality Index banding showed that the 1-hour concentrations were in the low banding throughout the monitoring period.

3.5.3 Directional Analysis

A polar frequency plot showing the mean NO_x concentrations for varying wind speeds and wind directions over the monitoring period is shown in figure 3.5.4. The plot shows that higher NO_x concentrations were seen for lower wind speeds, with the highest concentrations seen for wind directions 350° – 100°. Higher mean NO_x concentrations are seen for wind directions 150° – 190° for higher wind speeds, from the direction of the gas management compound on Walleys Quarry landfill site.

Figure 3.5.4: AQI pie chart



A radial plot of mean NO_x concentrations against wind direction is shown in Figure 3.5.5. The plot shows that the highest concentrations came from the wind sector 0°, 30° and 170°, with mean concentrations >20µg.m⁻³.

Figure 3.5.5: NO_x pollution rose

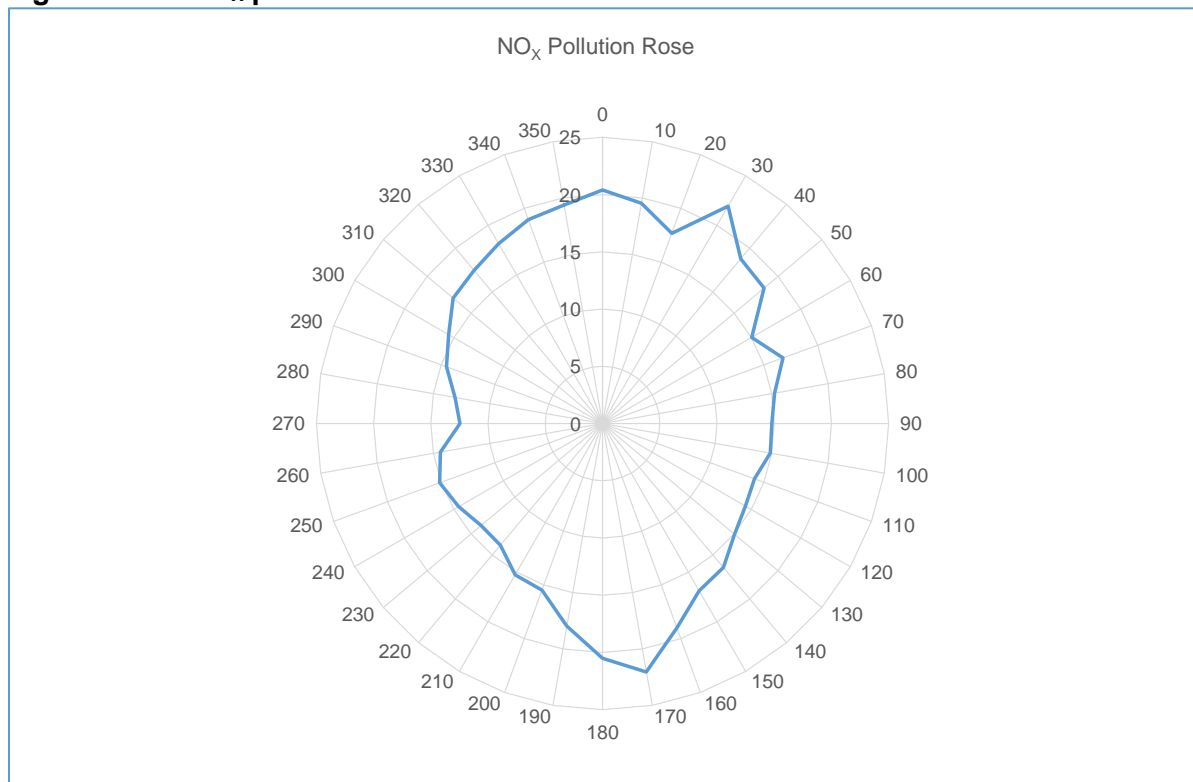


Figure 3.5.6 shows an array of plots showing the contribution to NO_x loading at the monitoring site for different percentiles.

Figure 3.5.6 shows that there were high NO_x values for the 99th percentile for wind directions 350°, 30° - 50°, 70° and 170°, suggesting infrequent events from these wind directions that can contribute to elevated NO_x concentrations. The concentrations appear elevated in the lower and higher percentiles for wind direction 160° - 180°, suggesting that there is a continuous source from this wind direction.

Figure 3.5.6: NO_x percentile rose

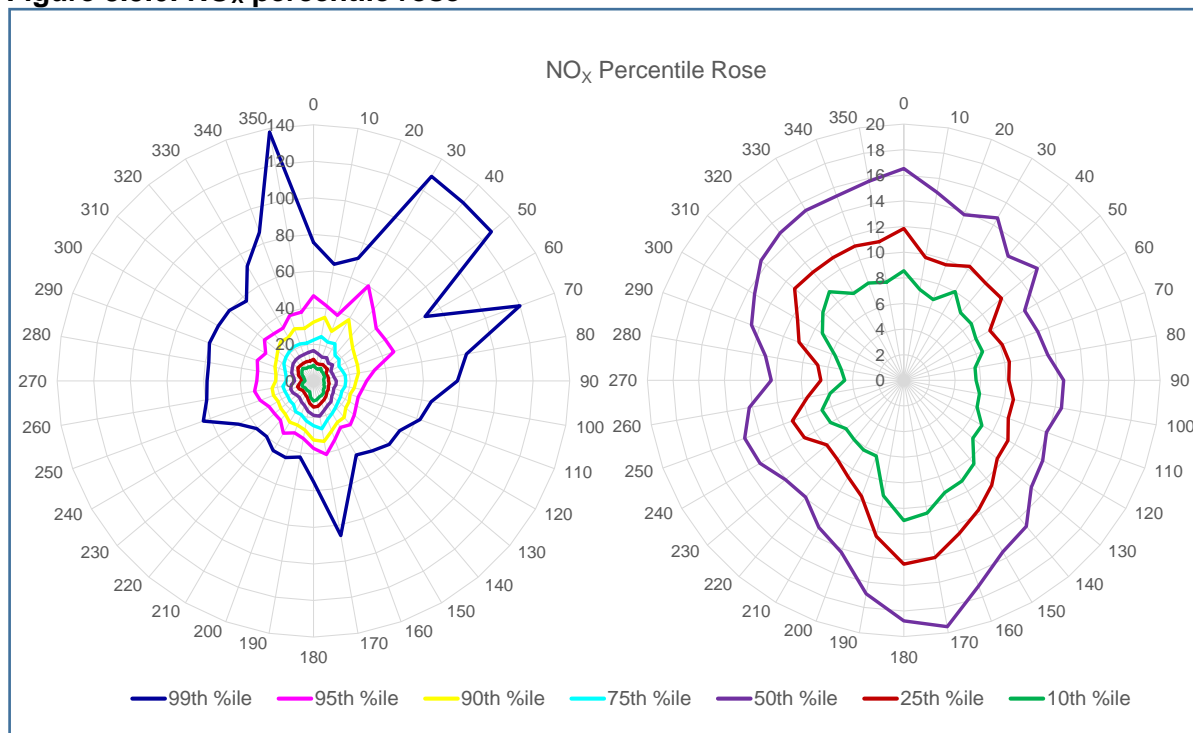
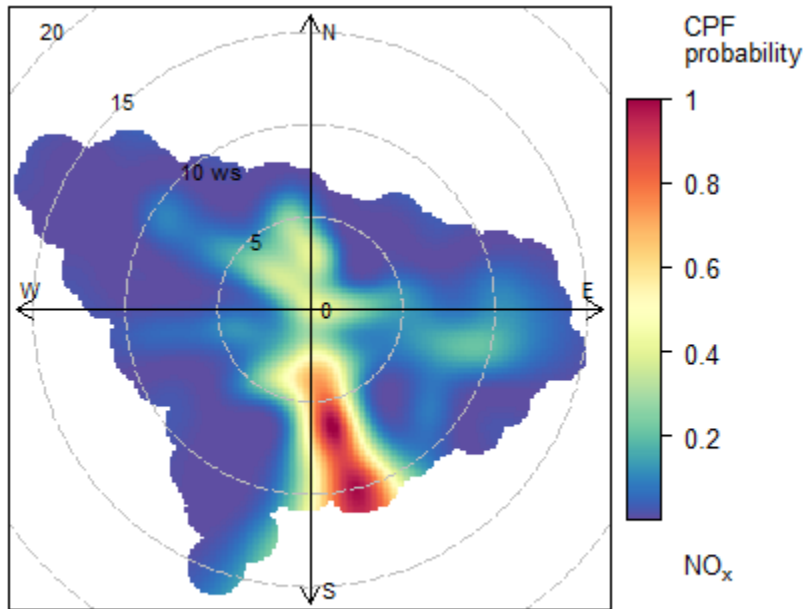


Figure 3.5.7 shows a conditional probability function plot for NO_x concentrations >75th percentile. The plot calculates the probability that NO_x concentrations would be greater than the 75th percentile value (19µg.m⁻³) for a particular wind speed and wind direction. Further information about this method can be found in Appendix J.

Figure 3.5.7 shows that high concentrations (greater than the 75th percentile of all observations) are most likely to occur between 150° – 180° from the direction of the gas management compound. There also appears to be a possibility of seeing elevated NO_x concentrations from other wind directions.

Figure 3.5.7: NO_x conditional probability function plot for concentrations >75th percentile



CPF at the 75th Percentile (=19 $\mu\text{g}\cdot\text{m}^{-3}$)

3.5.4 Diurnal and Weekday Analysis

A Diurnal polar plot for NO_x, for all wind speeds is shown in Figure 3.5.8. The plot shows that the highest NO_x concentrations were seen in the morning hours between 06:00 – 10:00, especially for wind direction 320° – 100° and between 19:00 -23:00 for wind direction 320° – 50°. Concentrations are generally higher from the direction of the landfill site between 07:00 – 24:00.

Figure 3.5.8: NO_x diurnal polar plot

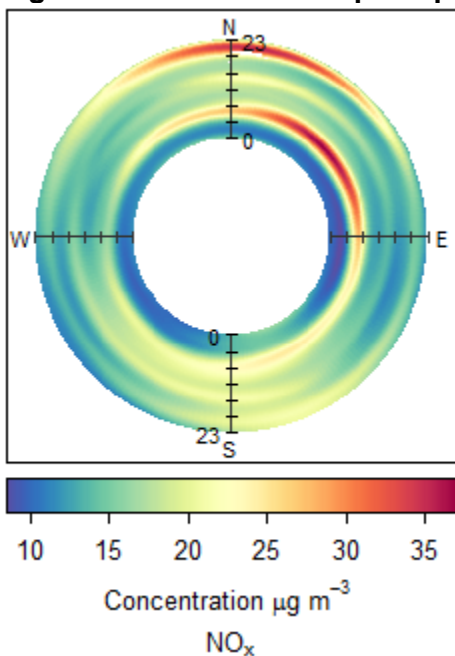
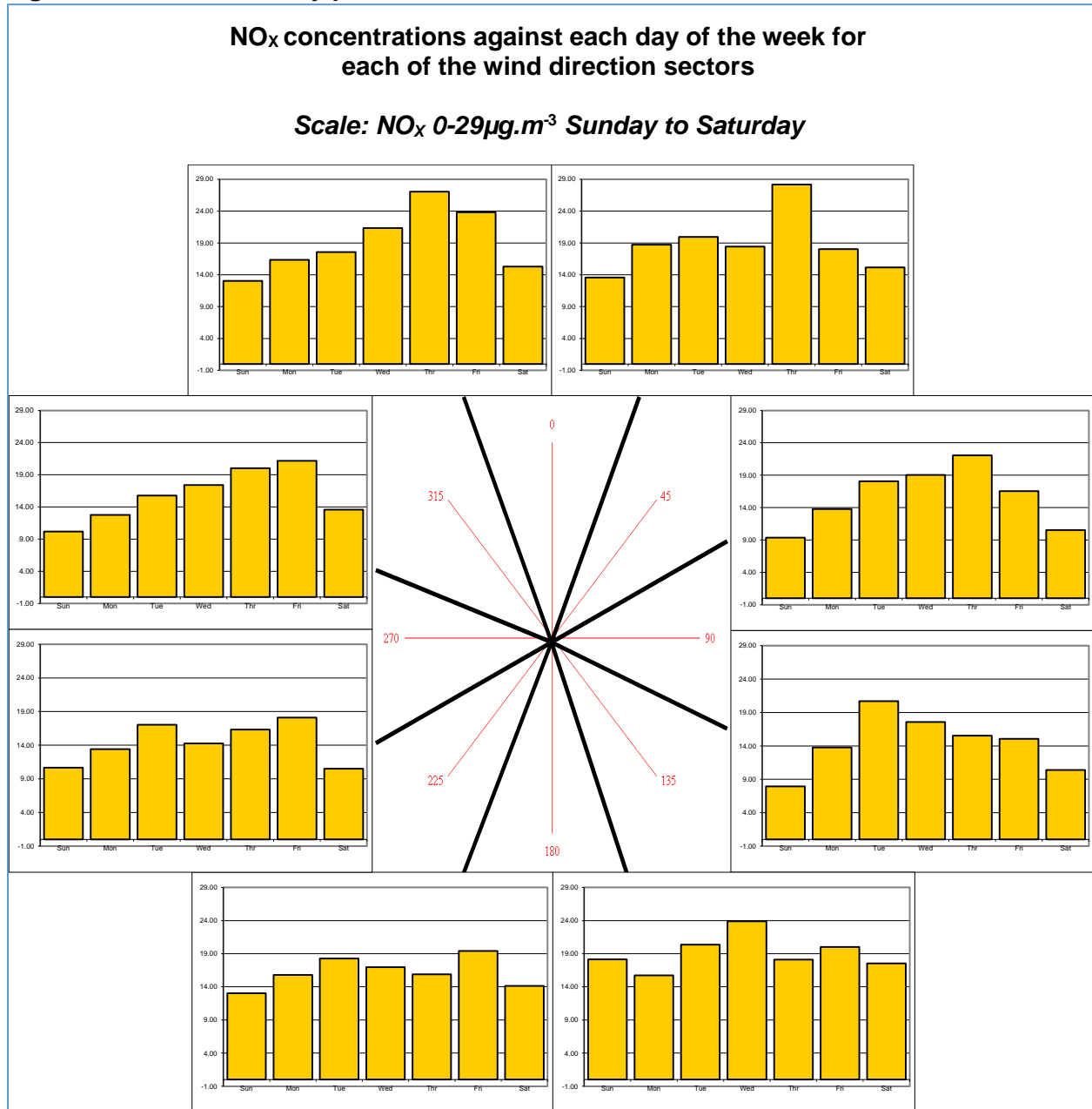


Figure 3.5.9 shows the weekday variation of mean NO_x concentrations for each 45° wind direction sector at the monitoring site. The plots for wind sectors 180° – 135° show higher mean NO_x concentrations on weekdays, with lower concentrations on weekends. Wind sectors 135° – 180° shows similar concentrations on weekdays and weekends, suggesting a more continuous source from the direction of the landfill site.

Figure 3.5.9: NO_x weekday plots



3.5.5 Conclusion

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

The mean NO₂ concentration over the monitoring period was 12.6µg.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 (40µg.m⁻³) would not be exceeded at the monitoring site.

Consideration of NO₂ concentrations against the AQI banding showed that concentrations were always in the low AQI banding during the monitoring period.

Consideration of meteorological conditions showed that higher NO_x concentrations were seen for lower wind speeds, with the highest concentrations seen for wind directions 350° – 100°. Higher mean NO_x concentrations were seen for wind directions 150° – 190° for higher wind speeds, from the direction of the gas management compound on Walleys Quarry landfill site.

Pollution rose analysis indicates that the highest mean NO_x concentrations measured at the MMF site were from a wind direction 0°, 30° and 170°, with mean concentrations >20µg.m⁻³.

Percentile rose analysis showed that there were infrequent elevated events for wind directions 350°, 30° - 50°, 70° and 170° and a continuous source from wind direction 160° – 180°.

