RICARDO-AEA

Air Quality at Heathrow Airport – Annual Report for 2013

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Executive Summary

This report presents a summary of the 2013 results from an ongoing programme of air pollution monitoring undertaken on behalf of Heathrow Airport Ltd. The aim is to monitor air pollution around the airport, to provide a reliable assessment of the pollutant concentrations to which local residents are exposed, and assess whether these meet applicable air quality standards and guidelines. The monitoring programme also aims to investigate how air pollutant concentrations have varied over time.

Monitoring continued at four sites.

- LHR2 which is located on the northern apron, near the airport boundary and perimeter road. This site has been used since 1993.
- London Harlington (which is part of the UK's national monitoring network, the Automatic Urban and Rural Network). The site was established in 2003.
- Green Gates (near the north western airport perimeter) which has been operational since 2001, and included in the survey since 2007.
- Oaks Road (a residential location to the south west) which has also been operational since 2001, and included in this survey since 2007.

Oxides of nitrogen and particulate matter (PM_{10} and the finer size fraction $PM_{2.5}$) were measured at all four sites throughout 2013. Ozone was measured only at Harlington. Indicative monitoring of hydrocarbons including benzene (by diffusion tubes) was also undertaken at LHR2.

All four sites met the Air Quality Strategy (AQS) objective for 1-hour mean NO_2 concentration in 2013. Air quality monitoring site LHR2 exceeded the AQS objective of 40 µg m^{-3} for annual mean NO_2 concentration, although the EU limit values and AQS objectives do not apply at the LHR2 site, because it is within the airport boundary where there is no public exposure. The other three sites met this objective.

All four sites met the AQS objectives for daily mean and annual mean PM_{10} particulate matter, and the target value for $PM_{2.5}$ particulate matter.

The Harlington site (the only one at which ozone was measured) had more than the 10 permitted exceedances of the AQS objective for this pollutant, in 2013.

The indicative annual mean concentration of benzene at Heathrow (LHR2) was well within the AQS objective.

Average concentrations of NO, NO_2, PM_{10}, $PM_{2.5}$ and ozone at the Heathrow sites were generally comparable to those measured at urban background air pollution monitoring sites in London.

The pattern of monthly averaged concentrations throughout the year showed that concentrations of the primary pollutant NO were typically highest in the winter months. NO_2, which has both primary and secondary components, showed a similar pattern. PM_{10} and $PM_{2.5}$ showed a much less pronounced seasonal pattern, which is quite common for particulates in urban areas. Ozone (measured at Harlington only) showed higher concentrations in the spring and summer. This is a typical seasonal pattern for ozone, which is formed from other pollutants in the presence of sunlight.

Meteorological measurements at LHR2 allowed the effect of wind speed and wind direction to be investigated. Bivariate plots of pollutant concentration indicated that nearby sources, such as the perimeter road, were probably the main source of NO. There were also high NO concentrations at greater wind speeds from the south west and north east. In the case of NO_2, there also appeared to be a contribution from the south west at higher wind speeds. For both PM_{10} and $PM_{2.5}$, concentrations were high under calm conditions but (particularly for

PM_{10}) there also appeared to be contributions from the north east and south west at a range of wind speeds.

Several periods of elevated PM_{10} concentration occurred during 2013, going into the Defra "Moderate" band. These periods of elevated particulate pollution were also observed at other sites throughout London. They appear to reflect regional variations in particulate pollution, and may not be directly connected with the airport.

Harlington had 16 days of "Moderate" $PM_{2.5}$ and one day of "High" $PM_{2.5}$. The latter occurred in September. All the other sites remained in the "Low" band for this particulate fraction.

There were 54 periods of elevated ozone concentration during 2013, with concentrations going into the "Moderate" band on 11 days.

In the long term, annual mean concentrations of total oxides of nitrogen and NO appear to show a general decrease over the past decade (although there is considerable year-to-year fluctuation). The trend for NO_2 is less clear. The proportion of NOx measured as NO_2 has increased. There is some indication that annual mean concentrations of PM_{10} have increased since 2008, but trends are not clear, and annual means are generally consistent with those measured at other sites in London. There is no significant trend in ozone (monitored at Harlington only).

Although the airport is likely to be a significant contributor to local air pollutant concentrations, there appears to be no relationship between air traffic movements and ambient pollutant concentrations, either on a seasonal or long-term basis. This indicates that variations in ambient concentration are mainly driven by other factors (such as variations in meteorological conditions and emissions from non-airport sources such as road transport and stationary combustion processes). Air quality in the wider region can also be significantly influenced by long-range transboundary air pollution.

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1 Introduction

1.1 Background

Heathrow Airport is the world's busiest international airport, handling approximately 72 million passengers in 2013. The airport is situated approximately 12 miles to the west of London, but within the general urbanised area of Greater London.

Airports are potentially significant sources of many air pollutants. Aircraft jet engines emit pollutants including oxides of nitrogen (NOx), carbon monoxide (CO), oxides of sulphur (SOx), particulate matter, hydrocarbons from partially combusted fuel, and other trace compounds. There are also pollutant emissions from the airside vehicles, and from the large number of road vehicles travelling to and from the airport each day. Also, Heathrow Airport is situated in an urban area, containing many domestic, commercial and industrial sources of pollution.

Heathrow Airport Ltd therefore carries out monitoring of ambient air quality at four sites around the airport: on the northern apron near the perimeter (site LHR2), and outside the airport boundary at Harlington, Green Gates and Oaks Road.

The pollutants monitored were as follows:

- oxides of nitrogen (nitric oxide (NO) and nitrogen dioxide (NO_2));
- particulate matter (PM_{10} and $PM_{2.5}$ fractions);
- ozone (O_3)
- volatile organic compounds (VOCs) – benzene, toluene, ethylbenzene and xylenes.

The monitoring is undertaken by Ricardo-AEA Ltd, on behalf of Heathrow Airport Ltd. 2013 was the 21st consecutive year of this ongoing monitoring programme, and this report presents and summarises the fully validated and quality controlled dataset for the period 1st January to 31st December 2013.

In addition to this report, Heathrow Airport has daily access to provisional data from the Heathrow monitoring sites via the Heathrow Airwatch website[1] and data from the UK's national air quality monitoring network, through the Defra UK Air Information Resource (UK-AIR)[2].

1.2 Objectives

The objective of the monitoring programme, as in previous years, was to provide information on levels of air pollution to which the neighbouring community may be exposed. The programme was also required to provide a reliable assessment in relation to applicable air quality standards and to determine any trends in air pollution concentrations over time. Additionally, meteorological data were used to investigate the importance of various sources of pollution.

It is important to note that the pollutants measured in this study will have originated from a wide variety of sources, both local and long range. Not all of these sources will be directly connected with the airport.

2 Details of the monitoring programme

2.1 Pollutants monitored

The monitoring programme concentrated on the pollutants which may be of concern around airports. These are listed below. The emission statistics presented here all come from the National Atmospheric Emissions Inventory (NAEI)[3].

2.1.1 Oxides of nitrogen

Combustion processes emit a mixture of oxides of nitrogen, mainly nitric oxide (NO) and nitrogen dioxide (NO_2), collectively termed NOx. NO is described as a "primary" pollutant, i.e. it is directly emitted from source. Though NO is not known to have any harmful effects on human health at ambient concentrations, it undergoes oxidation in the atmosphere to form the secondary pollutant NO_2. NO_2 is a respiratory irritant and is toxic at high concentrations. It is also involved in the formation of photochemical smog and acid rain and may cause damage to crops and vegetation.

Major outdoor sources of NOx in urban areas are fuel combustion in motor vehicles (which account for around one third of total UK emissions), power generation, heating plant and industrial processes. Of the NOx emissions (including NO_2) considered to be airport-related, 72% occur from the aircraft during take-off and landing, although much of this will be at some distance from airport ground-level. The Air Quality Expert Group (AQEG)[4] has stated that: "*Around a third of all NOx emissions from the aircraft (including ground-level emissions from auxiliary power units, engine testing etc, as well as take-off and landing) occur below 100 m in height. The remaining two-thirds occur between 100 m and 1000 m and contribute little to ground-level concentrations. Receptor modelling studies … show the impact of airport activities on ground-level NO_2 concentrations. Studies have shown that although emissions associated with road traffic are smaller than those associated with aircraft, their impact on population exposure at locations around the airport are larger*". Previous rounds of review and assessment within the LAQM process have not highlighted any cases where airports appear to have caused exceedances of air quality objectives for particulate matter measured as PM_{10}. Therefore, in the context of LAQM, the key pollutant of concern from airports is NO_2. Local Authorities whose areas contain airports with over 10 million passengers per annum must take these into account in their annual review and assessment of air quality[4].

2.1.2 Particulate matter

Airborne particulate matter varies widely in its physical and chemical composition, source and particle size. Particulate matter is categorised by particle size: it is most commonly monitored as PM_{10} (i.e. particles whose effective size is <10 µm) and $PM_{2.5}$ (i.e. particles with effective size <2.5 µm). Fine particles are of most concern, as they are small enough to penetrate deep into the lungs, where they can have the greatest impact upon health.

The main sources of airborne particulate matter in the UK are combustion (industrial, commercial and residential fuel use). This is followed by road vehicle emissions. Based on 2011 NAEI data, 0.07% of UK total PM_{10} emissions were believed to originate from civil aircraft taking off and landing[3]. Although this represents a small contribution to the national total, particulate matter is of concern at a local level because of its potential for health impacts.

2.1.3 Ozone

Ozone (O_3) is not emitted directly into the atmosphere in significant quantities, but is a secondary pollutant produced by reaction between nitrogen dioxide (NO_2) and hydrocarbons, in the presence of sunlight. Whereas nitrogen dioxide (NO_2) contributes to ozone formation, nitrogen oxide (NO) destroys ozone and therefore acts as a local sink. For this reason, ozone levels are not as high in urban areas (where NO is emitted from vehicles) as in rural areas. Ozone levels are usually highest in rural areas, particularly in hot, still, sunny weather conditions giving rise to "summer smog".

2.1.4 Volatile Organic Compounds

Volatile organic compounds (VOCs) include a wide range of carbon-based chemical species. These can be present either in the gaseous phase, or carried by particulate matter. The main UK sources of volatile organic compounds are solvent use, and the extraction and distribution of fossil fuels[3]. VOCs are also emitted from incomplete combustion of fuels in vehicles and other combustion processes.

It is not easy to measure all of these hydrocarbon species (particularly the most volatile) without expensive continuous monitoring systems. However, there are four moderately volatile species, all of which may be associated with fuels and vehicle emissions, which are easy to monitor using passive samplers. These are benzene, toluene, ethylbenzene and xylenes. They are not the largest constituents of vehicle emissions, but due to their moderate volatility they can be monitored using simple diffusive samplers.

(i) Benzene

Of the above four hydrocarbons, benzene is of greatest concern, as it is a known human carcinogen. The major source of benzene in ambient air is the evaporation and combustion of petroleum-based fuels. Data from the NAEI[3] for 2011 indicate that civil aircraft taking off and landing are estimated to make a negligible contribution to total UK benzene emissions. Benzene is the only one of the above compounds for which there are mandatory limit values or objectives for ambient concentrations.

(ii) Toluene

The main use of toluene is as a solvent in paints and inks. It also occurs in petrol in small concentrations. Toluene has been found to adversely affect human health, and there are occupational limits for workplace exposure, but no mandatory limits on outdoor ambient concentrations.

(iii) Ethylbenzene

Again, there are no limits for ambient concentration of ethylbenzene. Although there are occupational limits relating to workplace exposure, these are several orders of magnitude higher than typical outdoor ambient concentrations.