The probability of measuring higher NO_x concentrations (greater than the 75th percentile of all observations) was much more probable from wind directions 150° – 180°, from the direction of the gas management compound on the landfill site.

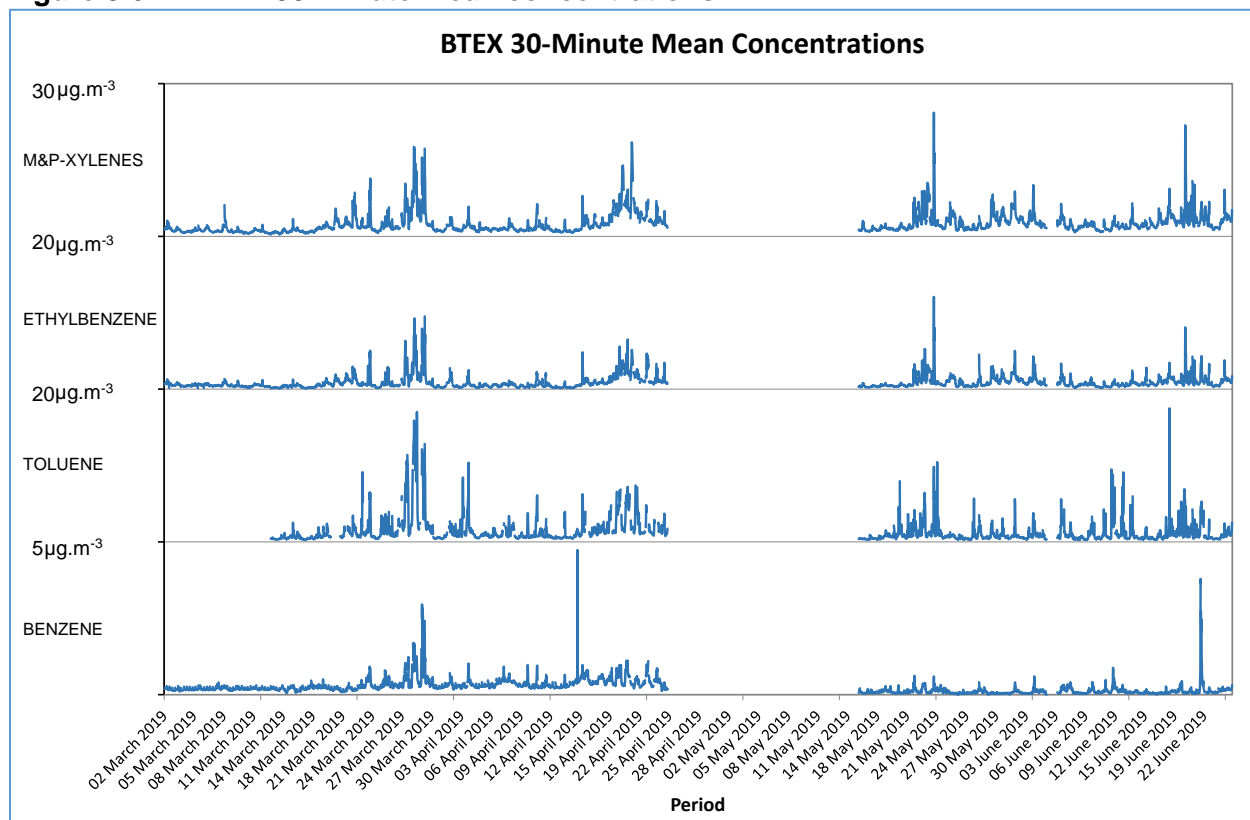
Consideration of the diurnal variation of NO_x concentrations showed that the highest NO_x concentrations were seen in the morning hours between 06:00 – 10:00, especially for wind direction 320° – 100° and between 19:00 - 23:00 for wind direction 320° – 50°. Concentrations were generally higher from the direction of the landfill site between 07:00 – 24:00.

Consideration of the weekday variation showed higher NO_x concentrations during the working week, with the exception of wind sector 135° – 180° which showed similar concentrations on weekdays and weekends, suggesting a more continuous source from the direction of the landfill site.

3.6 BTEX

Between 2 March 2019 and 25 June 2019 (116 days) airborne VOC concentrations were measured at a height of 2m above ground. The main VOCs monitored were benzene, toluene and m&p-xylene (BTEX), shown in Figure 3.6.1. Details of the instrumentation and methodology are given in Appendix G. The successful data collection over the monitoring period was 75%, with the loss of data between the 25 April and 15 May due to instrument error.

Figure 3.6.1: BTEX 30-minute mean concentrations



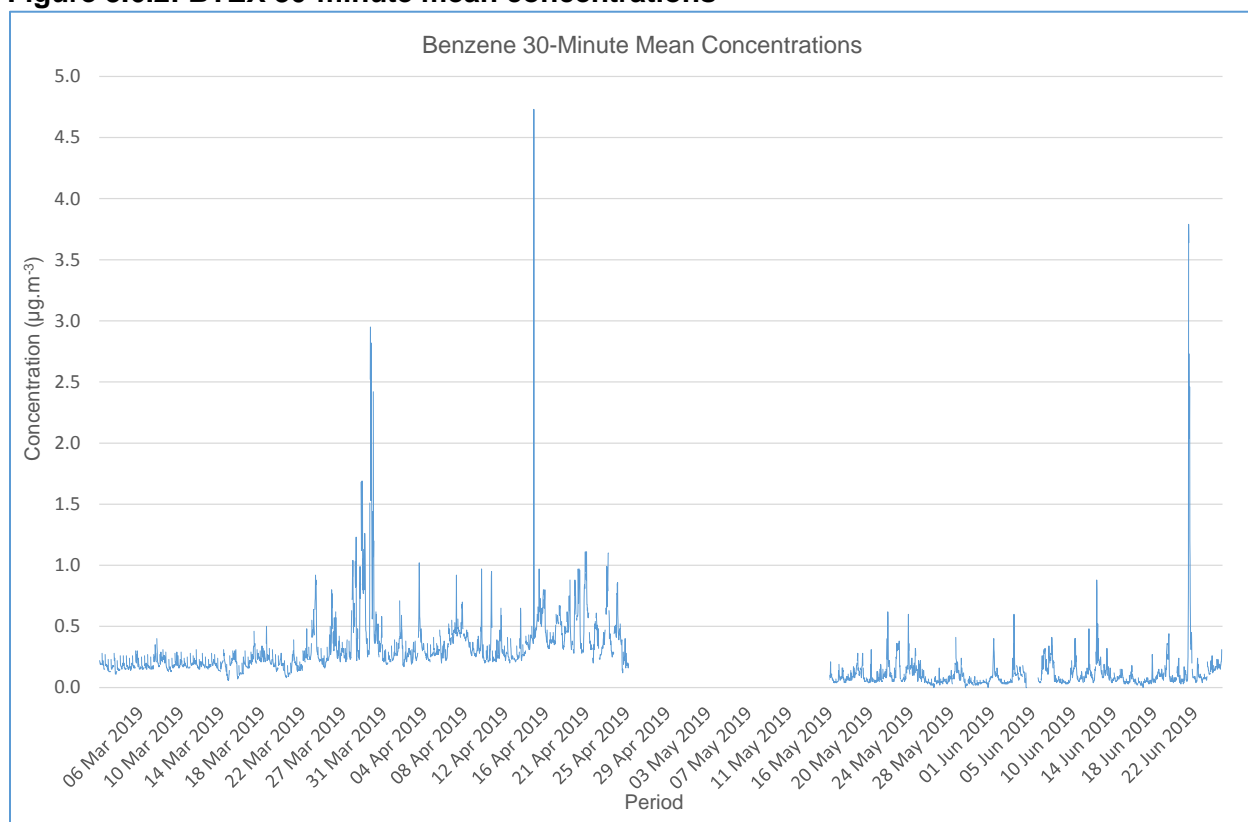
3.6.1 Comparison with Standards

3.6.1.1 Comparison with Air Quality Strategy (AQS) Objectives

Benzene was the only BTEX compound recorded at the monitoring site that has an AQS. A time series plot of benzene over the monitoring period is shown in Figure 3.6.2.

The AQS objective for benzene is expressed as an annual mean and is currently set at $5\mu\text{g.m}^{-3}$ (1.5ppb). The mean benzene concentration over the monitoring period was at $0.23\mu\text{g.m}^{-3}$, which is 5% 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 would not exceed the AQS objective.

Figure 3.6.2: BTEX 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 the 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.

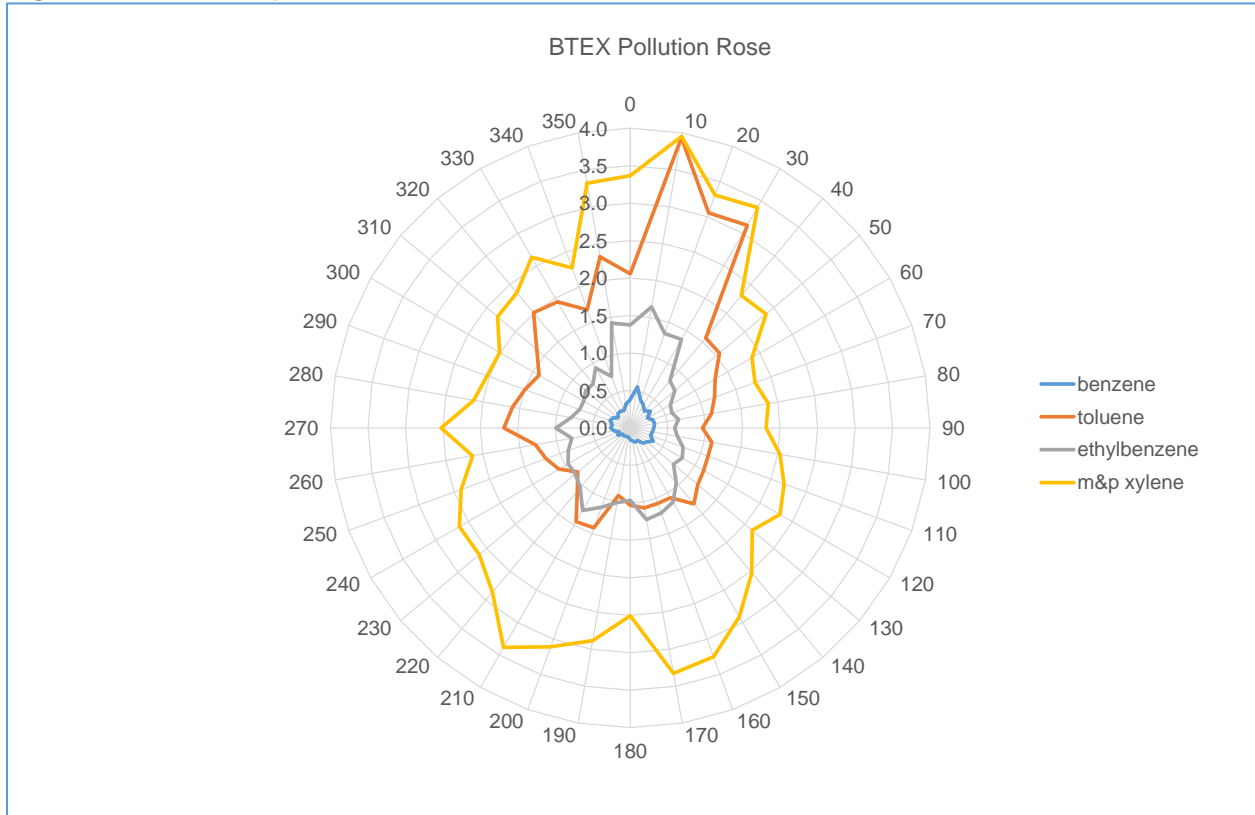
VOC	Long-term OEL (8hr-TWA)	Long-term EAL (annual mean)	Mean over monitoring period
Toluene	191mg.m ⁻³	1910ug.m ⁻³	1.35ug.m ⁻³
Ethylbenzene	441mg.m ⁻³	4410ug.m ⁻³	0.86ug.m ⁻³
m&p-Xylenes	220mg.m ⁻³	2200ug.m ⁻³	2.41ug.m ⁻³

Toluene also has two World Health Organisation (WHO) guidelines. The guideline for human health is 0.26mg.m⁻³ as a weekly mean. The maximum weekly mean over the period was 3.14µg.m⁻³ (0.003mg.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, was 17.5µg.m⁻³ (0.02mg.m⁻³). Therefore, toluene should not have caused odour annoyance in the vicinity of the monitoring site, during the monitoring period.

3.6.2 Directional Analysis

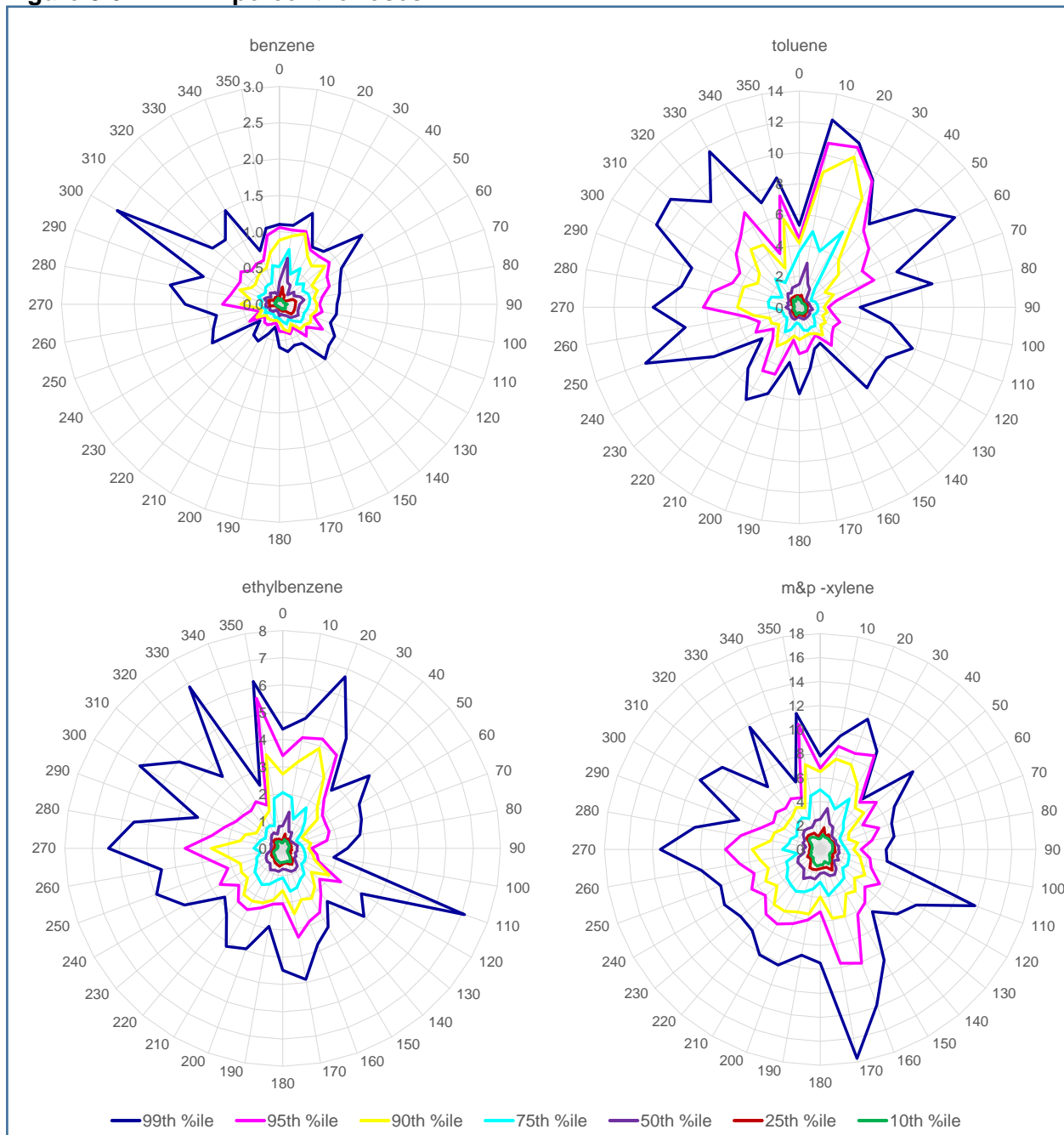
Radial plots of mean BTEX concentrations ($\mu\text{g}\cdot\text{m}^{-3}$) against wind direction are shown in Figure 3.6.3. The plot shows the wind directions where there are increases in mean concentration for each of the BTEX measured at the MMF. The highest mean BTEX concentrations are seen from the north for wind sector $350^\circ - 40^\circ$.