(iv) Xylenes

Xylene exists in ortho (o), para (p) and meta (m) isomers. There are no limits for ambient concentration of xylenes, although (as in the case of toluene and ethylbenzene) there are occupational limits relating to workplace exposure. Xylene is used as a solvent, and can cause odour nuisance near processes which use it (such as vehicle paint spraying).

2.2 Air quality limit values and objectives

This report compares the results of the monitoring survey with air quality limit values and objectives applicable in the UK. The relevant limit values and objectives are summarised below.

2.2.1 European Union

Throughout Europe, ambient air quality is regulated by the European Union (EU) Directive on ambient air quality and cleaner air for Europe (2008/50/EC)[5]. This Directive (referred to as the Air Quality Directive) consolidated three previously existing Directives, which set limit values for a range of air pollutants with known health impacts including NO_2, PM_{10} and benzene.

All Member States of the European Union are required to transpose the provisions of the Directive into their national law. The original Directives were transposed into UK law via the Environment Act 1995 and subsequent Statutory Instruments.

2.2.2 The UK Air Quality Strategy

The Environment Act mentioned above also placed a requirement on the Secretary of State for the Environment to produce a national Air Quality Strategy (AQS). This contains standards, objectives and measures for improving ambient air quality. The original Air Quality Strategy was published in 1997, and contained air quality objectives based on the recommendations of the Expert Panel on Air Quality Standards (EPAQS) regarding the levels of air pollutants at which there would be little risk to human health.

The Air Quality Strategy has since undergone a number of revisions. These have reflected improvements in the understanding of air pollutants and their health effects. They have also incorporated new European limit values, both for pollutants already covered by the Strategy and for newly introduced pollutants such as polycyclic aromatic hydrocarbons and $PM_{2.5}$ particulate matter. The latest version of the strategy was published by Defra in 2007[6].

All AQS objectives must be at least as stringent as the EC limit values. The current UK air quality objectives for the pollutants monitored at Heathrow Airport are presented in Table 2-1. In some cases Scotland, Wales or Northern Ireland have adopted different objectives; Table 2-1 shows the AQS objectives that apply in England. The ozone objective is not included in the Air Quality Regulations for the purposes of Local Air Quality Management, as ozone is a transboundary pollutant and difficult to control by local action. It is frequently exceeded in many areas of the UK, particularly in rural areas.

Table 2-1: Air quality objectives relevant to Heathrow monitoring programme

Pollutant	Air quality objective		To be achieved by
	Concentration	Measured as	
Benzene (England and Wales)	5 µg m^{-3}	Annual mean	31st December 2010
Nitrogen dioxide (NO_2)	200 µg m^{-3} not to be exceeded more than 18 times a year	1-hour mean	31st December 2005
	40 µg m^{-3}	Annual mean	31st December 2005
Particles (PM_{10}) (gravimetric) (All authorities)	50 µg m^{-3}, not to be exceeded more than 35 times a year	24 hour mean	31st December 2004
	40 µg m^{-3}	Annual mean	31st December 2004
Particles ($PM_{2.5}$) (gravimetric)	25 µg m^{-3}	Annual mean (non-mandatory target)	2020
Ozone (O_3)*	100 µg m^{-3} not to be exceeded more than 10 times a year	8 hourly running or hourly mean*	31st December 2005

** Ozone is not included as part of the LAQM regime.*

2.3 Locations of the monitoring sites

The pollutants that were monitored at each monitoring site are shown in Table 2-2. The LHR2 site has been in operation since 1993; the Harlington site commenced in 2003. The Green Gates and Oaks Road sites were originally set up for monitoring in connection with the Terminal 5 Construction Impact Assessment in 2001, but were retained as part of the ongoing monitoring programme from 2007 onwards.

Table 2-2: Air quality monitoring at Heathrow: Locations of monitoring sites

Site name	Description	Parameters monitored	Grid reference
LHR2	Old northern apron	NOx, PM_{10}, $PM_{2.5}$, benzene (indicative), wind speed, wind direction	508400 176750
Harlington	Imperial College Sports Ground, 1 km north of LHR2	NOx, PM_{10}, $PM_{2.5}$, ozone	508299 177809
Heathrow Green Gates	Bath Road, close to north west of airport	NOx, PM_{10}, $PM_{2.5}$	505630 176930
Heathrow Oaks Road	Residential area to south west of airport.	NOx, PM_{10}, $PM_{2.5}$	505740 174500

The site locations are shown in Figure 2-1.

Figure 2-1: Locations of monitoring sites

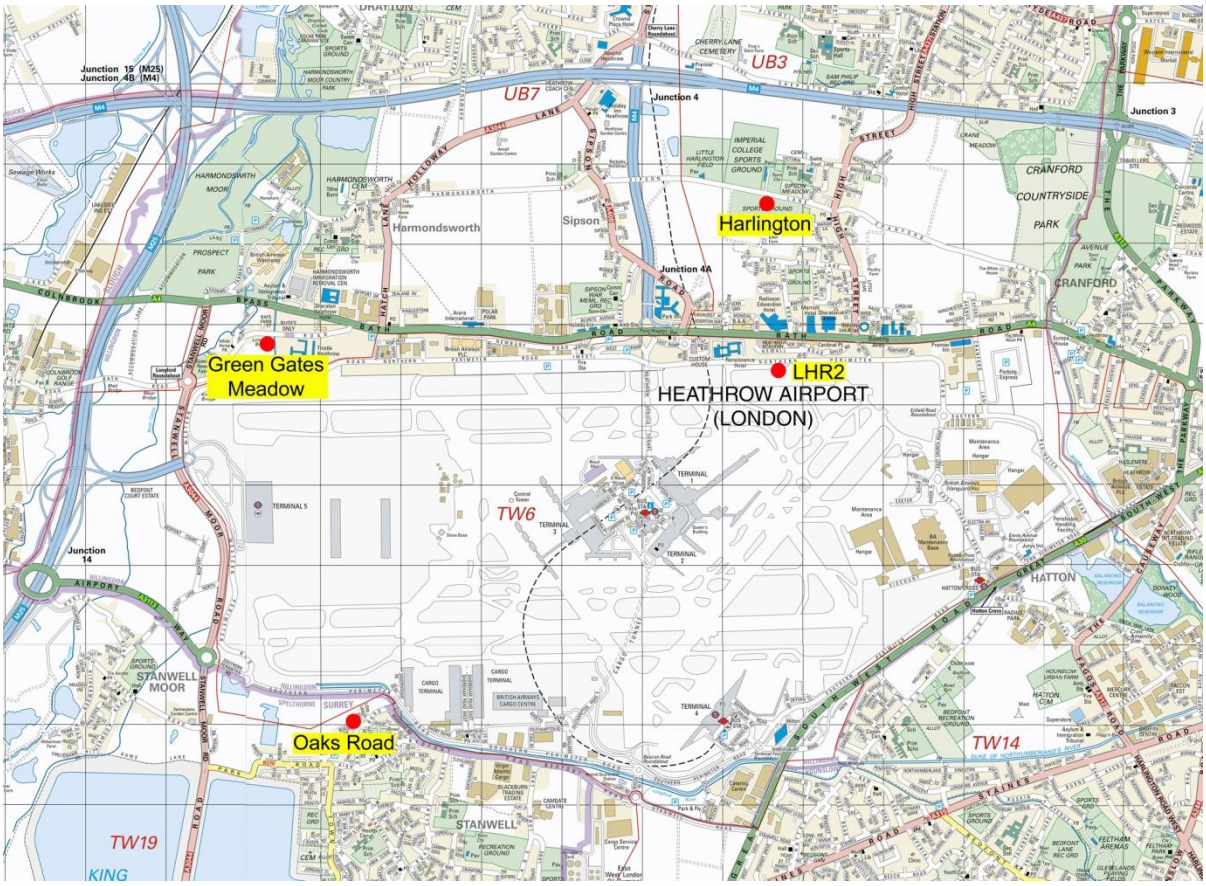


Figure 2-2 shows the LHR2 monitoring site. This is located on an area of the old apron between the northern runway and the northern perimeter road, 14.5 m from the kerb and 179 m from the runway centre. The prevailing wind direction is from the south west and hence this site, situated to the north east of the airport, was selected to monitor air pollutants arising from the airport area. The site falls into the category "other" as defined by the Defra Technical Guidance on air quality monitoring LAQM.TG (09)[7], i.e. "Any special source-orientated or location category covering monitoring undertaken in relation to specific emission sources such as power stations, car-parks, airports or tunnels." The EU limit values and AQS objectives only apply to locations where public exposure may occur. As LHR2 is located within the airport premises, where members of the public do not have access, these limits do not strictly apply.

Figure 2-3 shows the Harlington site. This was established to measure air pollution concentrations in residential areas close to the airport. The site is located in the grounds of the Imperial College Sports Ground, approximately 1 km north of LHR2 and 300 m from the western edge of Harlington. Since 1st January 2004, the site has been part of the Defra Automatic Urban and Rural Network (AURN), and meets the Air Quality Directive siting criteria. Because the site is part of the national network, it is classified according to the site types defined in the Air Quality Directive: its classification of “Urban Industrial” reflects the presence of the airport. Within the AURN, the site is known by its full name of “London Harlington” but will be referred to as “Harlington” in this report.

Figure 2-4 shows the Green Gates site. This site is close to Bath Road, which runs along the northern perimeter of the airport and is classified as “Other” according to LAQM.TG(09). Figure 2-5 shows the Heathrow Oaks Road site. This site is located in a residential area near to the south western boundary of the airport and is classified as an urban background site. Both Green Gates and Oaks Road meet the Directive criteria for urban background sites.

Figure 2-2: Heathrow LHR2 air quality monitoring site

Figure 2-3: London Harlington air quality monitoring site

Figure 2-4: Green Gates air quality monitoring site

Figure 2-5: Oaks Road air quality monitoring site

2.4 Monitoring methods

2.4.1 Automatic measurements

Continuous automatic analysers were used for monitoring oxides of nitrogen (NOx), PM_{10}, $PM_{2.5}$ and O_3. These provided real-time data. The analysers used the operating principles listed below.

- NO, NO_2: chemiluminescence analysers at all four sites.
- PM_{10}: Tapered element oscillating microbalance (TEOM) at LHR2, Green Gates and Oaks Road. Filter Dynamics Measurement Systems (FDMS) TEOM (a modified form of TEOM which measures both volatile and non-volatile fractions) at Harlington.
- $PM_{2.5}$: TEOM at LHR2, Green Gates and Oaks Road. FDMS TEOM at Harlington.
- O_3: UV absorption analyser, Harlington only.

Each analyser provided a continuous output, proportional to the pollutant concentration. The results were recorded by an external data logger, connected to a modem and interrogated by telephone to download the data to Ricardo-AEA. Data were downloaded hourly and were converted to concentration units at Ricardo-AEA. Quality assurance/quality control procedures were followed in line with current operational procedures within the Defra Automatic Urban and Rural Network (AURN)[8]. Details of these procedures are given in Appendix 1.

2.4.2 Volatile Correction Model correction of PM_{10} data

The TEOM particulate monitor uses a 50 °C heated sample inlet to prevent condensation on the filter. Although necessary, this elevated temperature can result in the loss of volatile and semi-volatile components of PM_{10}, such as ammonium nitrate.

It is not possible to address this problem by applying a simple correction factor. However, King's College London (KCL) has developed a Volatile Correction Model (VCM)[9], which allows TEOM PM_{10} data to be corrected for the volatile components lost as a result of the TEOM's heated inlet. The model uses data from nearby TEOM-FDMS particulate analysers, which measure the volatile and non-volatile components of the PM_{10}. The volatile component (which typically does not vary much over a large region) can be added to the TEOM measurement. KCL states that the resulting corrected measurements have been demonstrated as equivalent to the gravimetric reference equivalent. In this report, the VCM has been used to correct PM_{10} data where applicable. Where this has been done, it is clearly indicated.