Figure 3.6.3: BTEX pollution roses



An array of plots showing the contribution to BTEX loading at the monitoring site for different percentiles is shown in Figures 3.6.4. The plots show that the elevated concentrations for wind sector $350^\circ - 40^\circ$ can be seen in the higher and lower percentiles, suggesting a continuous source(s) from these wind directions.

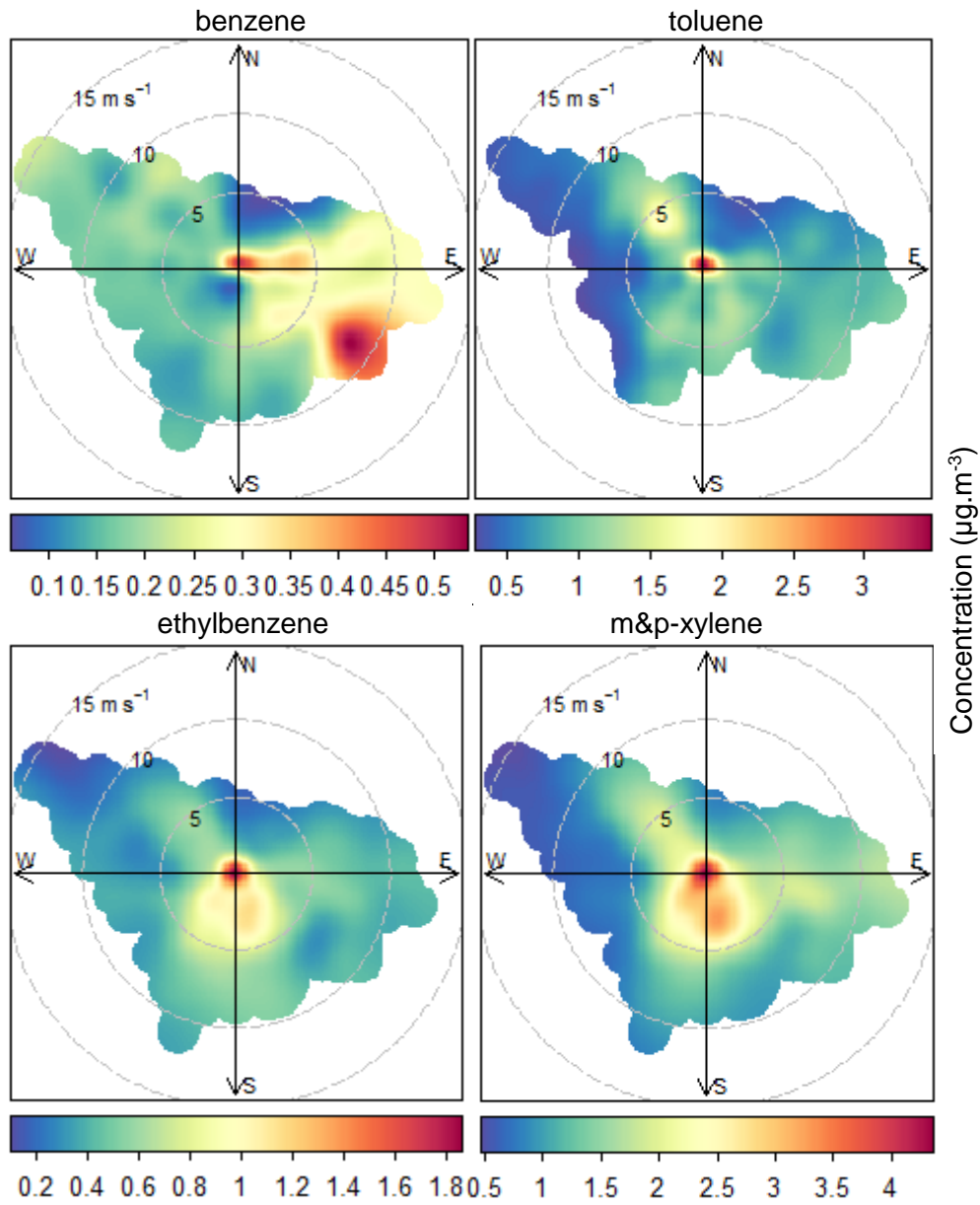
Figure 3.6.4: BTEX percentile roses



An array of plots showing the variation in BTEX concentrations with wind speed, seen for varying wind directions is shown in figure 3.6.5.

The plots show that the elevated BTEX concentrations to the north occur at low wind speeds. The benzene plot suggests that there was also a source between 60° – 150° that were seen at higher wind speeds. Both the ethylbenzene and m&p-xylene plots show elevated concentrations between 130° – 230° at wind speeds up to 5m.s⁻¹.

Figure 3.6.5: BTEX polar plots



3.6.3 Conclusion

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.

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, ethylbenzene and m&p-xylene, 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.

Consideration of the directional sources of BTEX suggested that there were continuous sources of BTEX for wind sector 350° – 40° which occurred at low wind speeds.

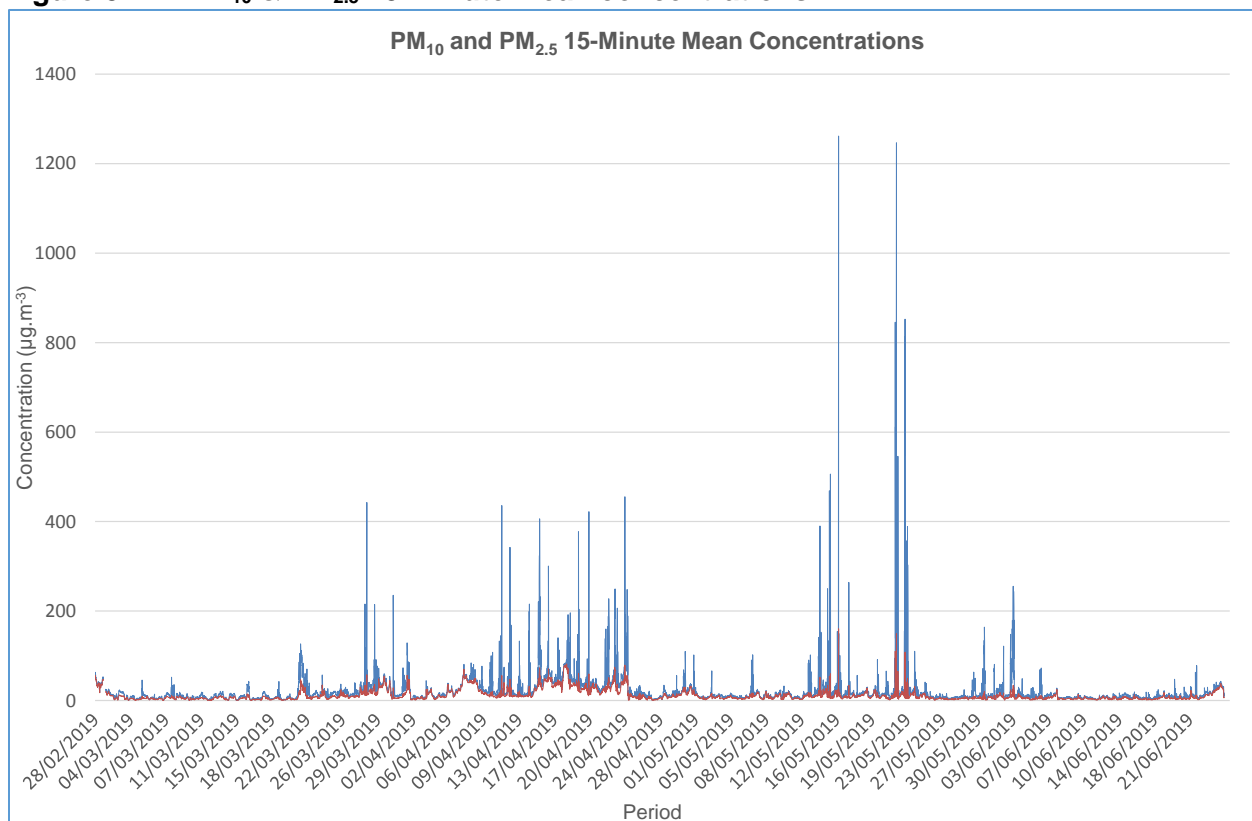
The plots also indicated that there was a benzene source between 60° – 150°, seen at higher wind speeds and an ethylbenzene and m&p-xylene source between 130° – 230° for wind speeds up to 5m.s⁻¹.

3.7 Particulate Matter (PM₁₀ & PM_{2.5})

Between 28 February 2019 and 25 June 2019 (118 days) PM₁₀ (particles <10µm in diameter) and PM_{2.5} (particles <2.5µm in diameter) concentrations were measured at the MMF (at a height of 2m above ground) using a Palas Fidas 200 instrument. Details of the instrumentation and methodology are given in Appendix H. Successful data collection of 15-minute data over the period was 99%.

A time series plot of 15-minute PM₁₀ and PM_{2.5} concentrations for the monitoring site is shown in Figure 3.7.1.

Figure 3.7.1: PM₁₀ & PM_{2.5} 15-minute mean concentrations



3.7.1 Comparison with Standards

3.7.1.1 Comparison with Air Quality Strategy (AQS) Objectives

The Air Quality Strategy (AQS) for England, Scotland, Wales and Northern Ireland, sets out air quality objectives and policy options to further improve air quality in the UK.

The AQS has two objectives for PM₁₀, the first is to limit the annual mean concentration to 40 µg.m⁻³ and the second objective states that the 24-hour mean (midnight – midnight) must not exceed 50µg.m⁻³ on more than 35 occasions during one year. The AQS objective for PM_{2.5} is an annual mean concentration of 25µg.m⁻³.

The mean PM_{10} concentration over the monitoring period at the MMF was $20.4\mu\text{g}\cdot\text{m}^{-3}$. 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 would not be exceeded at the monitoring site.

Figure 3.7.2 shows that for PM_{10} the 24-hour (midnight-midnight) mean concentration at the MMF site was greater than $50\mu\text{g}\cdot\text{m}^{-3}$ on 10 occasions during the monitoring period, the maximum concentration being $91.5\mu\text{g}\cdot\text{m}^{-3}$ on the 15 February 2019. If the assumption is made that the conditions during the monitoring period were representative of a typical year, then over a year the $50\mu\text{g}\cdot\text{m}^{-3}$ level for 24-hour (midnight-midnight) mean concentrations would be exceeded on 31 occasions and thus the AQS for 24-Hours (midnight-midnight) mean PM_{10} concentrations would not be exceeded. However, it is worth noting that this does not take into account changes in weather conditions or changes to local sources that might occur outside of the monitoring period.

A number of the exceedance days coincide with regional pollution episodes that were caused by polluted air from Europe as reported on the London Air website. These pollution episodes are likely to have contributed to the breaches in the daily mean PM_{10} values between the 8 April and 15 – 24 April. This is further supported in Figure 3.7.3 which shows elevated PM_{10} concentrations at some of the closest AURN monitoring sites in April 2019.

Figure 3.7.2: PM_{10} 24-hour mean concentrations

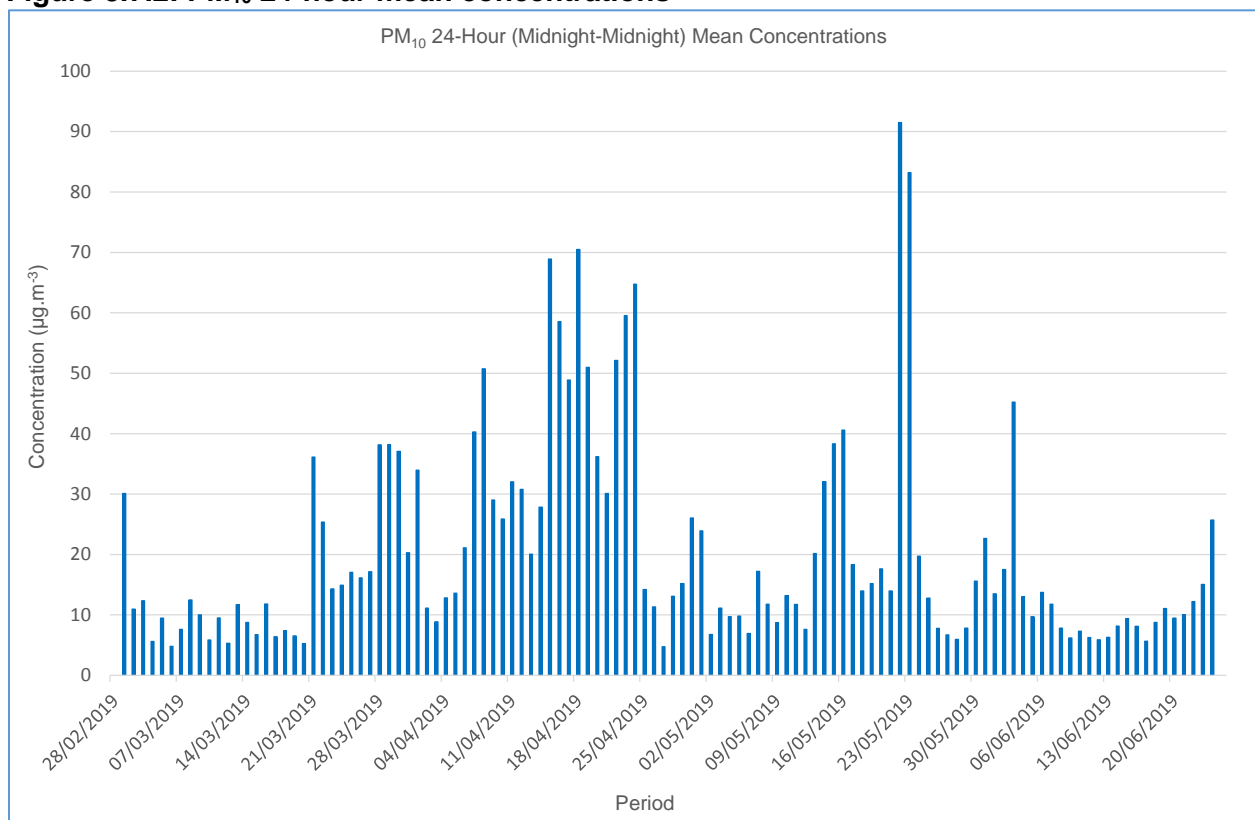
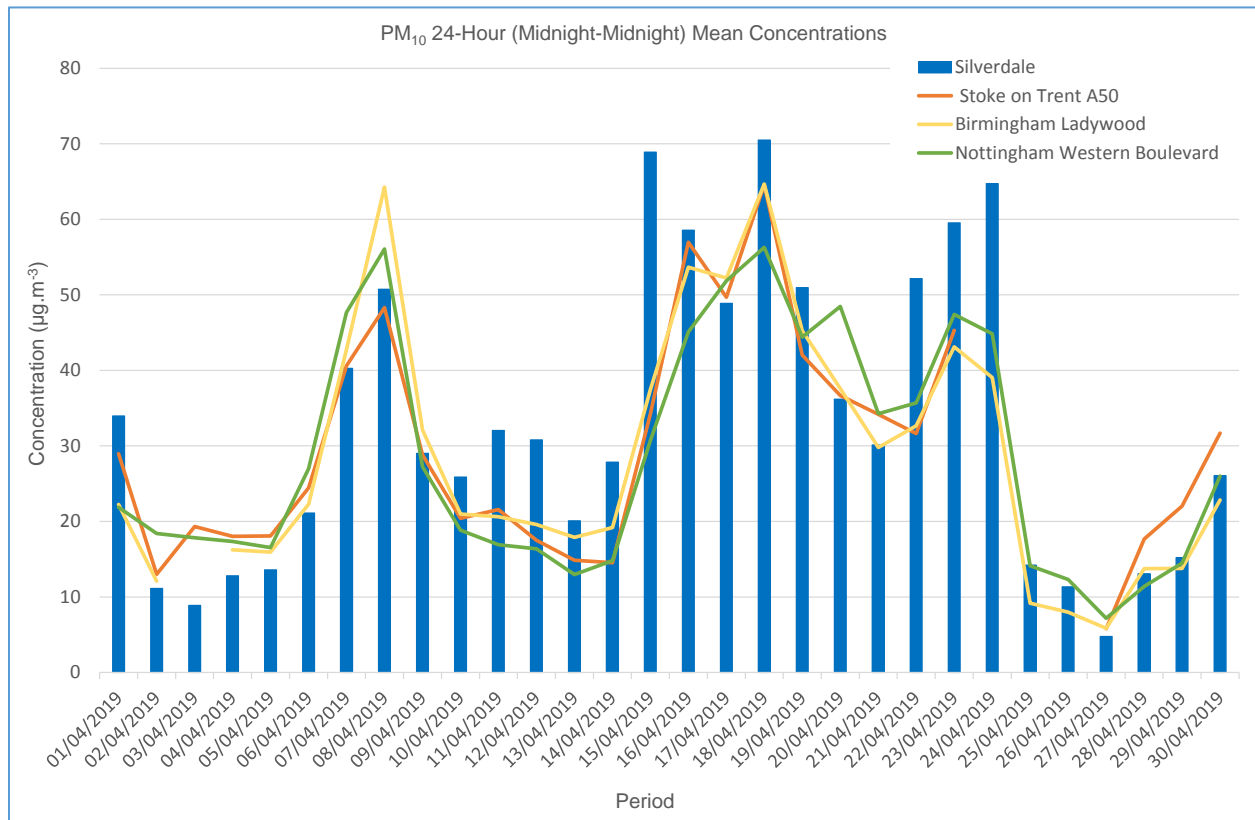