There is no requirement to correct $PM_{2.5}$ data measured using the TEOM, and no demonstrated and approved method for doing so.

2.4.3 Diffusive sampling of hydrocarbons

Diffusion tubes were used at LHR2 for indicative monitoring of a suite of four hydrocarbons – benzene, toluene, ethylbenzene and xylenes. Diffusion tubes are "passive" samplers, i.e. they work by absorbing the pollutants direct from the surrounding air and need no power supply. Hydrocarbon diffusion tubes of this type are referred to as "BTEX" tubes – an acronym comprising the initials of the four compounds they measure.

BTEX diffusion tubes consist of a small metal tube, approximately 9 cm long, and fitted at both ends with brass Swagelok fittings. They are packed with an absorbent material which traps the hydrocarbons to be monitored. A separate "diffusion cap" is supplied. Immediately before exposure, one Swagelok end fitting is replaced with the diffusion cap, which allows gases to diffuse into the tube but keeps the absorbent in place. The tube is then mounted vertically at the monitoring site, with the diffusion cap at the bottom. Hydrocarbons diffuse up the tube during exposure. At the end of the exposure period, the diffusion cap is removed and the tube re-sealed using the Swagelok fitting. The tube is then returned to the laboratory

for analysis. The average ambient pollutant concentration for the exposure period is calculated from the amount of pollutant absorbed.

BTEX diffusion tubes were prepared and analysed by Gradko International Ltd, and changed by Ricardo-AEA on a four-weekly basis.

Diffusion tubes are an indicative technique, with greater uncertainty than most automatic methods. The margins of uncertainty on the analysis were reported as being ± 9.6 % in 2013. Additional uncertainties arise from the exposure phase so it is usually estimated that the overall uncertainty on diffusion tube measurements is approximately ± 25% for BTEX hydrocarbons.

The limits of detection depend partly on analytical factors and partly on the exposure time. They therefore vary to some extent from month to month. During 2013 the limit of detection (LoD) varied was reported to be 5 ng (total mass on tube), equating to ambient concentrations ranging from 0.13 µg m^{-3} to 0.19 µg m^{-3}. **Results below 10 x the limit of detection have a higher level of uncertainty. For the ambient concentrations measured at Heathrow, this was the case for the majority of measurements. The BTEX hydrocarbon measurements are therefore likely to have overall uncertainty in excess of ± 25% and should be treated as indicative only.**

3 Results and discussion

3.1 Quality assurance and quality control

Following instrument and calibration gas checking, and the subsequent scaling and ratification of the data, the overall accuracy and precision figures for the pollutants monitored at the Heathrow sites are summarised in Table 3-1. These meet the data quality objectives of the Air Quality Directive[5]. "Precision" is defined as the repeatability of a measurement (i.e. how close replicate measurements are to one another) whilst "accuracy" refers to how close the measurement is to the "true" value.

Table 3-1: Estimated accuracy and precision of the data presented

Pollutant	Precision	Accuracy %
NO	± 2.5	± 15 %
NO_2	± 6.9	± 15 %
O_3	± 3.0	± 15 %
PM_{10}, $PM_{2.5}$	± 4	TEOM: ± 30 % or better (estimated*) VCM-corrected TEOM data : ± 25 % (estimated*) FDMS : ± 25 % (estimated*)

**accuracy of particle measurements with a TEOM instrument cannot be assessed reliably.*

3.2 Data capture

Overall data capture statistics for the two monitoring sites are given in Table 3-2. A data capture target of 90% is recommended in the Defra Technical Guidance LAQM.TG(09)[7].

Table 3-2: Data capture statistics for 2013

Site	NO	NO_2	PM_{10}	$PM_{2.5}$	O_3
LHR2	98.9 %	98.9 %	98.8 %	93.2 %	-
Harlington	86.3 %	86.3 %	95.2 %	98.4 %	99.0 %
Green Gates	99.1 %	99.1 %	98.6 %	99.1 %	-
Oaks Road	97.8 %	97.8 %	97.2 %	97.9 %	-

The data capture target was achieved for all measured pollutants at LHR2, Green Gates and Oaks Road. At Harlington the data capture target of 90 % was achieved for all measured pollutants except NO and NO_2.

The most significant gap was caused by an instrument failure between 1st April and 10th May 2013. This issue was raised with Heathrow Airport Ltd in a timely manner when it occurred: however, the Airport took the decision not to repair the instrument as it (together with the analysers at all the sites) was due to be replaced shortly. In addition, there were three other short interruptions to data collection.

Data gaps of greater than 24 hours are shown in Table 3-3.

Table 3-3: Significant data gaps during 2013

Site	Pollutant	Period	Number of days	Reason
Harlington	NO_2	25/03/2013-26/03/2013	1.2	Routine service
Harlington	NO_2	01/04/2013-10/05/2013	39.7	Instrument fault
Harlington	NO_2	08/08/2013-09/08/2013	1.3	Routine service
Harlington	NO_2	14/10/2013-15/10/2013	0.6	Operator error
Harlington	PM_{10}	20/12/2013-31/12/2013	12	"Noisy" data for volatile fraction.

3.3 Presentation of results

Summaries of the results of the automatic monitoring at the four sites around Heathrow are shown in Tables 3-4 to 3-7 for Heathrow LHR2, Harlington, Green Gates and Oaks Road respectively.

Time series charts of data for the full year are shown in Figure 3-1 for NO, Figure 3-2 for NO_2, Figure 3-3 for PM_{10}, Figure 3-4 for $PM_{2.5}$ and Figure 3-5 for ozone (at Harlington only). The hourly mean PM_{10} data shown in Figure 3-3 are "as measured", i.e. not VCM-corrected in the case of LHR2, Green Gates and Oaks Road.

The "native" units of the analysers used for the gaseous pollutants NO, NO_2 and O_3 are parts per billion by volume (ppb). The measured concentrations of the gaseous pollutants have been converted to micrograms per cubic metre (µg m^{-3}) in this report, for comparison with Air Quality Strategy objectives (which are also expressed in these units). The conversion factors used are given below:

- NO 1 ppb = 1.25 µg m^{-3}.
- NO_2 1 ppb = 1.91 µg m^{-3}.
- O_3 1 ppb = 2.00 µg m^{-3}.
- C_6H_6 (benzene) 1 ppb = 3.25 µg m^{-3}.
- C_7H_8 (toluene) 1 ppb = 3.83 µg m^{-3}.
- C_8H_{10} (ethylbenzene and xylenes) 1 ppb = 4.41 µg m^{-3}.

All are quoted at 20 °C and 1atmosphere pressure.

The mass concentration of NOx has been calculated as follows:

$$NOx\ \mu g\ m^{-3} = (NO\ ppb + NO_2\ ppb) \times 1.91.$$

This conforms to the requirements of the Air Quality Directive[5] and is also the convention generally adopted in air quality modelling.

PM_{10} is conventionally reported in units of µg m^{-3}, micrograms per cubic metre. In this report PM_{10} measured using the TEOM instrument are presented

(i) "as measured", and
(ii) converted to gravimetric equivalent by use of the KCL Volatile Correction Model (VCM)[9].

For the purposes of comparison with air quality objectives, VCM-corrected data have been used. However, when considering diurnal patterns and relationships between pollutant

concentrations and wind direction, the TEOM data have been used as measured, i.e. the VCM has not been applied.

At Harlington the PM_{10} measurements were made using an FDMS analyser, so no VCM correction was necessary.

Table 3-4: Air pollution statistics for Heathrow LHR2, 2013

Measure	NO µg m^{-3}	NO_2 µg m^{-3}	NOx µg m^{-3}	PM_{10} as measured µg m^{-3}	PM_{10} (VCM corrected) µg m^{-3}	$PM_{2.5}$ µg m^{-3}
Maximum 15-minute mean	1,038	292	1,878	-	-	81
Maximum hourly mean	939	260	1,694	185	187	78
Maximum running 8-hour mean	571	166	1,038	69	-	50
Maximum running 24-hour mean	338	114	631	53	-	35
Maximum daily mean	318	110	596	52	71	32
Average	38	48	106	20	25	11
Data capture %	98.9	98.9	98.9	98.8	98.8	93.2

Table 3-5: Air pollution statistics for Harlington, 2013

Measure	NO µg m^{-3}	NO_2 µg m^{-3}	NOx µg m^{-3}	PM_{10} µg m^{-3}	$PM_{2.5}$ µg m^{-3}	Ozone µg m^{-3}
Maximum 15-minute mean	825	334	1,557	-	-	168
Maximum hourly mean	793	271	1,478	114	103	156
Maximum running 8-hour mean	554	223	1,068	90	76	146
Maximum running 24-hour mean	320	162	644	70	58	86
Maximum daily mean	316	161	644	67	56	85
Average	18	38	66	20	14	36
Data capture %	86.3	86.3	86.3	95.2	98.4	99.0

Table 3-6: Air pollution statistics for Green Gates, 2013

Measure	NO µg m^{-3}	NO_2 µg m^{-3}	NOx µg m^{-3}	PM_{10} as measured µg m^{-3}	PM_{10} (VCM corrected) µg m^{-3}	$PM_{2.5}$ µg m^{-3}
Maximum 15-minute mean	826	164	1,421	-	-	66
Maximum hourly mean	758	149	1,306	136	138	60
Maximum running 8-hour mean	471	119	829	55	-	42
Maximum running 24-hour mean	334	95	594	47	-	36
Maximum daily mean	277	89	507	47	65	30
Average	20	33	63	16	21	10
Data capture %	99.1	99.1	99.1	98.6	98.6	99.1

Table 3-7: Air pollution statistics for Oaks Road, 2013

Measure	NO µg m^{-3}	NO_2 µg m^{-3}	NOx µg m^{-3}	PM_{10} as measured µg m^{-3}	PM_{10} (VCM corrected) µg m^{-3}	$PM_{2.5}$ µg m^{-3}
Maximum 15-minute mean	576	174	995	-	-	134
Maximum hourly mean	576	168	995	130	128	86
Maximum running 8-hour mean	415	116	724	56	-	44
Maximum running 24-hour mean	285	101	508	50	-	36
Maximum daily mean	231	101	423	49	68	34
Average	16	34	58	17	22	10
Data capture %	97.8	97.8	97.8	97.2	97.2	97.9

Figure 3-1: Hourly mean concentrations of nitric oxide at Heathrow monitoring sites, 2013

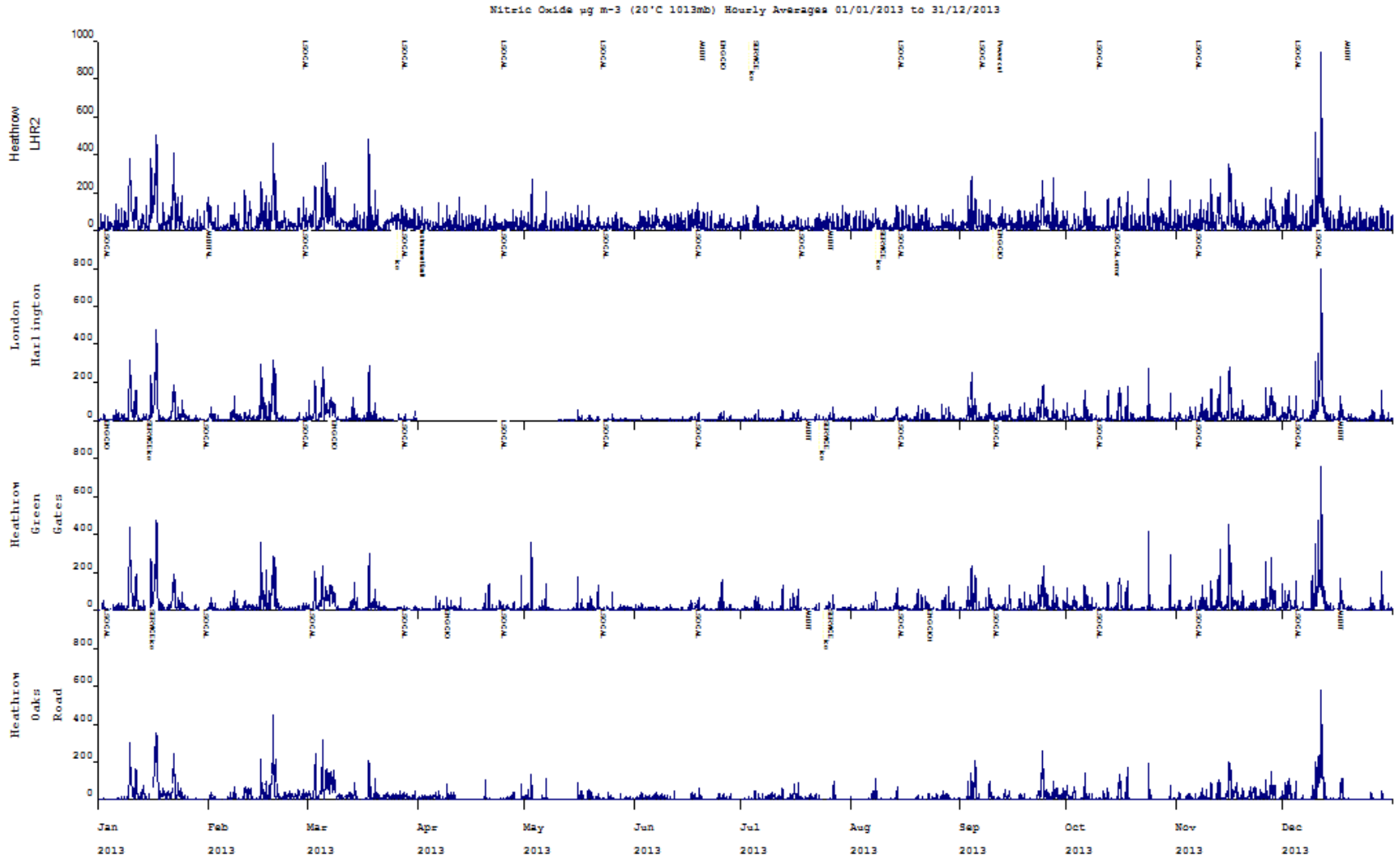


Figure 3-2: Hourly mean concentrations of nitrogen dioxide at Heathrow monitoring sites, 2013

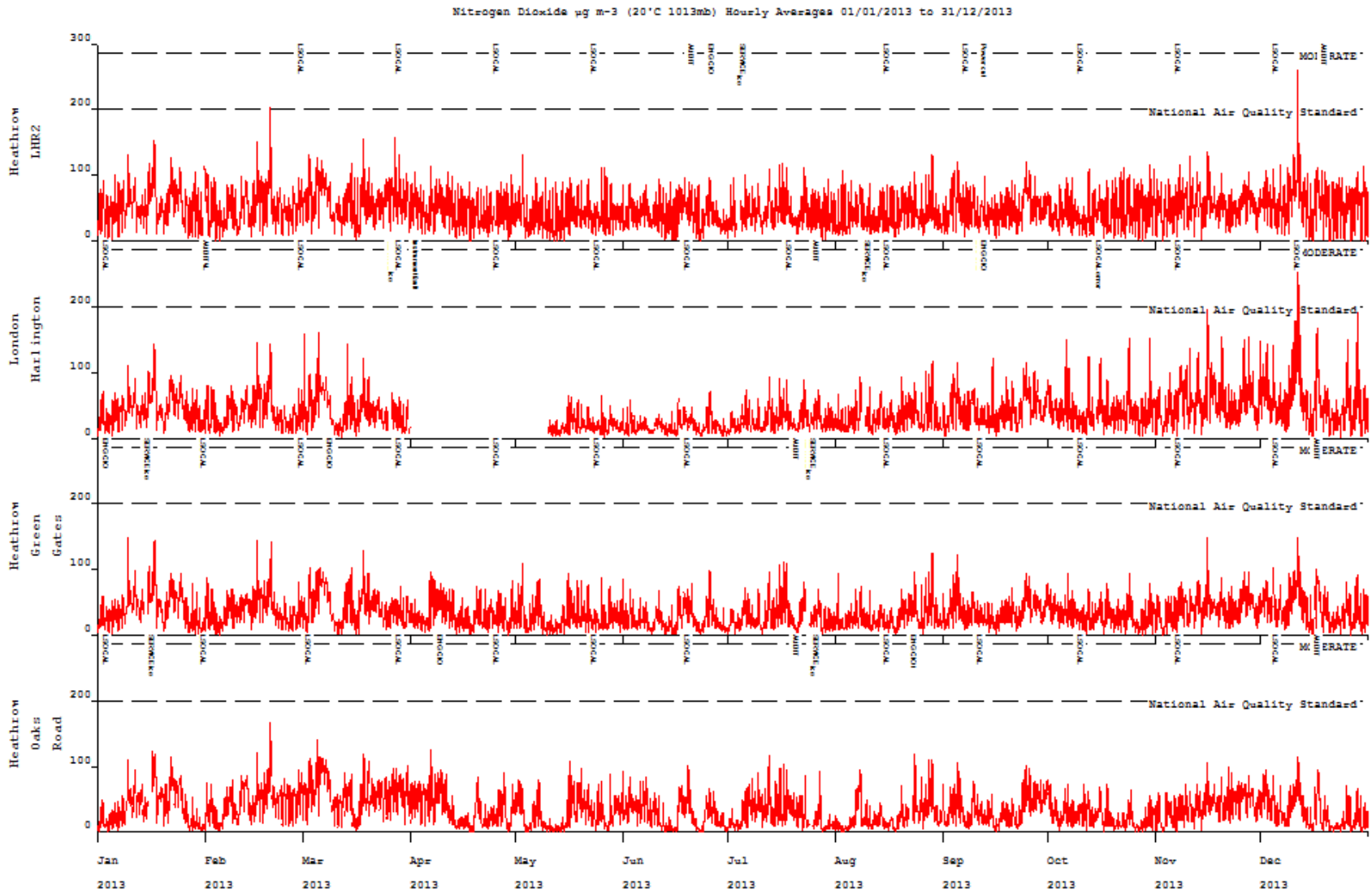


Figure 3-3: Hourly mean concentrations of PM_{10} (as measured, i.e. uncorrected TEOM at LHR2, Green Gates and Oaks Road) at Heathrow monitoring sites, 2013

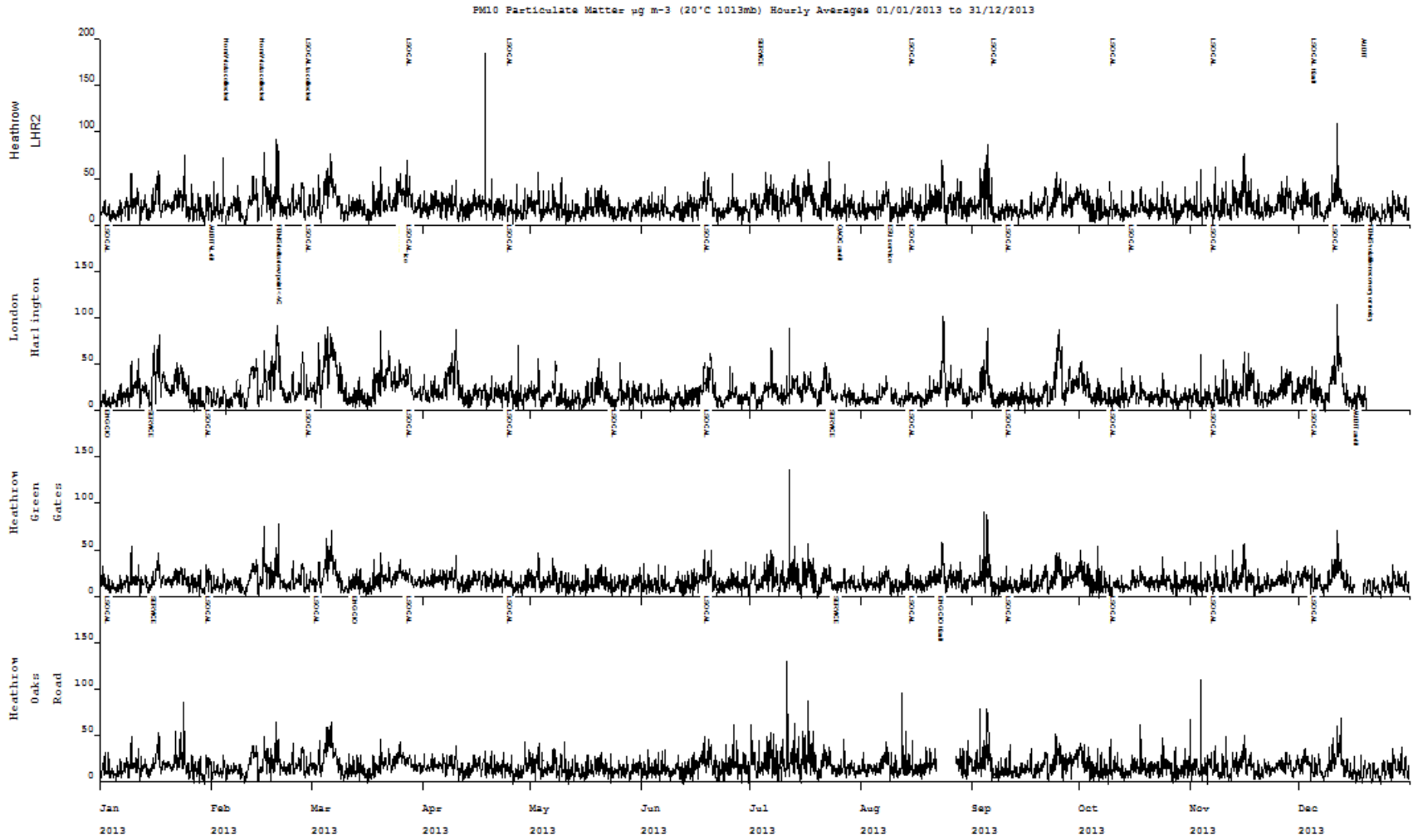


Figure 3-4: Hourly mean concentrations of $PM_{2.5}$ at Heathrow monitoring sites, 2013