Figure 3.7.3: PM₁₀ 24-hour mean concentrations for April 2019 at Silverdale and AURN sites

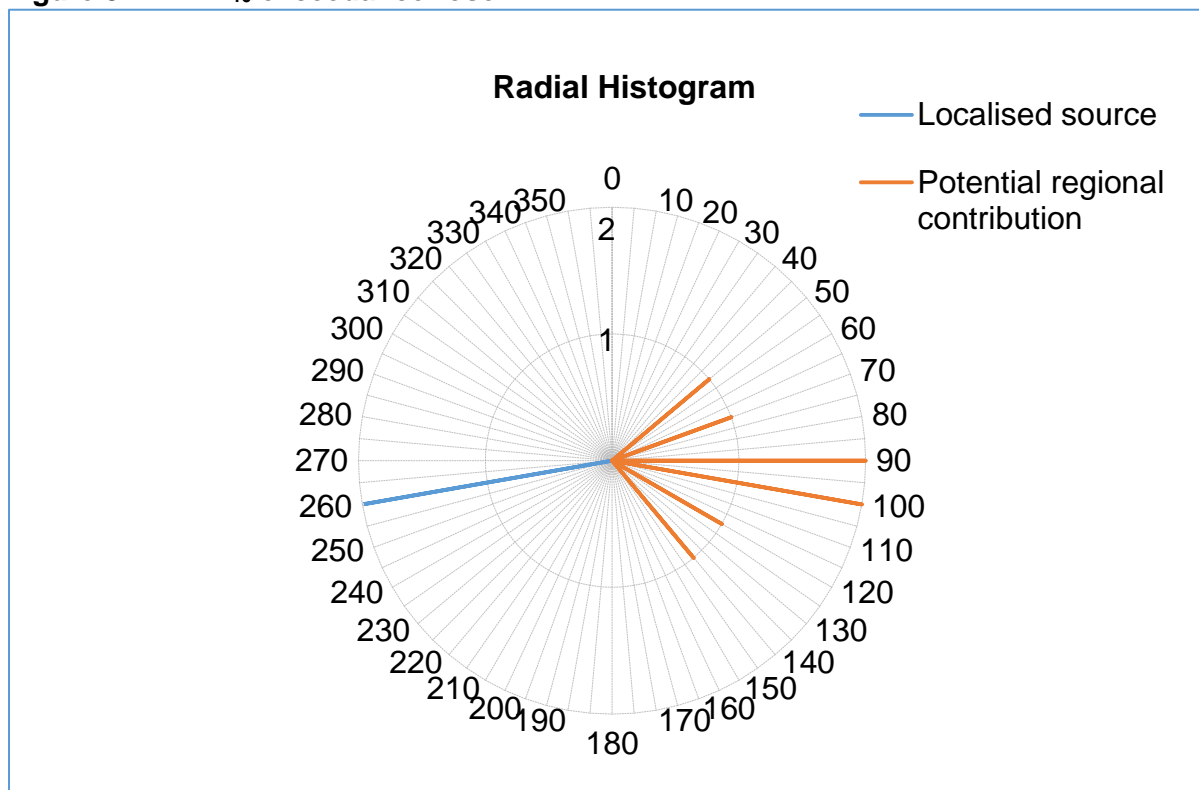


The mean PM_{2.5} concentration over the monitoring period at the MMF was 11.4µg.m⁻³. If the assumption is made that the conditions during the monitoring period were representative of a typical year, then the results would indicate that the AQS annual mean objective for PM_{2.5} would not be exceeded at the monitoring site.

Figures 3.7.4 shows the number of exceedances of the PM₁₀ 24-hour (midnight-midnight) mean against mean wind directions, for each 10° wind sector (based on a 24-hour mean) over the monitoring period at the monitoring site.

Figure 3.7.4 shows that for eight days during the monitoring period the daily mean PM₁₀ concentration was greater than 50µg.m⁻³ when the 24-hour mean wind directions were between 50° - 140°. The direction of these pollution events from an easterly wind, supports that these events that occurred in April were most likely contributed by regional PM₁₀ pollution. There were also two events where the mean wind directions was from 260°.

Figure 3.7.4: PM₁₀ exceedance rose



3.7.2 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.

Figures 3.7.5 and 3.7.6 look retrospectively at the daily PM₁₀ and PM_{2.5} concentrations at the monitoring site in relation to the Air Quality Index banding.

Figure 3.7.5 shows that the PM₁₀ 24-hour mean concentrations were in the low banding at the monitoring site for greater than 93% of the monitoring period and in the moderate banding for 5% of the monitoring period. There were two days during the monitoring period (2%) where the daily mean PM₁₀ concentration sat in the high AQI banding.

Figure 3.2.5: PM₁₀ AQI pie chart

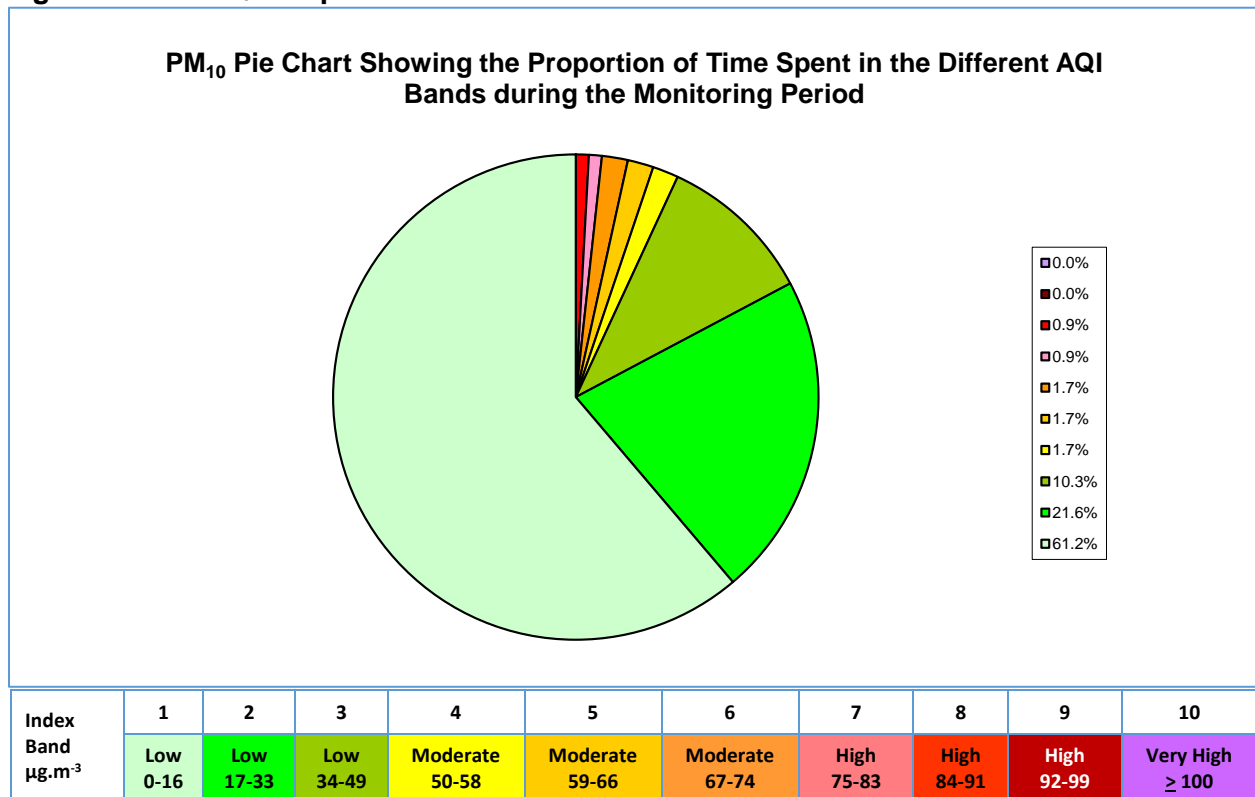


Figure 3.2.6: PM_{2.5} AQI pie chart

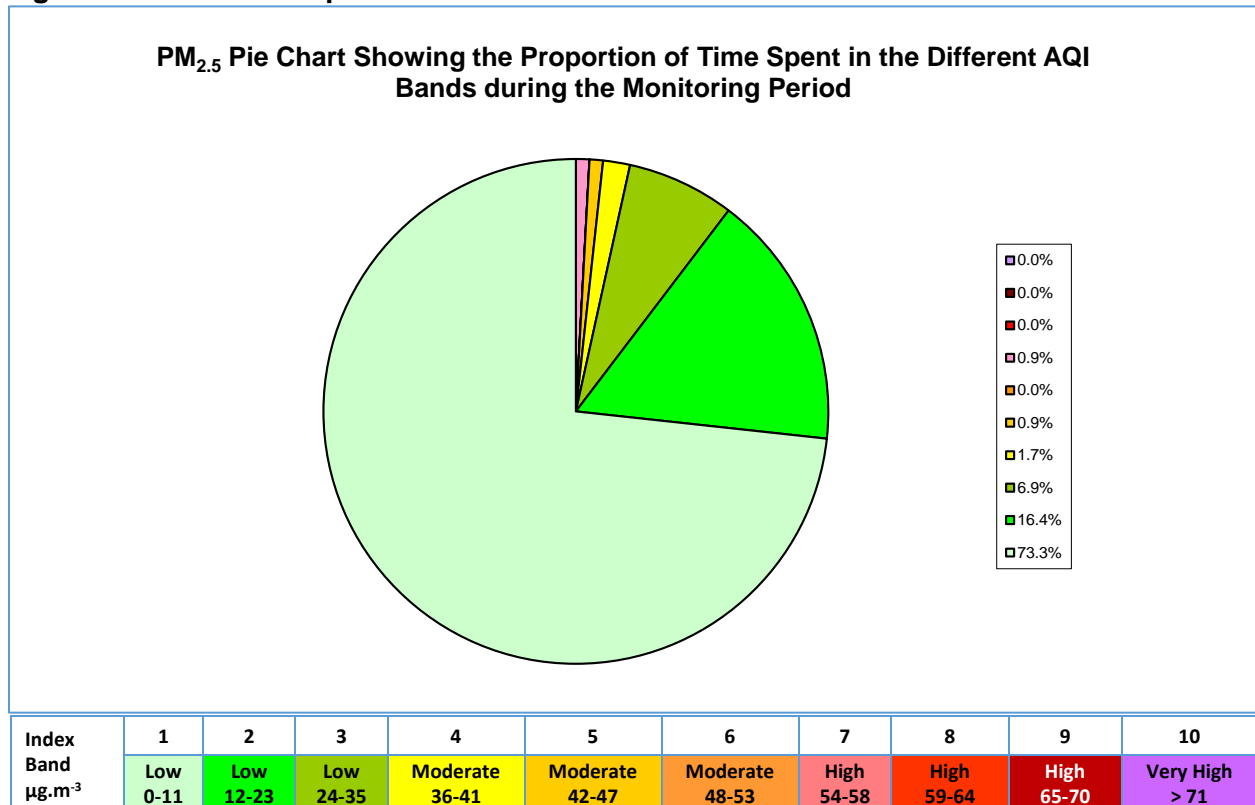
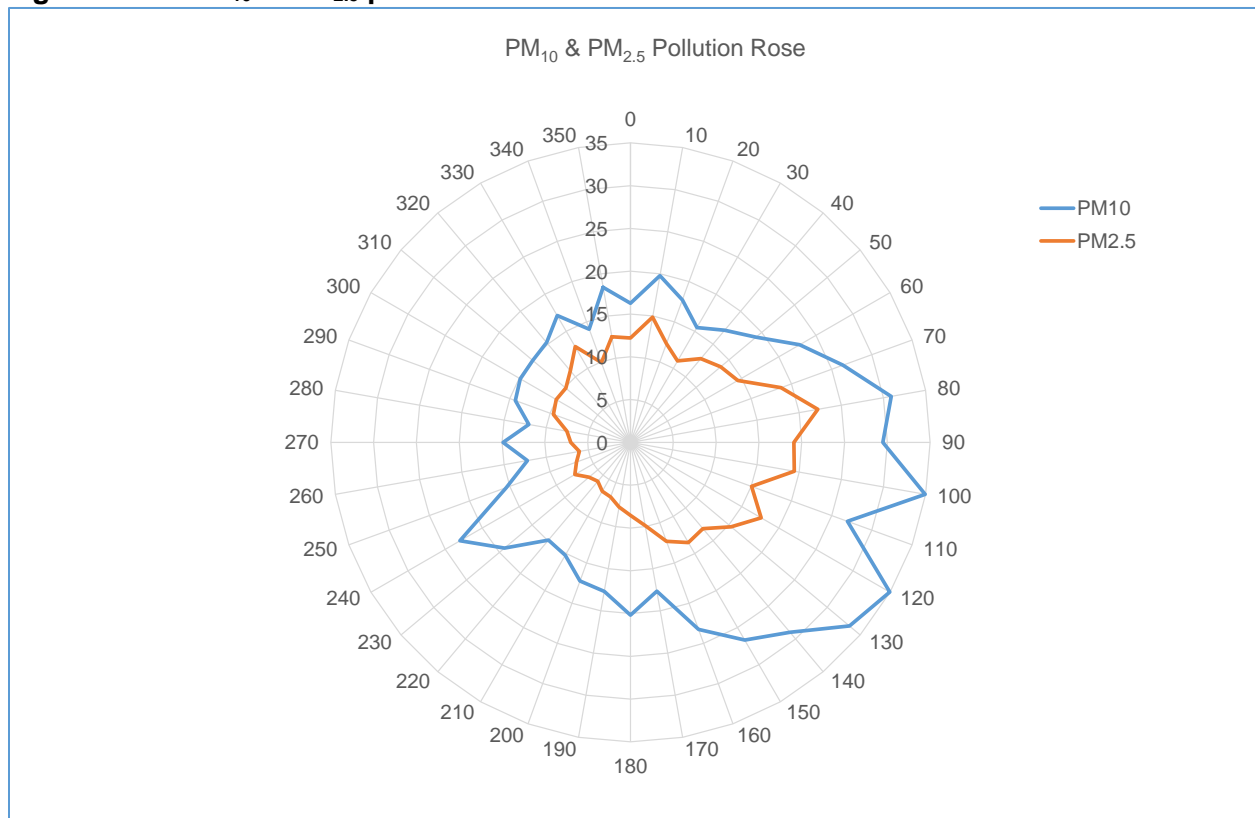


Figure 3.7.6 shows that the PM_{2.5} 24-hour mean concentrations were in the low banding at the monitoring site for 97% of the monitoring period and in the moderate banding for 2% of the monitoring period. There was one day during the monitoring period (1%) where the daily mean PM_{2.5} concentration sat in the high AQI banding.