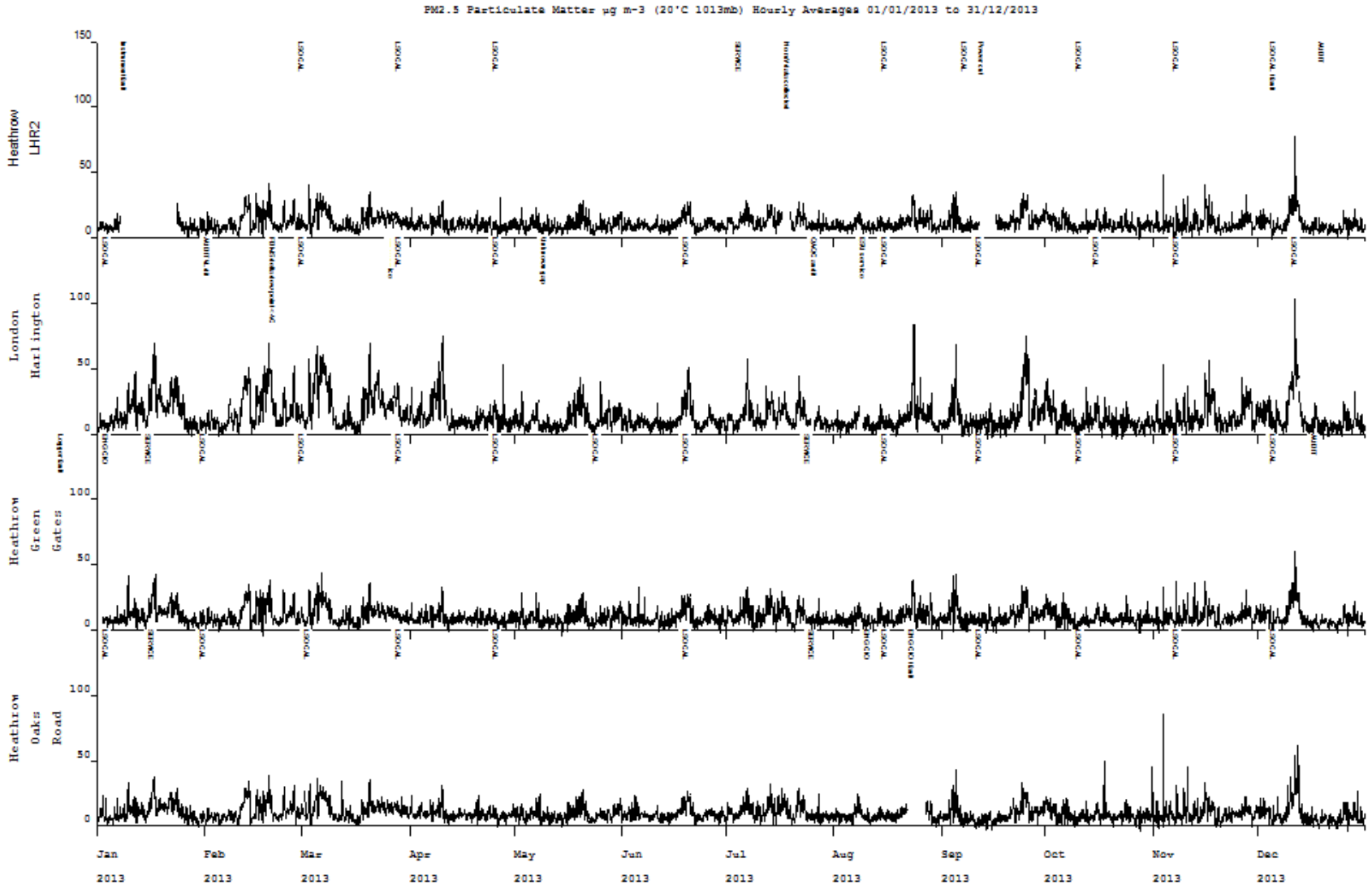
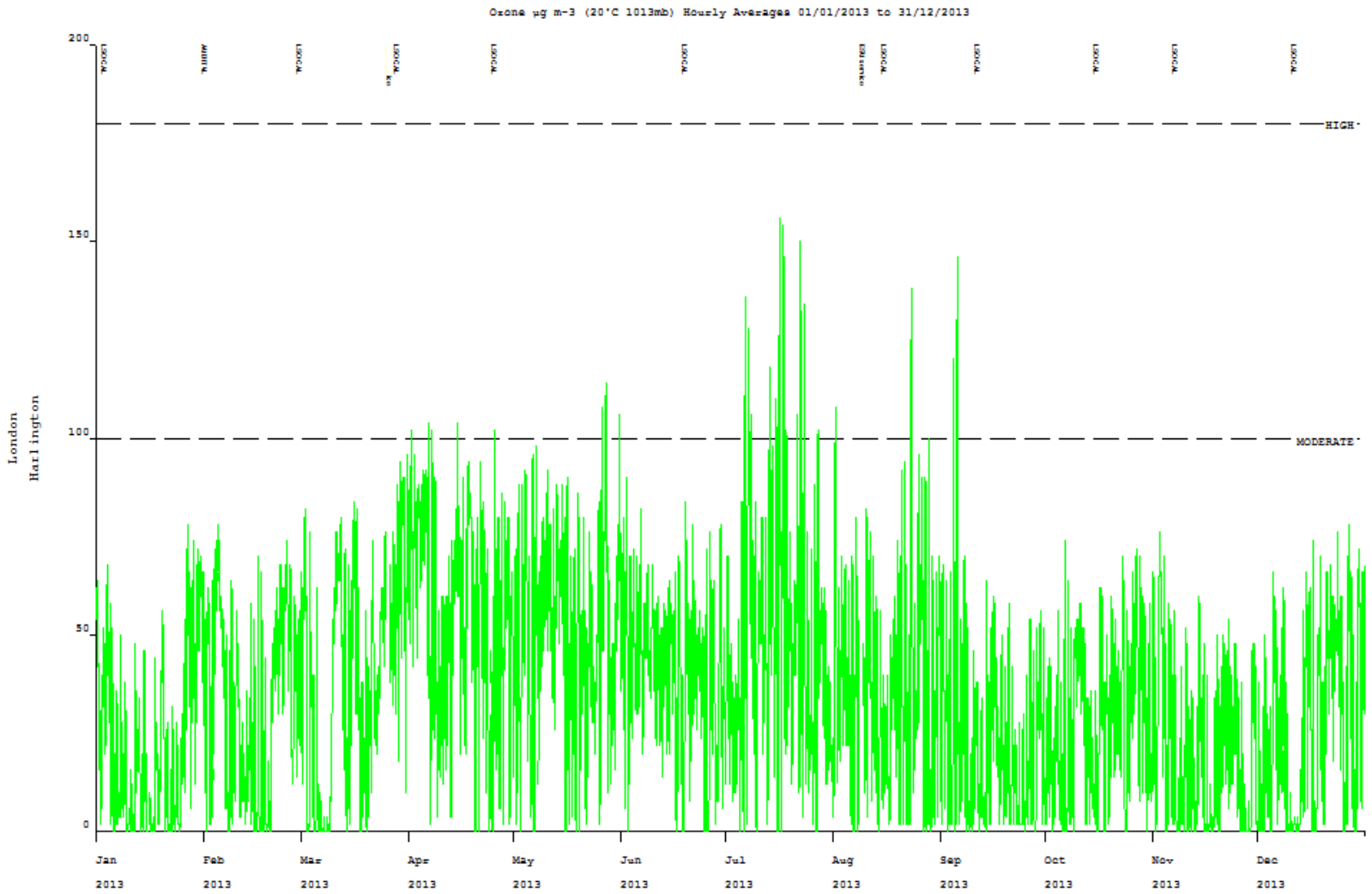


Figure 3-5: Hourly mean concentrations of ozone at Harlington, 2013



Mean concentrations of hydrocarbons, as measured indicatively using diffusion tubes, are shown in Table 3-8. Results were generally low, and frequently close to, or below, the limit of detection (LoD). Therefore, these data should be treated as indicative only. Values below the limit of detection (<LoD) are shown in red. In line with current guidance, when calculating the annual mean, values below the LoD have been treated as ½ LoD. For example, a value of <0.10 µg m^{-3} has been treated as 0.05 µg m^{-3} when calculating the annual means.

Table 3-8: Concentrations of hydrocarbon species at LHR2, 2013

Period sampled		Pollutant/concentration µg m^{-3}				
Date on	Date off	Benzene	Toluene	Ethyl benzene	m, p-xylene	o-xylene
31/12/2012	31/01/2013	0.63	0.85	0.13	0.47	0.13
31/01/2013	27/02/2013	0.75	1.01	0.15	0.41	0.15
27/02/2013	27/03/2013	0.52	0.73	0.13	0.64	0.13
27/03/2013	24/04/2013	0.97	1.66	0.52	1.12	0.36
24/04/2013	22/05/2013	0.69	1.53	0.50	1.10	0.44
22/05/2013	19/06/2013	0.72	1.38	0.41	0.89	0.36
19/06/2013	17/07/2013	0.42	1.60	0.48	0.94	0.52
17/07/2013	14/08/2013	0.32	0.96	0.48	0.83	0.48
14/08/2013	06/09/2013	0.46	1.34	0.34	0.70	0.33
06/09/2013	09/10/2013	0.47	1.45	0.33	0.96	0.34
09/10/2013	06/11/2013	0.60	1.65	0.41	0.78	0.31
06/11/2013	04/12/2013	0.55	1.37	0.84	1.28	0.50
04/12/2013	03/01/2014	0.75	0.81	0.13	0.13	0.13
Annual mean *		**0.60**	**1.26**	**0.37**	**0.79**	**0.32**

** Values < LoD shown as ½ LoD, in red. Averages in this table are calculated by treating < LoD values as ½ LoD.*

3.4 Comparison with Air Quality Strategy objectives

This section compares the results from the Heathrow monitoring study in 2013 with relevant AQS objectives. Full details of the applicable AQS objectives are summarised in Table 2-1. Defra air pollution bands are shown in Appendix 2.

3.4.1 Nitrogen dioxide

The AQS objectives for nitrogen dioxide are as follows. These had to be achieved by December 31st 2005.

- 200 µg m^{-3} as an hourly mean, not to be exceeded more than 18 times per year.
- 40 µg m^{-3} as an annual mean.
- There is also a limit for annual mean total oxides of nitrogen (NOx), of 30 µg m^{-3}, for protection of vegetation. However, this is relevant only in rural areas, so is not considered here.

Oxides of nitrogen were monitored at all four Heathrow sites. LHR2 and Harlington both recorded occurrences of hourly means in excess of 200 µg m^{-3}, but neither site had more than 18 exceedances. Green Gates and Oaks Road had no hourly mean NO_2 concentrations greater than 200 µg m^{-3}. Therefore, all sites met the AQS objective for hourly mean NO_2.

The annual mean NO_2 concentrations at the four sites were 48 µg m^{-3} at LHR2, 38 µg m^{-3} at Harlington, 33 µg m^{-3} at Green Gates and 34 µg m^{-3} at Oaks Road. Only LHR2 therefore exceeded the annual mean objective for NO_2 in 2013. As noted in section 2.3, the AQS objectives do not strictly apply at LHR2 as there is no public exposure. The other three sites met this objective.

3.4.2 PM_{10}

The AQS objectives for PM_{10} are as follows. These have been in force since December 31st 2005.

- 50 µg m^{-3} gravimetric 24-hour (daily) mean not to be exceeded more than 35 times per year.
- 40 µg m^{-3} gravimetric annual mean.

PM_{10} was monitored at all four sites. Data obtained using the TEOM instruments (at LHR2, Green Gates and Oaks Road) have been corrected using the King's College London Volatile Correction Model.

The number of daily means above 50 µg m^{-3} in 2013, after VCM correction (where applicable) and where data capture was 90% or more, were as follows:

- LHR2: 10 days
- Harlington: 8 days.
- Green Gates: 7 days
- Oaks Road: 8 days

None of the four sites exceeded 50 µg m^{-3} more than 35 times in the year and they all therefore met the daily mean PM_{10} objective.

The annual mean PM_{10} concentrations based on the VCM-corrected TEOM data (and FDMS in the case of Harlington), were as follows:

- LHR2: 25 µg m^{-3}
- Harlington: 20 µg m^{-3}
- Green Gates 21 µg m^{-3}
- Oaks Road 22 µg m^{-3}.

All sites were therefore well within the AQS objective of 40 µg m^{-3} for annual mean PM_{10} during 2013.

3.4.3 $PM_{2.5}$

The 2007 revision of the AQS introduced the following objectives for $PM_{2.5}$.

- An annual mean objective of 25 µg m^{-3}, as a non-mandatory target for 2020.
- An exposure reduction target, for urban background exposure (i.e. urban areas away from major roads – such as parks, residential areas) of 15% reduction in annual mean $PM_{2.5}$ concentration between 2010 and 2020.

The 2013 annual means at the four sites were 11 µg m^{-3} at LHR2, 14 µg m^{-3} at Harlington, 10 µg m^{-3} at Green Gates and 10 µg m^{-3} at Oaks Road. All four sites therefore met the 2020 objective. Continued monitoring in future years will demonstrate whether the exposure reduction target of 15 % is achieved between the years 2010 and 2020.

3.4.4 Ozone

The AQS objective for ozone is:

- 100 µg m^{-3} as a daily maximum 8-hour running mean (not to be exceeded more than 10 times per year).

Ozone was measured at Harlington only. Harlington exceeded the AQS objective for ozone on 11 days during 2013. This is above the permitted maximum of 10 days during the year. The site has exceeded the objective several times in recent years; most recently in 2011. Ozone exceedances can vary considerably from year to year, depending on meteorological factors, so it is possible that further exceedances will occur in future years. Also, it is important to view the number of exceedances at Harlington in the context of the number measured at other sites in London and the south east - see section 3.8.

3.4.5 Benzene

The AQS sets the following objectives for benzene.

- 3.25 µg m^{-3} (for the calendar year mean in Scotland and Northern Ireland), to have been achieved by 31st December 2010.
- 5 µg m^{-3} (for the calendar year mean in England and Wales), to have been achieved by 31st December 2010.

Only the 2010 England and Wales objective has been considered in this report.

Benzene was monitored indicatively at LHR2 using BTEX diffusion tubes, with exposure periods of nominally four weeks. Individual measurements ranged from 0.32 µg m^{-3} to 0.97 µg m^{-3}. The annual mean benzene concentration recorded for 2013 was 0.60 µg m^{-3}. This is well below the AQS objective of 5 µg m^{-3}.

3.5 Temporal variation in pollutant concentrations

3.5.1 Seasonal variation

Figure 3-6, Figure 3-7, Figure 3-8 and Figure 3-9 show the variation of monthly averaged pollutant concentrations during 2013 at LHR2, Harlington, Green Gates and Oaks Road respectively. **Monthly means are only shown where data capture was at least 75%.** Because the intention is to show seasonal patterns rather than absolute values, PM_{10} data measured using the TEOM have been presented “as measured” (i.e. they have not been corrected using the Volatile Correction Model).