3.7.3 Directional Analysis

A radial plot of mean PM₁₀ and PM_{2.5} concentrations against wind direction at the MMF site are shown in Figure 3.7.7.

Figure 3.7.7: PM₁₀ & PM_{2.5} pollution rose



The highest mean PM₁₀ concentrations are seen for wind sectors 70° - 150°, with mean concentrations >25µg.m⁻³.

The highest mean PM_{2.5} concentrations are seen for wind sectors 70° - 130°, with mean concentrations >15µg.m⁻³.

An array of plots showing the contribution to PM₁₀ and PM_{2.5} loading at the MMF monitoring site for different percentiles are shown in Figures 3.7.8 and 3.7.9.

Figure 3.7.8 shows that for PM₁₀ the contribution from the sources between 70° - 150° show an elevation in the lower and higher percentiles, suggesting a continuous particulate source from these wind directions that leads to elevations in PM₁₀ concentrations at the monitoring site. The

source between 230° – 270° is only seen in the higher percentiles, suggesting an intermittent PM₁₀ source that can cause elevated PM₁₀ concentrations.

Figure 3.7.8: PM₁₀ percentile rose

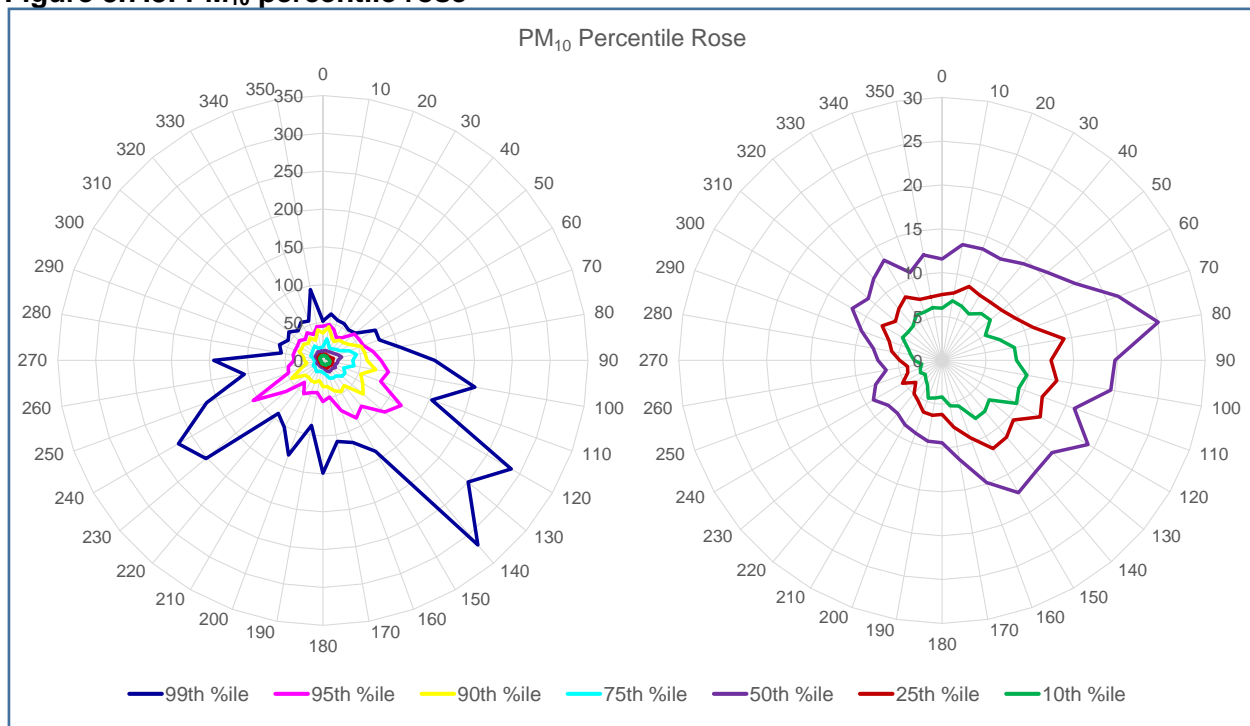


Figure 3.7.9: PM_{2.5} percentile rose

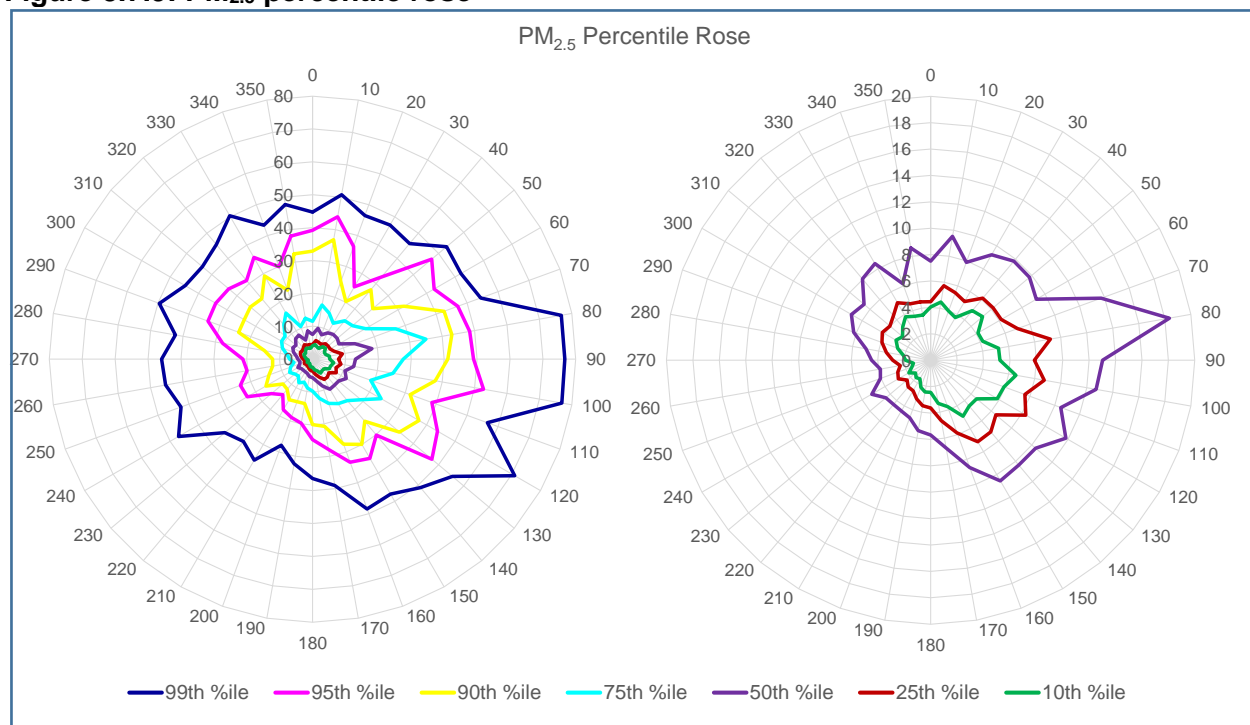


Figure 3.7.9 shows that the contribution from the sources between 70° - 130° show an elevation in the lower and higher percentiles, suggesting a continuous source from these wind directions that leads to elevations in $PM_{2.5}$ concentrations at the monitoring site.

Figure 3.7.10 shows the variation in PM_{10} and $PM_{2.5}$ concentrations ($\mu\text{g}\cdot\text{m}^{-3}$) with wind speed, seen for varying wind directions at the MMF monitoring site.

Figure 3.7.10: PM_{10} and $PM_{2.5}$ polar plots

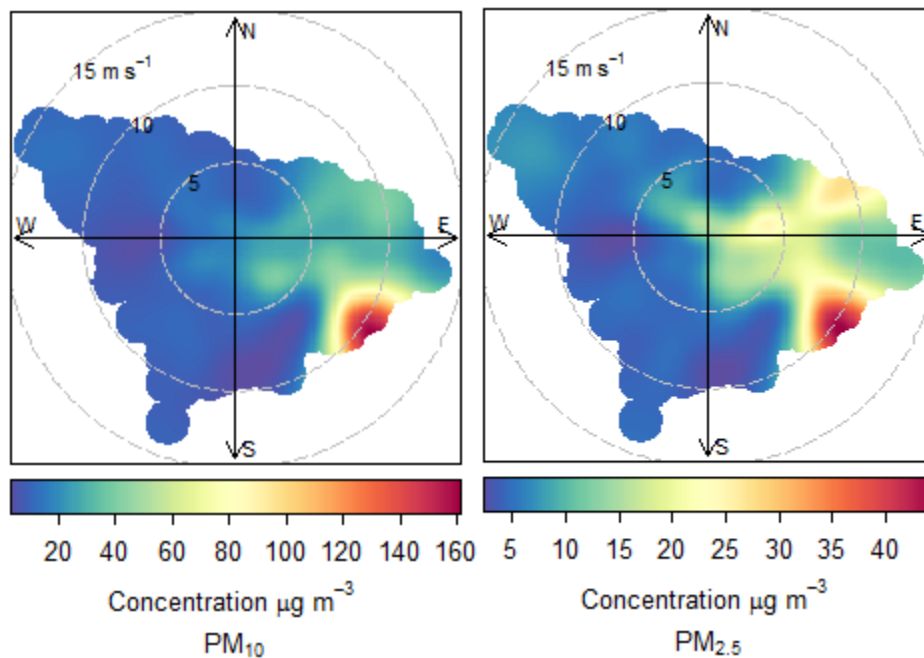


Figure 3.7.10 shows elevated PM_{10} and $PM_{2.5}$ concentrations for a range of wind speeds between 60° – 140° . The highest elevated PM_{10} and $PM_{2.5}$ concentrations are seen at high wind speeds $>5\text{m}\cdot\text{s}^{-1}$ between 110° – 140° .

3.7.4 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 3.7.11 shows the mean levels of PM_{10} and $PM_{2.5}$ at the monitoring location for each hour of the day shown for each 45° wind direction sector.

Figure 3.7.11 shows that there were elevated PM_{10} concentrations during the daytime for wind sectors 90° – 135° and 180° – 270° that was not as apparent in the $PM_{2.5}$ data, suggesting that there were more local sources of PM_{10} generated during the working day from these wind directions.

Figure 3.7.11: PM₁₀ and PM_{2.5} diurnal plots

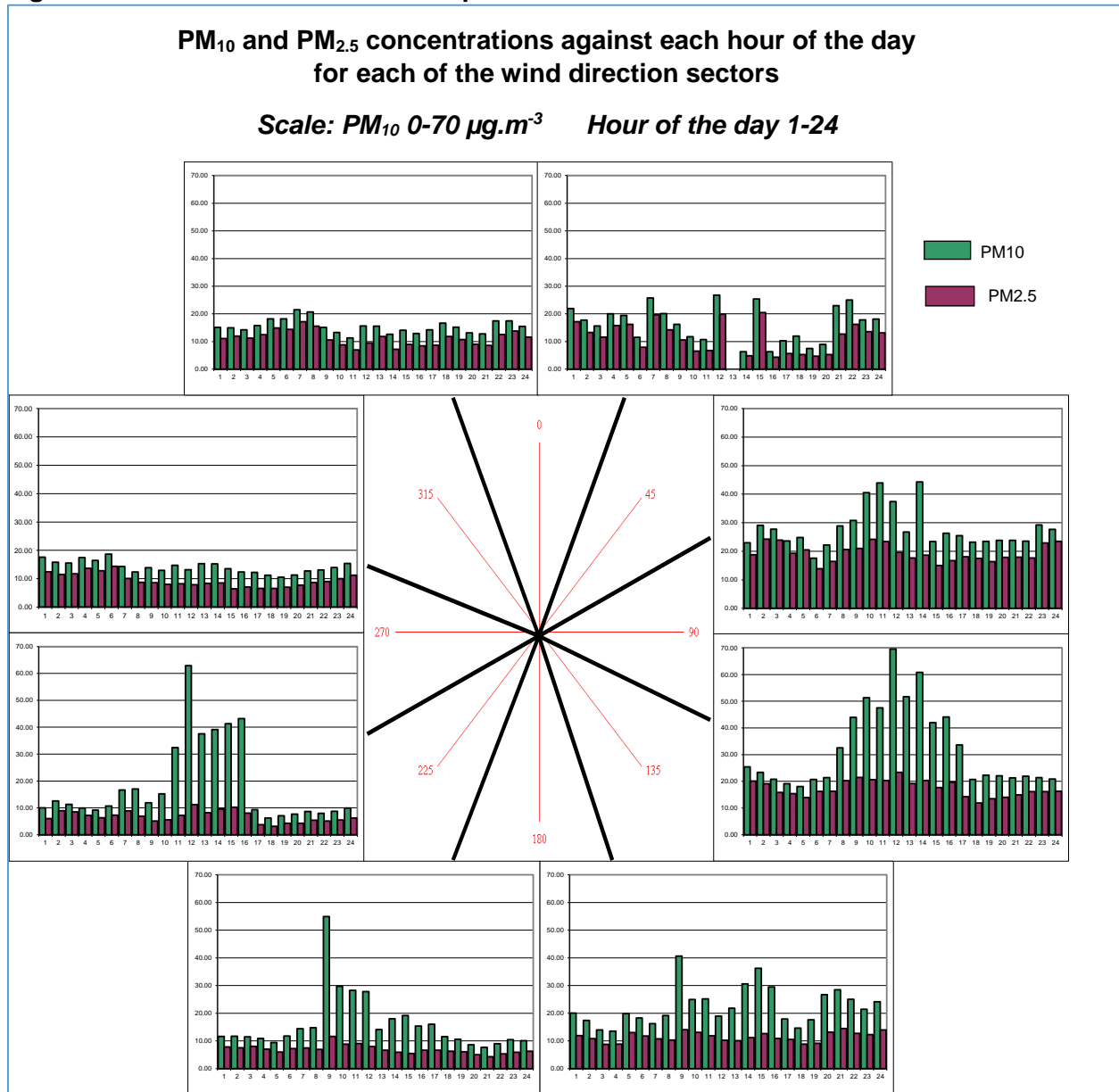
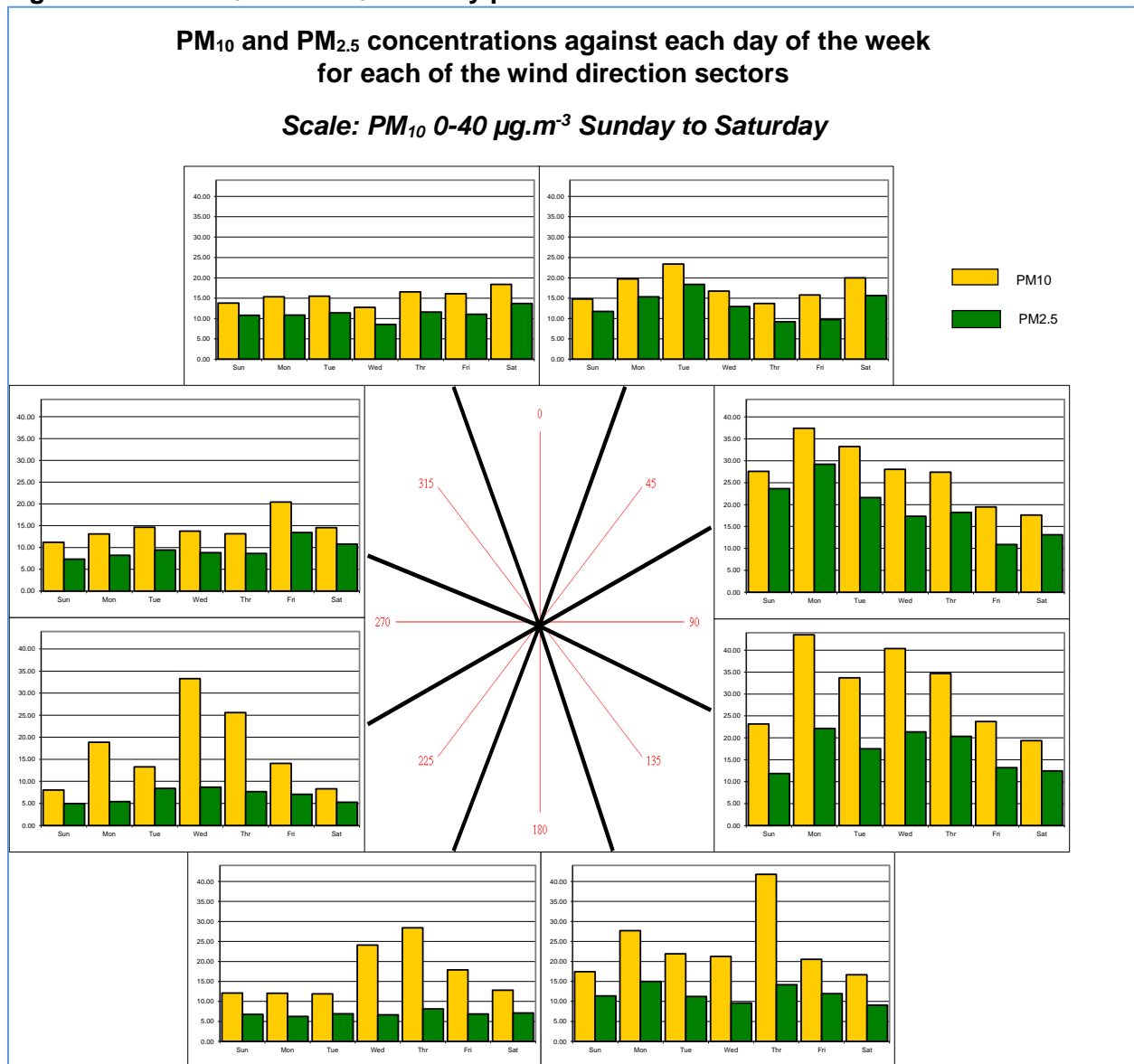