Figure 3-6: Seasonal variation in pollutant concentrations at LHR2, 2013

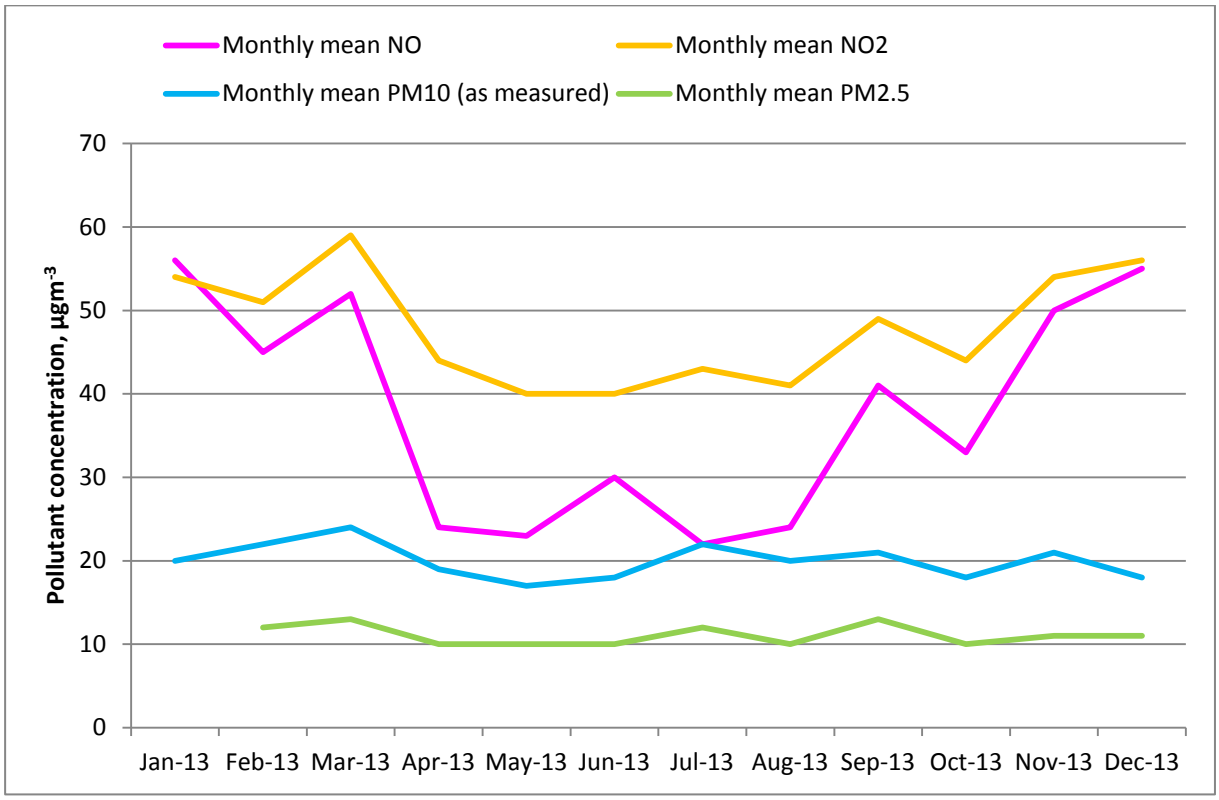


Figure 3-7: Seasonal variation in pollutant concentrations at Harlington, 2013

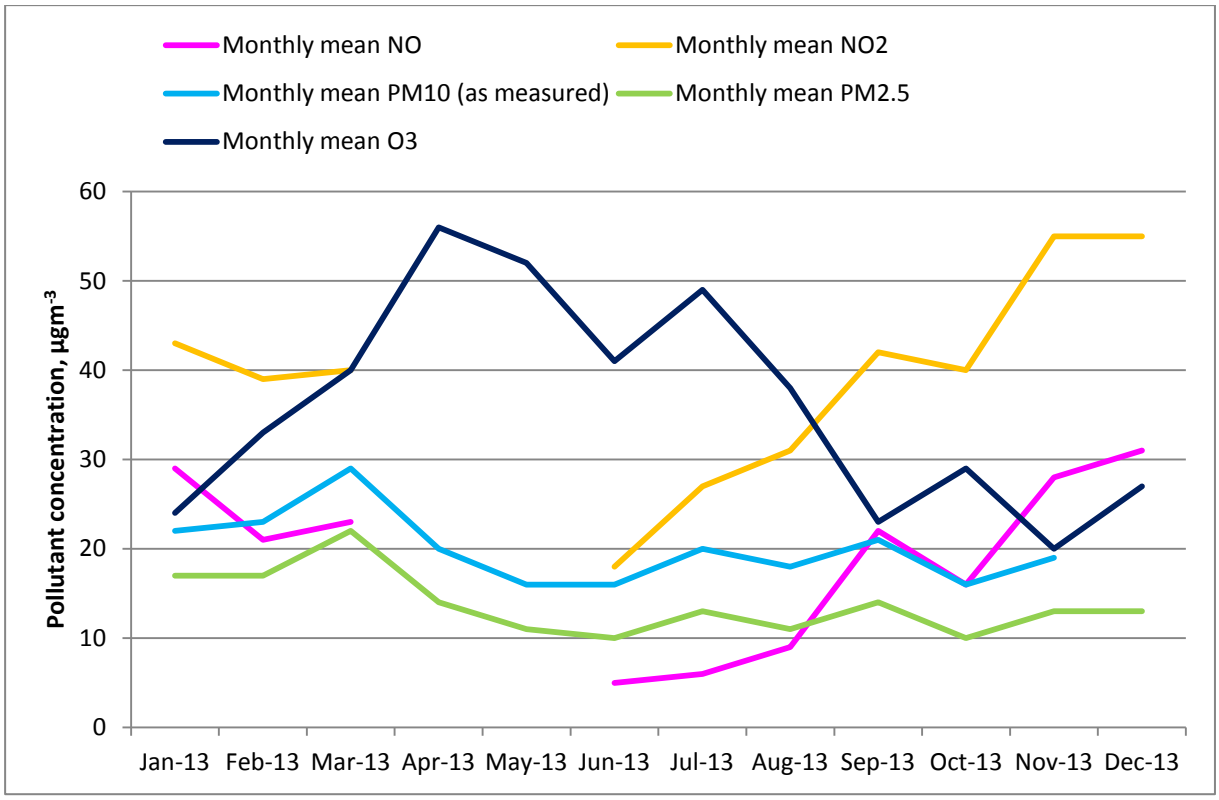


Figure 3-8: Seasonal variation in pollutant concentrations at Green Gates, 2013

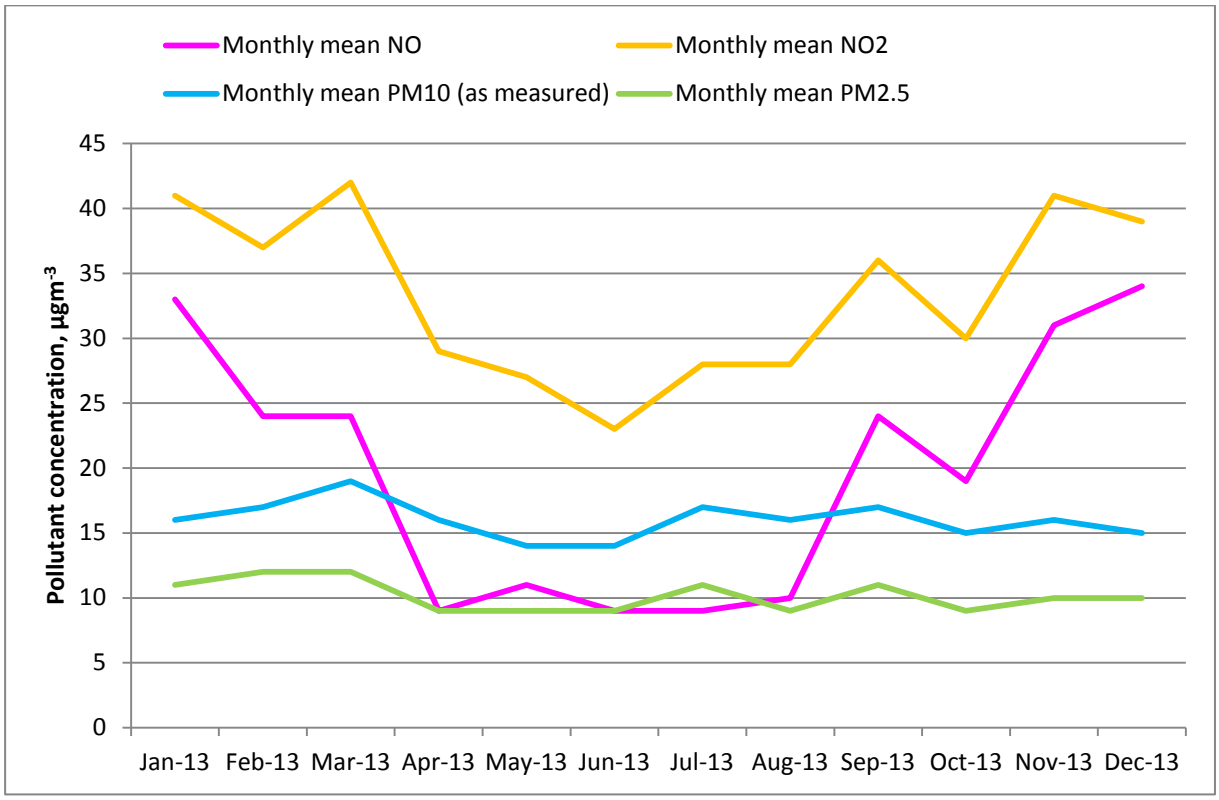
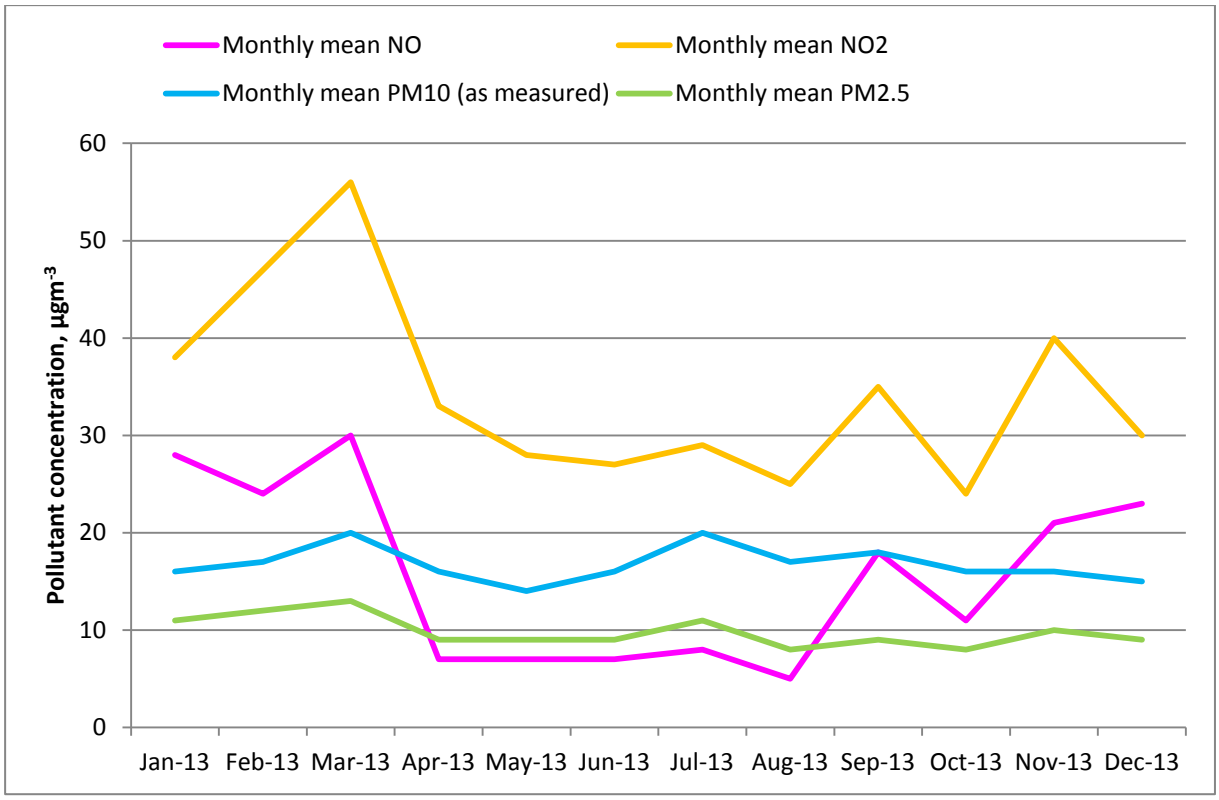


Figure 3-9: Seasonal variation in pollutant concentrations at Oaks Road, 2013



Both NO and NO_2 were generally higher in the winter months than in the summer. This is a typical pattern for urban areas. In 2013, the highest concentrations of these pollutants occurred in March and/or November to January, showing a trend that was consistent with expected seasonal patterns.

As in previous years, PM_{10} and $PM_{2.5}$ concentrations showed much less seasonal variation than oxides of nitrogen. However, concentrations of particulate matter peaked slightly at all sites around March, when high concentrations of volatile particulate matter were measured across the UK.

Ozone was measured at Harlington only. This secondary pollutant is not usually emitted directly from any source, but is formed in the atmosphere from reactions involving other pollutants. The highest concentrations were in spring and summer. This is the typical seasonal pattern for this pollutant, which occurs at highest levels in hot, still, sunny weather conditions and can give rise to "summer smog".

The overall patterns observed were similar to those found at most urban monitoring sites. Highest levels of primary pollutants tend to occur during the winter months, when lower temperatures and decreased wind speeds often lead to periods of reduced pollutant dispersion. For secondary pollutants, in particular ozone, high concentrations can often occur during summer months when chemical reactions in the atmosphere are promoted by high temperatures and strong sunlight.

3.5.2 Diurnal variation

The average variation of hourly concentrations throughout the day, at the four Heathrow sites, is shown in Figures 3-10 to 3-13.