Figure 3.7.12 shows the weekday variation of mean PM₁₀ and PM_{2.5} concentrations for different wind directions at the MMF. The plots show that there were higher PM₁₀ concentrations during weekdays for wind directions 90° – 180° and 225° – 270°. High PM₁₀ and PM_{2.5} concentrations are seen on weekdays and weekends for wind direction 90° – 180°.

Figure 3.7.12: PM₁₀ and PM_{2.5} weekday plots



3.7.5 Conclusion

Comparison of the PM₁₀ data with the annual and 24-hour (midnight-midnight) mean AQS objectives indicated that the current standards would not be exceeded at the monitoring site.

Comparison of the PM_{2.5} data with the annual mean AQS objectives indicated that the current standard would not be exceeded at the monitoring site.

Consideration of PM₁₀ concentrations against the AQI banding showed that PM₁₀ concentrations were in the low banding at the monitoring site for 93% of the monitoring period and in the moderate banding for 5% of the monitoring period. There were two days during the monitoring period (2%) where the daily mean PM₁₀ concentration sat in the high AQI banding.

Consideration of PM_{2.5} concentrations against the AQI banding showed that concentrations were in the low banding at the monitoring site for 97% of the monitoring period and in the moderate banding for 2% of the monitoring period. There was one day during the monitoring period (1%) where the daily mean PM_{2.5} concentration sat in the high AQI banding.

Most of the days where the highest PM₁₀ and PM_{2.5} concentrations were seen were associated with regional pollution episodes, with easterly winds contributing polluted air from Europe.

Pollution rose analysis indicates that the highest mean PM₁₀ and PM_{2.5} concentrations measured at the monitoring site were from easterly wind directions between 70° - 150° and 70° - 130° respectively.

Percentile rose analysis suggested that the source of increased particulate at the monitoring site was continuous when the wind was between 70° - 150°. There was also an intermittent PM₁₀ source between 230° – 270°.

Wind speed variation analysis showed elevated PM₁₀ and PM_{2.5} concentrations at wind speeds >5m.s⁻¹ for wind directions between 110° – 140°.

Diurnal analysis suggests that the PM₁₀ source between 90° -135° is seen during the daytime only, suggesting a local source generated during the working day.

Weekday analysis showed that there were higher PM₁₀ concentrations during weekdays for wind directions 90° – 180° and 225° – 270° and higher PM₁₀ and PM_{2.5} concentrations seen on both weekdays and weekends for wind direction 90° – 180°.

4 Conclusion

Comparing the collected data from the monitoring at Silverdale with the AQS objectives showed that the monitoring location was subject to concentrations of PM₁₀, PM_{2.5}, NO₂, benzene, that were expected to meet their respective AQS objectives.

The H₂S 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 H₂S was within health limits but exceeded odour limits for 1% of the monitoring period.

The MMF was originally sited at a different monitoring location between the 15 January 2019 and 12 February 2019 (28 days) Comparison of the H₂S data with the WHO guidelines for odour annoyance of 7µg.m⁻³, as 30-minute mean concentrations, indicated that over this shorter monitoring period, the air quality at the monitoring site exceeded this guideline for around ~6% of the time, showing that the highest H₂S concentrations were seen in January and February over the winter months.

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

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

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

Pollutant	Averaging Time	AQS	Standard	Maximum Concentration	Permitted Exceedance (A)	Measured Exceedance	Extrapolated Exceedance* (B)	Projected Compliance Ratio (B/A)
PM ₁₀	24-hr (midnight-midnight)	2000	50µg.m ⁻³	91.5µg.m ⁻³	35/year	10	31	0.89
NO ₂	1-hr	2000	200µg.m ⁻³	60.7µg.m ⁻³	18/year	0	0	0.00

* Extrapolated from effective monitoring period

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

Pollutant	Averaging Time	AQS	Standard (A) ($\mu\text{g.m}^{-3}$)	Measurement* (B) ($\mu\text{g.m}^{-3}$)	Projected Compliance Ratio (B/A)
PM ₁₀	Year	2000	40	20.4	0.51
PM _{2.5}	Year	2007	25	11.4	0.46
NO ₂	Year	2000	40	12.6	0.32
Benzene	Year	Addendum 2003	5	0.23	0.05

* Extrapolated from effective monitoring period

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

Pollutant	Averaging Time	Standard	Standard (A) ($\mu\text{g.m}^{-3}$)	Measurement* (B) ($\mu\text{g.m}^{-3}$)	Projected Compliance Ratio (B/A)
NO _x	Year	2000 AQS	30	16	0.53

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

◇ The areas where the UK vegetation and ecosystem air quality objectives apply are based on the monitoring criteria for the vegetation and ecosystems limit values set under the 1st Air Quality Directive

1. More than 20km from an agglomeration (i.e. an area with a population of more than 250,000);
2. More than 5km away from industrial sources regulated under Part A of the Environment Act 1990 (and/or Part A1 sites under PPC regulations);
3. More than 5km away from motorways
4. More than 5km away from built up areas of more than 5000 people

*Extrapolated from effective monitoring period

Table 4.4 Impact summary of H₂S 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)	150 $\mu\text{g.m}^{-3}$	0
	30-Minute	7 $\mu\text{g.m}^{-3}$	1
Toluene	Weekly	0.26 mg.m^{-3}	0
	30-min	1 mg.m^{-3}	0

Table 4.5 Impact summary of VOC compliance with their EALs

Pollutant	Averaging Time	Standard	Standard (A) ($\mu\text{g}\cdot\text{m}^{-3}$)	Measurement* (B) ($\mu\text{g}\cdot\text{m}^{-3}$)	Projected Compliance Ratio (B/A)
Toluene	Year	Long-term EAL	1910 $\mu\text{g}\cdot\text{m}^{-3}$	1.35	0.00
Ethylbenzene	year	Long-term EAL	4410 $\mu\text{g}\cdot\text{m}^{-3}$	0.86	0.00
Xylenes	Year	Long-term EAL	2200 $\mu\text{g}\cdot\text{m}^{-3}$	2.41	0.00

* Extrapolated from effective monitoring period

Comparison of the data with the Defra Air Quality Index showed that levels during the study remained in the low banding of the Air Quality index for NO₂. PM₁₀ and PM_{2.5} daily mean concentrations remained primarily in the low banding of the index. PM₁₀ concentrations were in the moderate and high bandings for 5% and 2% of the monitoring period respectively. PM_{2.5} concentrations were in the moderate and high banding for 2% and 1% of the monitoring period respectively.

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

Directional analysis showed that there was a continuous source of CH₄ and H₂S from the direction of Walleys Quarry Landfill site and that a build-up of these compounds was seen under conditions of low wind speed and temperature and high pressure.

CH₄ concentrations were measured at lower concentrations at monitoring locations further away from the landfill site, suggesting that these sites were located further from the main source, this was supported by directional analysis showing that the highest CH₄ concentrations were from the direction of the landfill site.

Directional analysis suggests that there is also a relatively continuous NO_x source from the direction of the gas management compound on Walleys Quarry landfill site.

There was a much higher probability of measuring higher H₂S, CH₄ and NO_x concentrations (above the 75th percentile of the data set) when the wind was blowing from the direction of the landfill site.

Ethylbenzene and m&p-xylene concentrations were also above background concentrations from the direction of the landfill site at wind speeds <5m.s⁻¹.

Most of the days where the highest PM₁₀ and PM_{2.5} concentrations were seen were associated with regional pollution episodes, with easterly winds contributing polluted air from Europe. There was also an intermittent PM₁₀ source during the monitoring period between 230° – 270°. The data also suggests that there is a more localised PM₁₀ source for wind sector 90° – 135° that contributes to elevated concentrations during the working day, and on weekdays.

A time series plot for the pollutants monitored is shown in Figure 4.1

Table 4.6: Summary of mean pollution roses (H₂S and CH₄ roses for wind speeds >1m.s⁻¹)

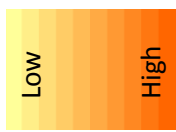
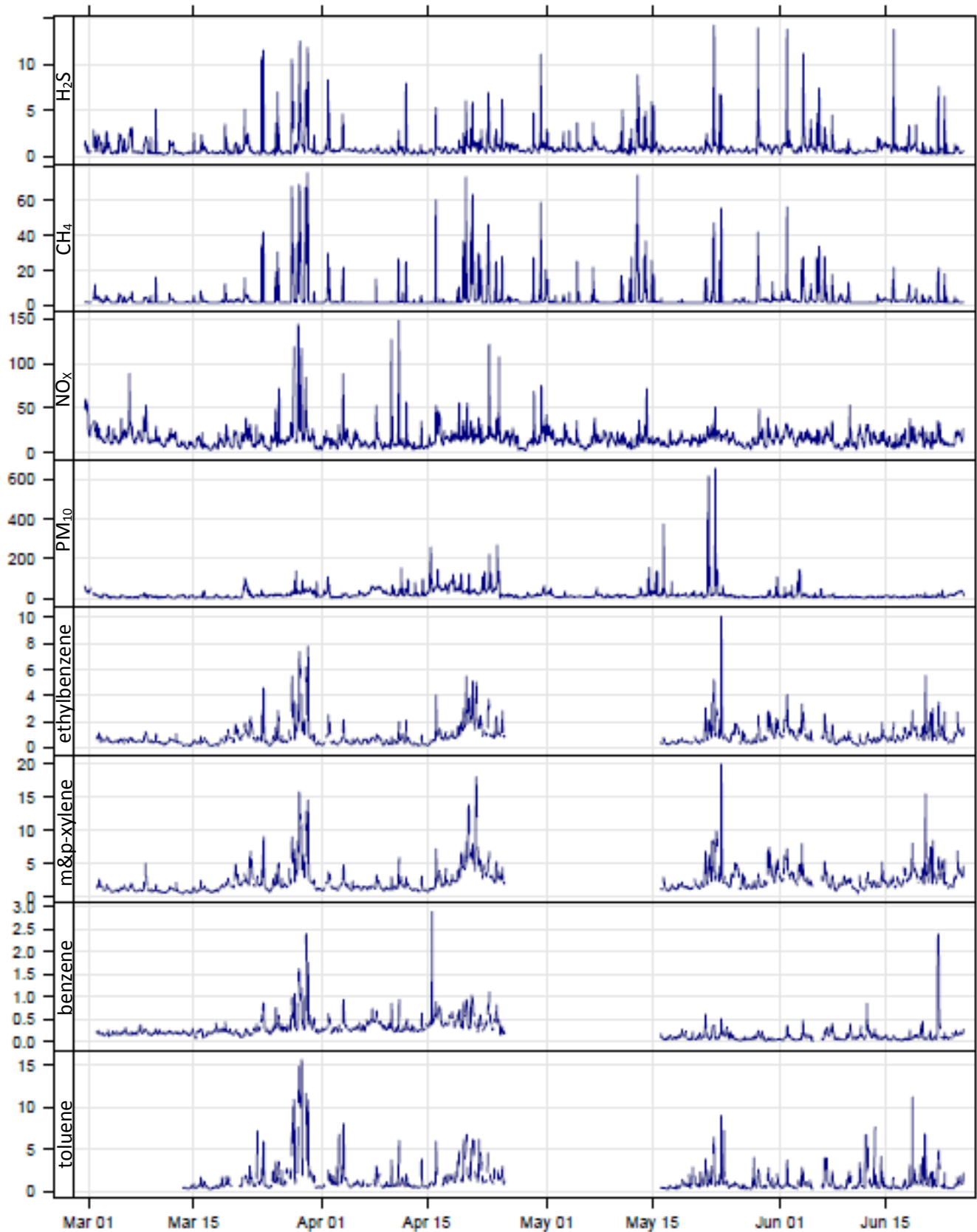
	Wind Direction (Degrees)																																						
	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320	330	340	350	360			
H ₂ S	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
CH ₄	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
NO _x	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
m&p-xylene	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
ethylbenzene	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
toluene	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
benzene	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
PM ₁₀	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low
PM _{2.5}	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low

Figure 4.1: 1-hour time series



5 References

1. Carslaw, D.C. (2015). The openair manual — open-source tools for analysing air pollution data. Manual for version 1.1-4, King's College London.
2. Department for Environment, Food and Rural Affairs (July 2007), The Air Quality Strategy for England, Scotland, Wales and Northern Ireland, (HMSO)
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Appendix A Additional Data (15 January 2019 and 12 February 2019)

This report provides the results of a study to investigate ambient air quality in the vicinity of Walleys Quarry Landfill, in Silverdale. The study was carried out by the Environment Agency's Ambient Air Monitoring (AAM) Team, on behalf of the Staffordshire Warwickshire and West Midlands Area.

The MMF was originally sited at a monitoring location in the car park of Garners garden centre (Site1 shown in Figure A1) between the 15 January 2019 and 12 February 2019 (28 days). This appendix presents the data collected over this short monitoring period. The MMF was then moved approximately 60m to a new location (Site 2).

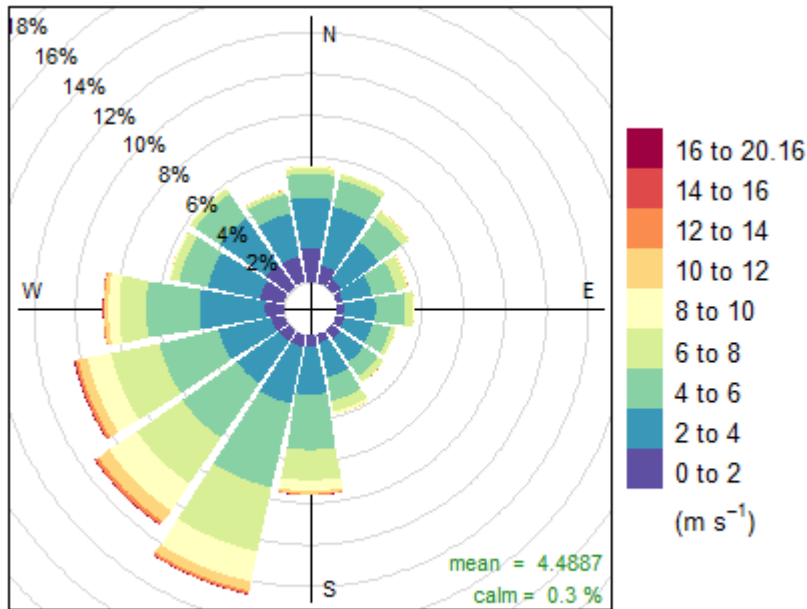
Figure A1: Map of Site 1 and Site 2 monitoring locations



The frequency distribution of wind direction at different wind speeds between 15 January 2019 and 12 February 2019 (28 days) is shown in Figure A2. The plot shows that over the period the dominant wind direction was from the south-west.

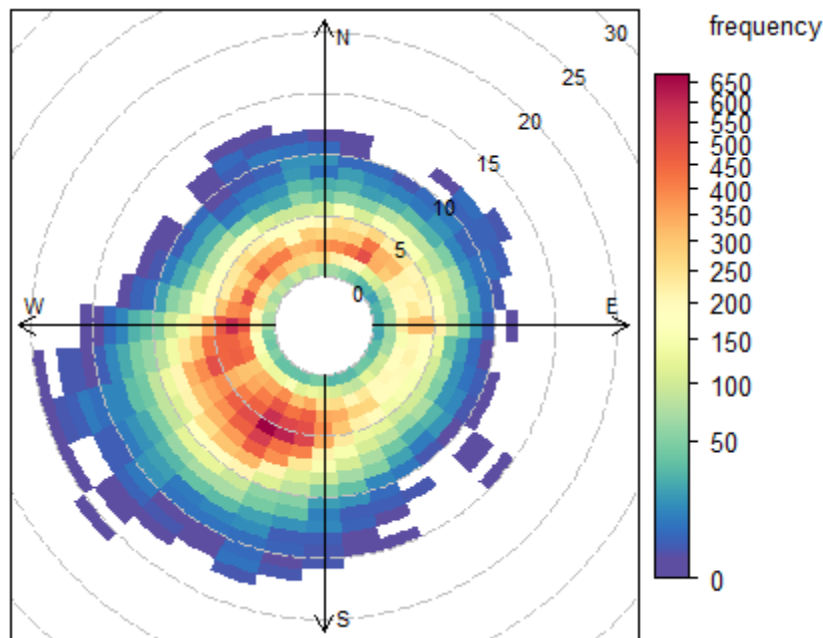
Figure A3 shows that the most prevalent wind speeds were between $2-10\text{m}\cdot\text{s}^{-1}$ between $180^\circ - 270^\circ$. The wind speed frequencies for all wind directions are summarised in Table 3.1.1.

Figure A2: Wind Rose (%)



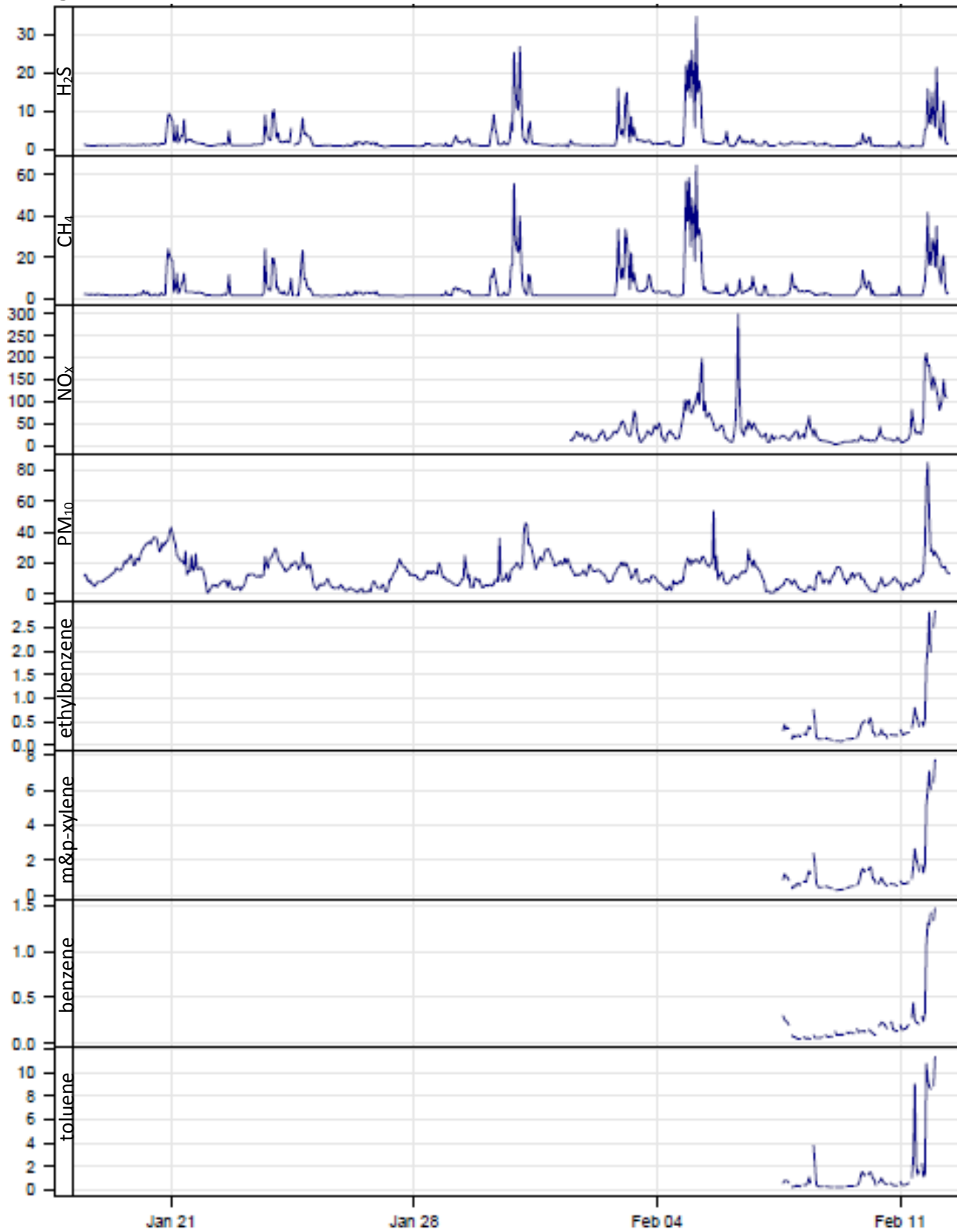
Frequency of counts by wind direction (%)

Figure A3: Polar plot of wind speed frequency (from 5-minute values)



A time series plot for the pollutants monitored between 15 January 2019 and 12 February 2019 (28 days) is shown in Figure A4. The BTEX data is only reported from the 7th February 2019, due to technical problems with the instrument prior to this date. The data shows a similar trend in H_2S and CH_4 concentrations.

Figure A4: 1-Hour Mean Concentrations



Appendix B 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 Silverdale study was MMF3. The pollutants measured using MMF3 were:

- particles (PM₁₀ & PM_{2.5})
- hydrogen sulphide (H₂S)
- methane (CH₄)
- oxides of nitrogen (NO_x)
- BTEX (benzene, toluene, ethylbenzene, m&p-xylene)

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,
- temperature
- pressure

Wind direction and wind speed measurements are taken at an elevation of 8m above the ground and from positions where the wind approach was unobstructed. The temporal resolution of the data is 5 minutes. Temperature and pressure were measured by the particulate monitor (Fidas 200) at an elevation of 2m above the ground. The temporal resolution of the data is 15 minutes.

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

Appendix C 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 D Hydrogen Sulphide (H₂S)

Hydrogen sulphide (H₂S) is a colourless, toxic and flammable gas, with a characteristic odour of 'rotten eggs'.

Sources

Hydrogen sulphide is produced naturally in the environment by emissions from volcanoes and geothermal activity, microbial decomposition of organic material in the absence of oxygen (anaerobic digestion) in swamps and saltmarshes and is an important participant in the natural sulphur cycle. Natural sources account for 90% of the global H₂S emissions, whilst the other 10% is emitted from anthropogenic sources such as oil refineries, coke ovens, tanneries, paper mills (using the Kraft process (sulphate process)), wastewater treatment plants, viscose rayon textile production, landfills and farm manure storage facilities, to name but a few.

Human Health and Standards

'Although it is unlikely that the general population will be exposed to a level of H₂S high enough to cause adverse health effects' ⁽¹⁾, levels around some industrial sources can cause a nuisance due to the unpleasant odour associated with the hydrogen sulphide. The odour threshold (point above which an odour can be perceived by 50% of a human panel) for H₂S is between 0.2 – 2ug.m⁻³ depending on the purity. However, at these levels the human nose can only detect that an odour is present, the characteristic 'rotten egg' odour is not perceptible until 3-4 times this threshold level.

The World Health Organisation (WHO) has set two guidelines for H₂S, a health standard and an odour threshold above which substantial complaints with regard to odour nuisance should be expected.

Health guideline: 150ug.m⁻³ as a 24-hour mean

Odour guideline: 7µg.m⁻³ as a 30-minute mean

The health guideline is based on the lowest level of H₂S to cause an adverse effect, which is 15mg.m⁻³ (15,000µg.m⁻³), where it has been shown to cause eye irritation. A high protection (safety) factor of 100 is then applied and the guideline of 0.15mg.m⁻³ (150µg.m⁻³) over a 24-hour averaging time is the result.

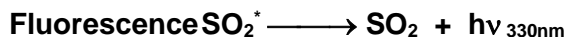
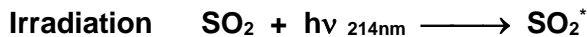
The high protection factor applied to create the guideline for health is a result of the marked toxicity of H₂S with increasing concentration above the first observable adverse effect.

H₂S analyser

The analyser used to measure hydrogen sulphide is an API T101 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.

The operation of the sulphur dioxide analysers is based on the measurement of fluorescence from SO₂ due to absorption of UV energy. An ultraviolet (UV) lamp emits radiation that passes through a filter admitting only light with a wavelength of 214nm. This radiation excites SO₂ molecules in the sampling air. These excited SO₂ molecules quickly return to their ground

state by emitting a photon at a longer wavelength (330nm) and this fluorescence can then be measured by a PMT with a secondary UV filter. The equations describing the reactions are:



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

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

where I_0 is the UV light intensity, a the absorption coefficient of SO_2 , x the path length, and (SO_2) the concentration of SO_2 . When the SO_2 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 SO_2 . 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.

References

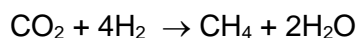
1. 'Hydrogen Sulphide: General Information', Public Health England, Toxicology Department, CRCE, PHE 2009 (version 1)
2. World Health Organisation (2000), *WHO Air Quality Guidelines for Europe*
3. 'Model T101 UV Fluorescence H₂S Analyser', User Manual, Teledyne Advanced Pollution Instrumentation, August 2016

Appendix E Methane (CH₄)

Methane, commonly known as marsh gas, is a colourless, odourless gas with a melting point of -184°C and boiling point -164°C. Its main environmental impact is from its relatively high potential for global warming. It affects the radiation balance of the Earth by absorbing infrared radiation and converting it to heat, therefore increased methane concentrations lead to increased surface temperatures.

Sources

Methane is produced by anaerobic bacterial fermentation processes in water that contains substantial organic matter, such as swamps, marshes, rice fields, lakes and landfills. This microbial degradation of organic matter may be written:



Methane is also produced by enteric fermentation in mammals and other species.

Until the late 1970s, it was accepted that the background concentration of methane was in the range of 1.4 – 1.6 ppm, since then ambient levels have risen to a background norm of approximately 1.8ppm. The increase in methane background concentrations is mainly due to an increase in the emissions from primary sources. However the reduction in environmental levels of the hydroxide radical [OH] brought about by the increased levels of carbon monoxide (CO) also plays a part.

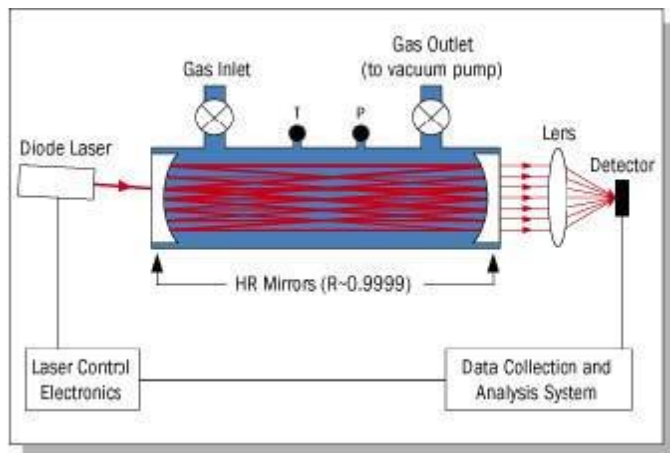
CH₄ Analysers

The analyser used was a Los Gatos CH₄ analyser, which uses Off Axis Integrated Cavity Output Spectroscopy (OA-ICOS).

'Until recently, high-sensitivity trace-gas measurements have been possible only by using expensive lasers (e.g., lead-salt or quantum-cascade) or broadband lamps that operate in the mid-infrared region where absorption features are strong. LGR's advances in cavity-enhanced absorption-spectroscopy techniques provide dramatic increases in the optical path length and as a result, enable ultrasensitive trace-gas measurements using robust, reliable, room-temperature diode lasers that operate in the near infrared.

Off-Axis ICOS utilizes a high-finesse optical cavity as an absorption cell as shown in Figure 8. Unlike conventional multi-pass arrangements, which are typically limited to path lengths less than two-hundred meters, an Off-Axis ICOS absorption cell effectively traps the laser photon so that, on mean, they make thousands of passes before leaving the cell. As a result, the effective optical path length may be several thousands of meters using high-reflectivity mirrors and thus the measured absorption of light after it passes through the optical cavity is significantly enhanced. For example, for a cell composed of two 99.99% reflectivity mirrors spaced by 25 cm, the effective optical path length is 2500 meters.

Figure 1: Schematic diagram of an Off-Axis ICOS Instrument



Because the path length depends only on optical losses in the cavity and not on a unique beam trajectory (like conventional multipass cells or cavity-ring-down systems), the optical alignment is very robust allowing for reliable operation in the field. The effective optical path length is determined routinely by simply switching the laser off and measuring the necessary time for light to leave the cavity (typically tens of microseconds).

As with conventional tunable-laser absorption-spectroscopy methods, the wavelength of the laser is turned over a selected absorption feature of the target species. The measured absorption spectra is recorded and combined with measured gas temperature and pressure in the cell, effective path length, and known line strength, used to determine a quantitative measurement of mixing ratio directly and without external calibration.'

References

1. Los Gatos Economical Ammonia Analyser User Manual.

Appendix F Oxides of Nitrogen (NO_x)

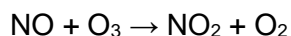
Nitrogen dioxide is a gas produced by the reaction of nitrogen and oxygen in combustion processes. The nitrogen is most commonly atmospheric nitrogen, although nitrogen atoms in the combustion fuel can also be involved. The reaction usually takes place in two stages, the first, at high temperature, between 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 sometime 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 PM₁₀.

Sources

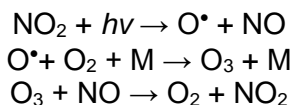
There are several natural sources of oxides of nitrogen in the atmosphere, including lightning and forest fires. However, by far the largest amount is formed as a consequence of combustion of fossil fuels - petrol, oil, coal and gas. In the UK in 1994 fossil fuelled power stations accounted for 24% of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

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



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

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



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

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:



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

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

Assessment of compliance for NO₂ chemiluminescence analyser according to ISO 14956			
MonitorLabs ML 9841B Nitrogen Dioxide Analyser			
2000 NAQS for NO ₂ concentrations		1 hour limit value 105ppb	
Measurement performance related to dynamic conditions			
Performance Characteristic	Value	Distribution Type	Standard Uncertainty at 100ppb
Linearity	1% of reading	Rectangular	0.6ppb
Precision	0.5ppb or 1% of reading	Normal	1ppb
Zero Drift	2ppb	Rectangular	0.6ppb
Span Drift	0.5% of reading	Rectangular	0.3ppb
Noise	0.25ppb	Rectangular	0.15ppb
Losses in collection system (i.e. sample lines, filters etc)	10%	Rectangular	6ppb
Standard uncertainty of Calibration gas	10%	Rectangular	6ppb
Total standard uncertainty			8.5ppb
Total uncertainty for NO₂ (95% confidence)			14ppb

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

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

Appendix 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 carbon-containing 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 G2.1 lists a number of VOCs, and gives their emission due to motor vehicles and non-motor vehicle sources, extracted from the NAEI 1997. Table G2.1 also 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 (C₂H₄) 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).

Table F2.1 VOC Emission Data and POCPs

Measured VOC	Motor Vehicle Emissions (kt/Annum) \$	Non-Motor Vehicle Emissions (kt/annum) \$	Total Emissions (kt/annum) \$	POCP \$\$
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

\$ 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

Appendix H Particulate (PM₁₀ & PM_{2.5})

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

Sources

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

The major PM components are 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 PM concentration is a Palas Fidas 200 optical measuring system. It provides measurements of TSP, PM₁₀, PM₄, PM_{2.5} and PM₁ in real time and stores them as 15-minute means.

The Fidas measures PM using an optical light scattering technique and uses an algorithm to calculate concentrations based upon the number and size distribution of particles.

The Fidas has a flow volume of 0.3 m³/h (flow rate of 4.8 l/m). The inlet is fitted with a Sigma-2 (TSP) sampling head which allows the full range of particle sizes to reach the Intelligent Aerosol Drying System (IADS). The IADS conditions the sampled air, which helps prevent possible measurement inaccuracies due to condensation during periods of high ambient air humidity.

Once the sample has been conditioned the particle size is determined using the Lorenz-Mie scattered light analysis of single particles by an optical aerosol spectrometer. The spectrometer measures the scattered light impulse generated by each particle as it is illuminated by a white LED light at an angle of 90°. The number of scattered light impulses allows the determination of the particle number and the height of the impulse is related to particle size. The scattered light signal is then allocated to a particle size diameter bin using a calibration curve and measurement of the signal number. The bins are then used to form a histogram of the measured particle sizes.

A number of computational steps are required to convert the measured particle sizes in to a mass concentration. The measured size distribution is altered to a distribution based on a representative index for environmental aerosol. To account for the variability in the shape of each particle the distribution is altered from optical diameter (spherical shape) to reflect the aerodynamic diameter (variable shape) of the particles. Once the distribution has been altered to account for the refractive index and diameter the EU particle distribution line is used to apply the cut curves for each of the PM fractions.

The data is then converted from particle size to particle mass using a size dependent density algorithm. This system allows for a lower detection limit of 180nm with a sampling range of 0.18 - 18µm.

Appendix I Percentile Analysis

Percentile analysis provides a method of looking at the distribution of concentrations within a data set.

Excel calculates percentiles by first sorting the concentrations into ascending order and then ranking each concentration. It then uses the following formula's

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

P = the percentile you want

n = the total number of values

I = the integer part of the ranking

D = the decimal part of the ranking

r = rank

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

Y_I = value corresponding to the rank I

p = Value of the required percentile

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

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

By separating the data into various wind sectors, it allows you to assess which wind directions are having the greatest influence on pollutant concentrations at the monitoring site. By calculating the mean 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.

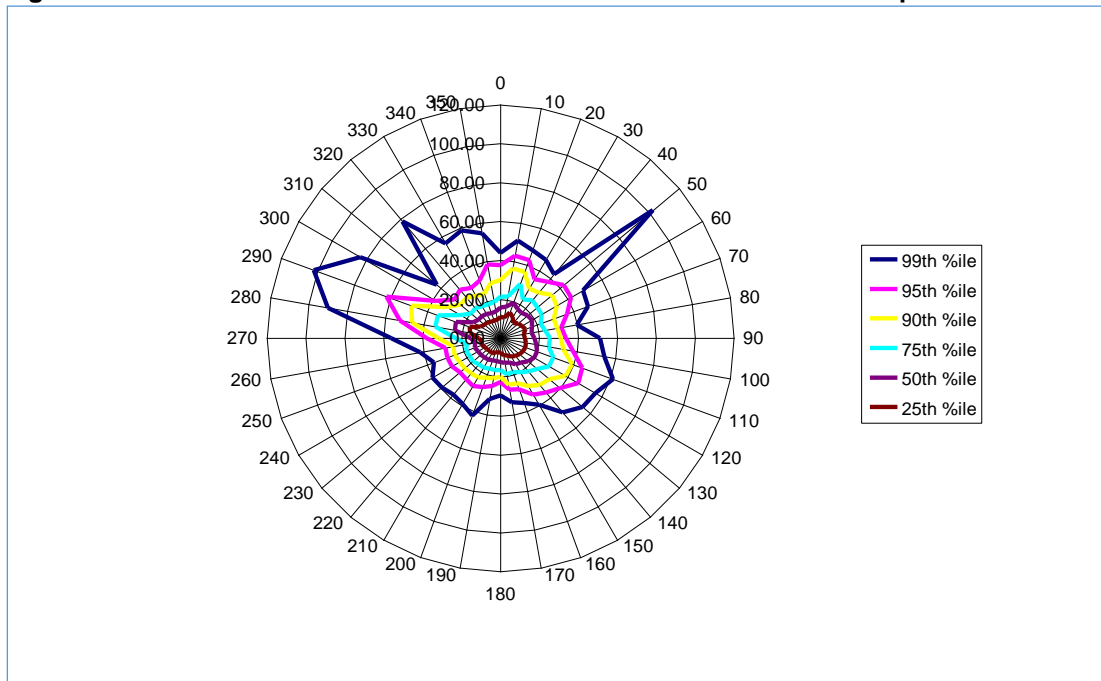


Figure 2. Shows a bias at 260° that is only evident in the 99th percentile.

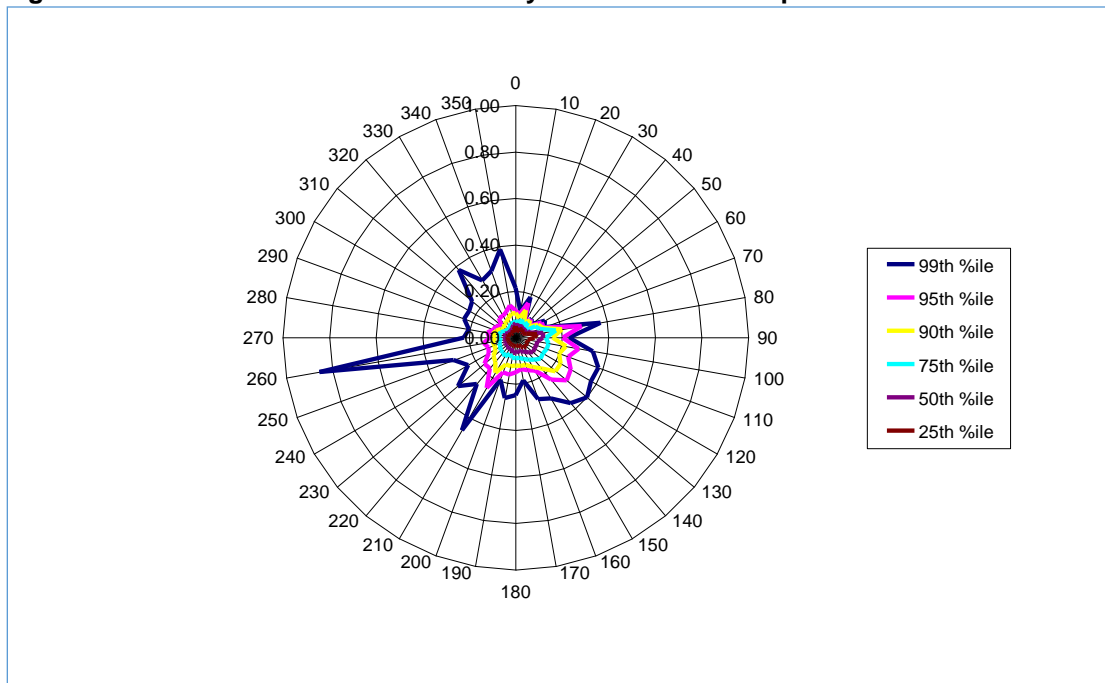
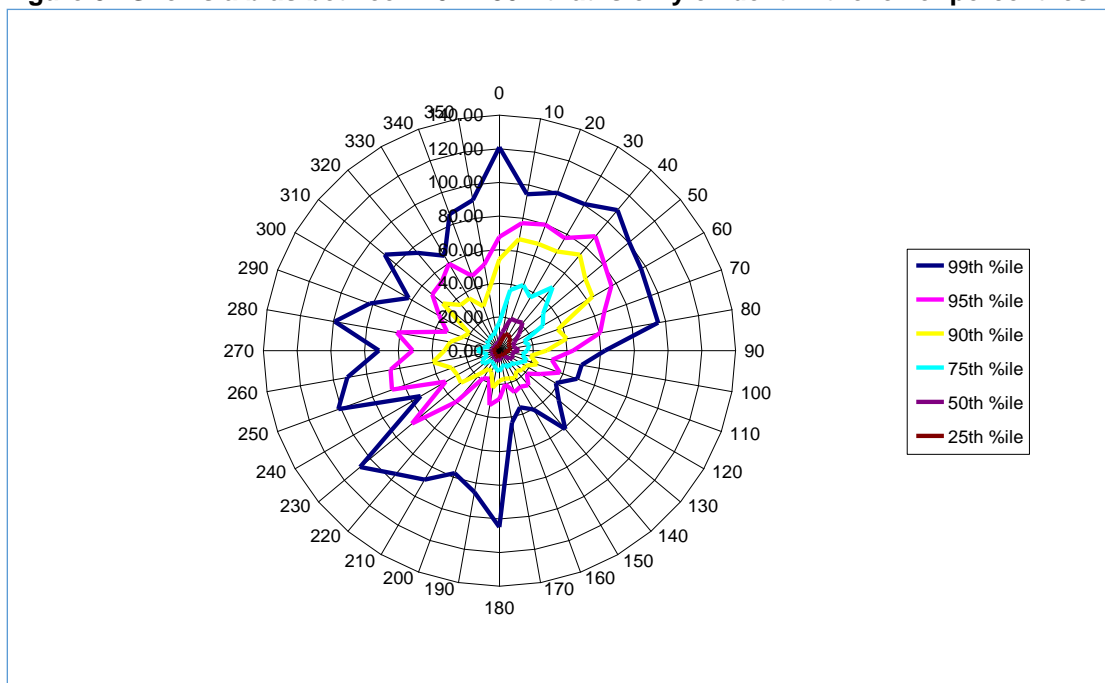


Figure 3. Shows a bias between 20° – 50° that is only evident in the lower percentiles.



Appendix J Conditional Probability Function (CPF) plots in Openair

Conditional Probability Function (CPF) plots have been used in this report, using the Openair software package in R, to help identify the wind direction and wind speeds from which the most prominent pollutant sources are likely to occur.

The Conditional Probability Function calculates the probability that in a particular wind sector the concentration of a species is greater than some specified value. The value specified is usually expressed as a high percentile of the species of interest e.g. the 75th or 90th percentile. CPF analysis is very useful for showing which wind directions are dominated by high concentrations and give the probability of doing so (example in Figure 1).

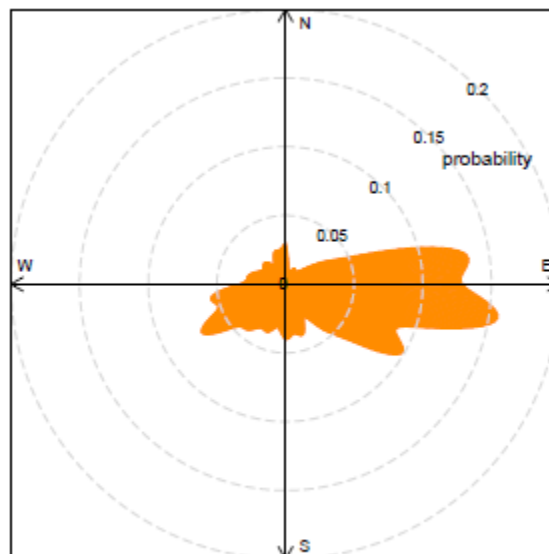
The CPF is defined as

$$CPF_{\Delta\theta} = m_{\Delta\theta} | C_{\geq x} / n_{\Delta\theta}$$

Where $m_{\Delta\theta}$ is the number of samples in the wind sector θ having concentration C is greater than or equal to a threshold value x , and $n_{\Delta\theta}$ is the total number of samples from wind sector $\Delta\theta$. Thus, CPF indicates the potential for a source region to contribute to high air pollution concentrations. Conventionally, x represents a high percentile of concentration e.g. the 75th or 90th percentile.

Therefore where you have experienced a high number of data points with values greater than your chosen threshold value, for a particular wind direction, you will have a higher probability value for that wind direction.

Figure 1: CPF plot of SO₂ concentrations at Marlybone Road



CPF at the 95th percentile (=11.3)

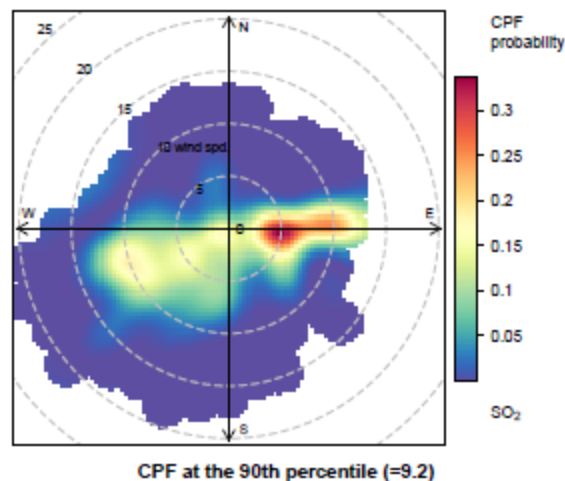
The conditional bivariate probability function (CBPF) couples ordinary CPF with wind speed as a third variable, allocating the observed pollutant concentration to cells defined by ranges of wind direction and wind speed rather than to only wind direction sectors (example in Figure 2).

It can be defined as:

$$CBPF\Delta\theta, \Delta u = m\Delta\theta, \Delta u \mid C \geq x / n\Delta\theta, \Delta u$$

Where $m\Delta\theta, \Delta u$ is the number of samples in the wind sector $\Delta\theta$ with wind speed interval Δu having concentration C greater than a threshold value x , $n\Delta\theta, \Delta u$ is the total number of samples in that wind direction-speed interval.

Figure 2: Polar plot of SO₂ concentrations at Marylebone Road based on the CPF function



Therefore where you have experienced a high number of data points with values greater than your chosen threshold value, for a particular wind direction and wind speed, you will have a higher probability value for that wind direction and speed.

The extension to the bivariate case provides more information on the nature of the sources because different source types can have different wind speed dependencies. The use of a third variable can therefore provide more information on the type of source in question. It should be noted that the third variable plotted on the radial axis does not need to be wind speed, it could for example be temperature. The key issue is that the third variable allows some sort of discrimination between source types due to the way they disperse.

The scale of a CPF plots ranges from 0 – 1, from lowest to highest probability.

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2. Uria-Tellaetxe, I. and D. C. Carslaw (2014). "Conditional bivariate probability function for source identification". In: Environmental Modelling & Software 59, pp. 1–9. DOI: 10.1016/j.envsoft.2014.05.002 (cit. on pp. 125, 135, 136).

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