Figure 3-10: Diurnal variation in pollutant concentrations at LHR2, 2013

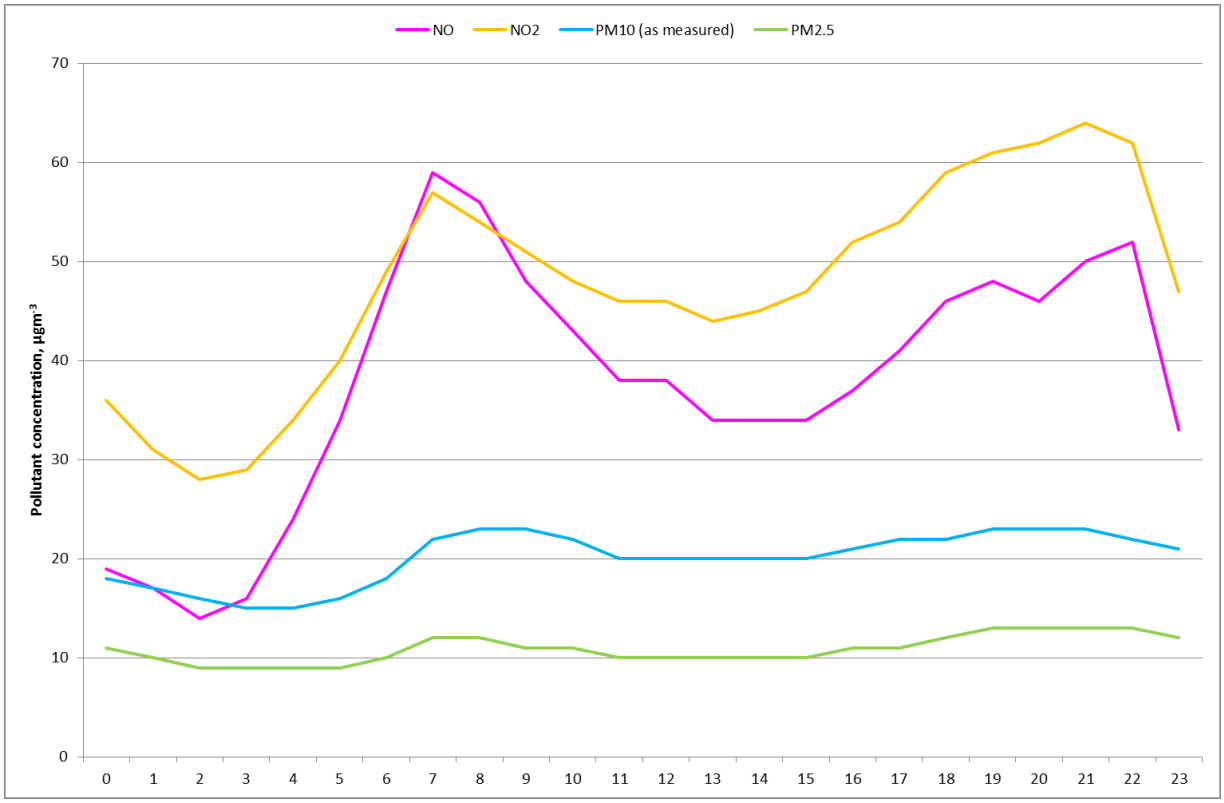


Figure 3-11: Diurnal variation in pollutant concentrations at Harlington, 2013

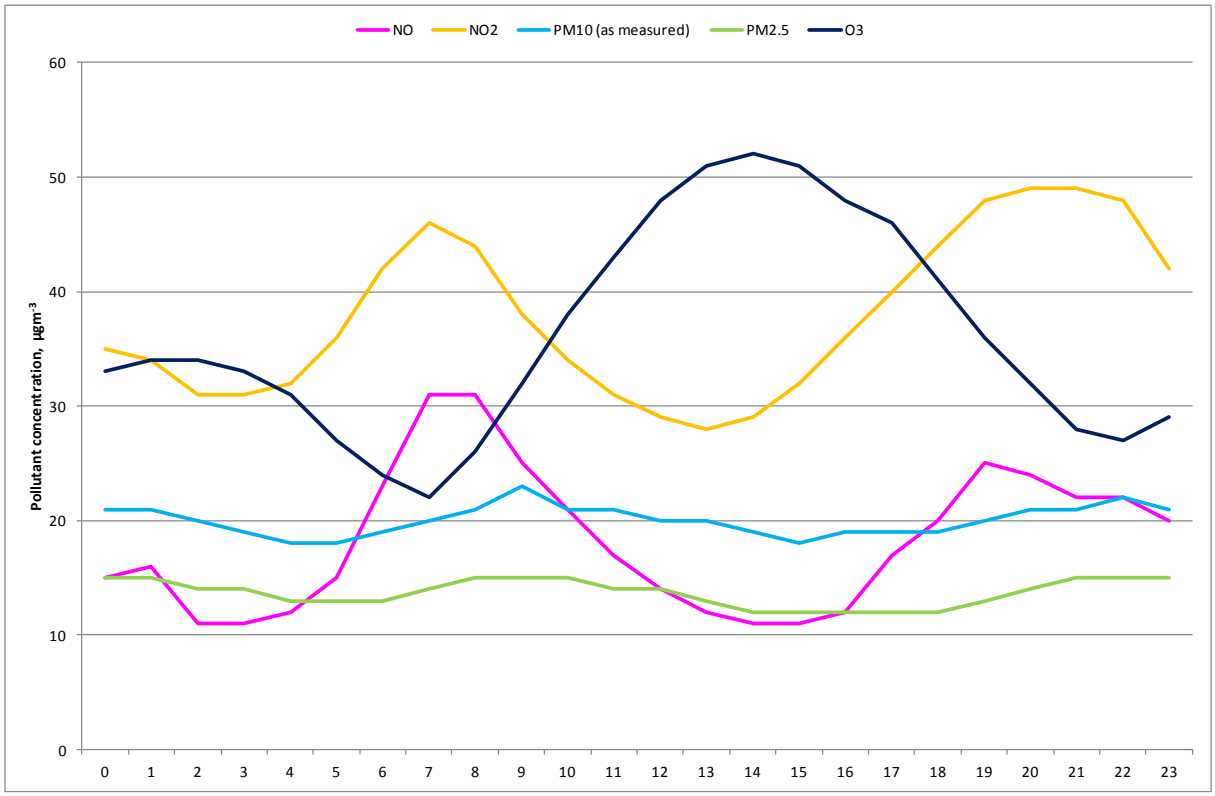


Figure 3-12: Diurnal variation in pollutant concentrations at Green Gates, 2013

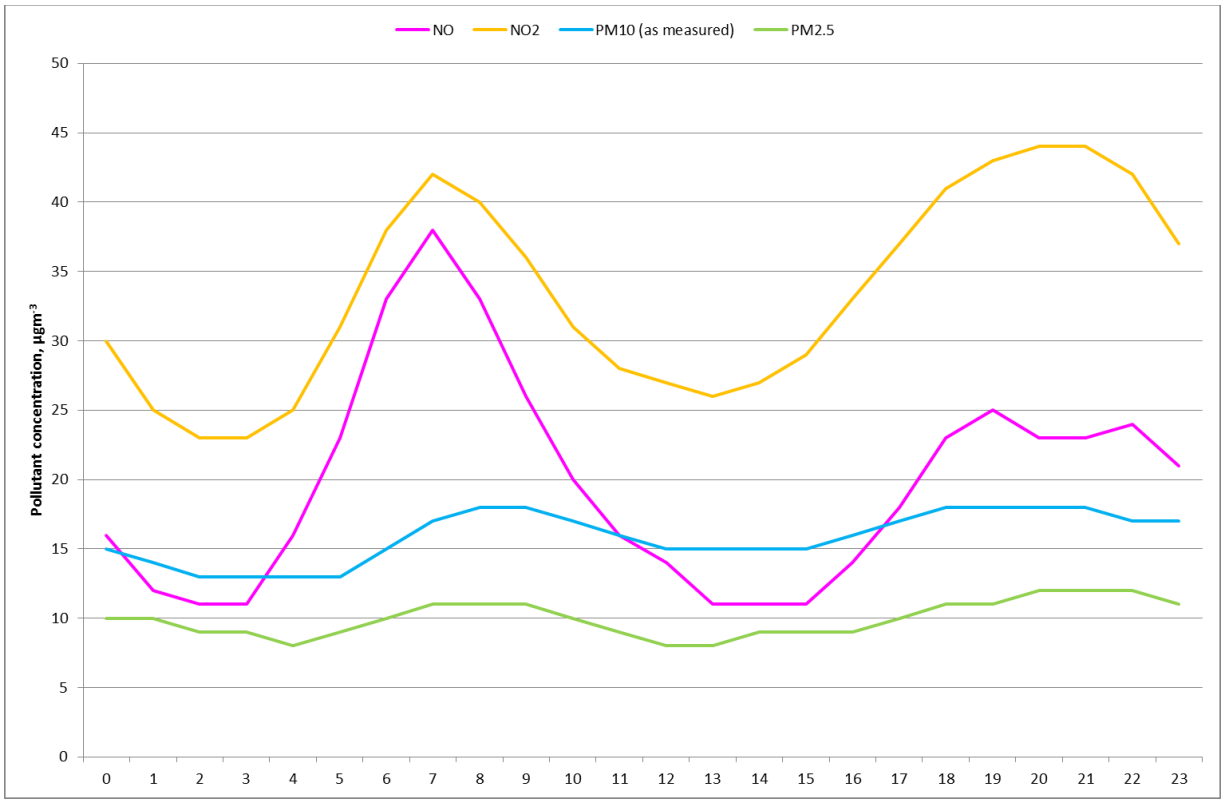
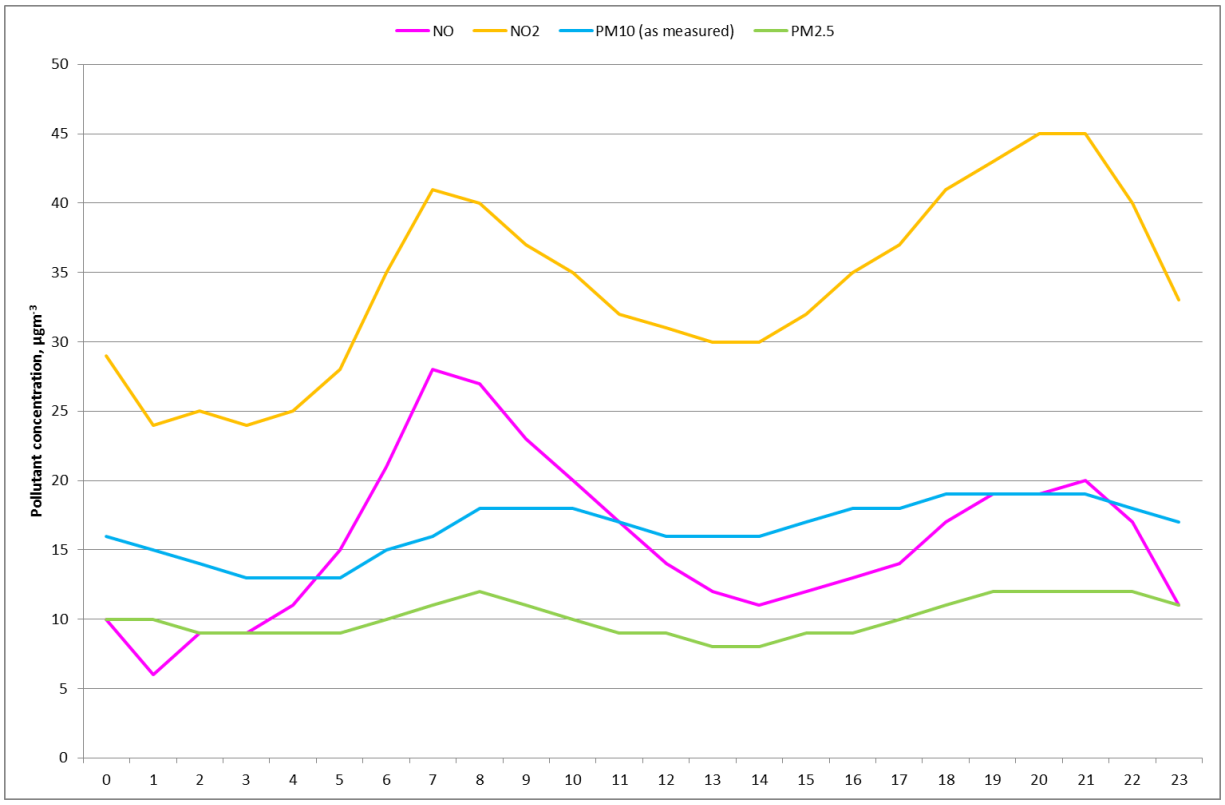


Figure 3-13: Diurnal variation in pollutant concentrations at Oaks Road, 2013



The PM_{10} data shown here are TEOM (or FDMS) data as measured – TEOM data have not been corrected to gravimetric equivalent using the VCM.

The curves for NO at all sites showed the typical daily cycle for these pollutants in urban areas. The distinct morning peaks at around 07:00 probably arose from general rush-hour road traffic emissions. Concentrations decreased during the middle of the day, with a lower and broader evening rush-hour peak occurring between 15:00 and 22:00.

For NO_2, which has secondary components, the morning rush-hour peak is again visible, and was in most cases higher than the morning NO peak (the exception was LHR2, where the average NO concentration was slightly higher than the NO_2 concentration). The afternoon NO_2 peak was higher than the morning peak at all four Heathrow sites. This is likely to be because concentrations of oxidising agents in the atmosphere (particularly ozone) tend to increase in the afternoon, leading to enhanced oxidation of NO to NO_2.

The diurnal patterns for PM_{10} and $PM_{2.5}$ are determined by two main factors. The first is emissions of primary particulate matter, from sources such as vehicles. The second factor is the reactions that occur between sulphur dioxide, NOx and other chemical species, forming secondary sulphate and nitrate particles. Morning and afternoon rush-hour peaks for PM_{10} and $PM_{2.5}$ could be seen at all four sites, but these were less pronounced than those for oxides of nitrogen.

Ozone (measured at Harlington only) exhibited a typical diurnal pattern for ozone, with the highest concentrations occurring in the afternoons.

3.6 Periods of elevated pollution

This section briefly reviews the periods of higher pollution that occurred during the year. These are identified on the basis of the Defra Daily Air Quality Index, used to communicate information about current and forecast air quality to the public, allowing people who are sensitive to air pollution to take appropriate action. The index provides a simple indication of pollution levels and is based on a scale of 1-10, divided into four bands (“Low”, “Moderate”,

"High" and "Very High"). "Low air pollution is between 1 and 3, "Moderate" is between 4 and 6, "High" is between 7 and 9, and "Very High" is 10.

The concentration ranges associated with each band within the index are presented in Appendix 2.

3.6.1 Nitrogen dioxide

The Defra air quality bandings for NO_2 are based on the hourly mean. The upper threshold of Defra's "Low" band for NO_2 pollution is 200 µg m^{-3} (the same as the 1-hour mean AQS objective) LHR2 entered the "Moderate" band three times on two separate days. Harlington recorded "Moderate" hourly mean NO_2 concentrations on six occasions but all were within one day.

3.6.2 PM_{10}

The Defra air quality bandings for PM_{10} refer to a 24 hour period. After VCM correction where applicable, PM_{10} data were in the Defra "Low" air quality band (i.e. fixed daily mean lower than 51 µg m^{-3}) the majority of the time at all four sites. However, the daily mean went into the "Moderate" band or higher (daily mean greater than 50 µg m^{-3}) on several occasions at all four sites. Notable days or periods on which the daily mean PM_{10} concentration went into the "Moderate" band (daily mean > 50 µg m^{-3}) or exceeded the AQS objective (also 50 µg m^{-3}) during 2013 are shown in Table 3-9.

Table 3-9: Periods of elevated PM_{10} concentration during 2013

Date	Site
17th January 2013	Harlington
19th February 2013	LHR2, Green Gates, Oaks Road
4th March 2013	LHR2, Harlington
5th-7th March 2013	LHR2, Harlington, Green Gates, Oaks Road
22nd March 2013	Harlington
10th April 2013	LHR2, Harlington, Green Gates, Oaks Road
5th September 2013	LHR2, Green Gates, Oaks Road
24th September 2013	LHR2
25th September 2013	LHR2, Harlington, Green Gates, Oaks Road
11th December 2013	LHR2, Harlington
12th December 2013	Harlington, Oaks Road

It is likely that several of these events were related to regional changes in PM_{10}, rather than arising from activities at Heathrow. This is borne out by comparison with other London AURN sites such as London Bloomsbury, London North Kensington and London Marylebone Road. At least one of these sites showed high levels of PM_{10} on 17th January, 5th-7th March, 22nd March, 10th April, 25th September and 11th December.

3.6.3 $PM_{2.5}$

All sites except Harlington remained within the Defra "Low" band for $PM_{2.5}$ in 2013. Harlington, however, had 16 days of "Moderate" $PM_{2.5}$ on the dates shown below.

- 17th January
- 12th-13th February

- 18th February
- 4th–7th March
- 20th March
- 22nd March
- 10th April
- 20th June
- 24th August
- 10th-12th December.

There was also one day of "High" $PM_{2.5}$, on 25th September. Several of these dates coincided with days of "Moderate" PM_{10}.

3.6.4 Ozone

The maximum daily 8-hour mean ozone concentration (measured at Harlington only) went into the "Moderate" band on 54 occasions on 11 days.

3.7 Discussion of data in relation to sources

In order to investigate the possible sources of air pollution being monitored at Heathrow Airport, meteorological data recorded at the LHR2 site were used to add a directional component to the air pollutant concentrations.

Figure 3-14 shows the wind speed and direction data. The lengths of the "spokes" against the concentric circles indicate the percentage of time during the year that the wind was measured from each direction. In 2013, the prevailing wind directions were from the SW (35%) and NE (31%), accounting for 35% and 31% respectively. Each "spoke" is divided into coloured sections representing wind speed intervals of 2 m s^{-1} as shown by the scale bar in the plot. The mean wind speed was 3.6 m s^{-1}. This is a relatively high mean wind speed and reflects the exposed position of the monitoring site.

Figure 3-14: Wind rose for LHR2, showing frequencies of measurements of wind speed and direction

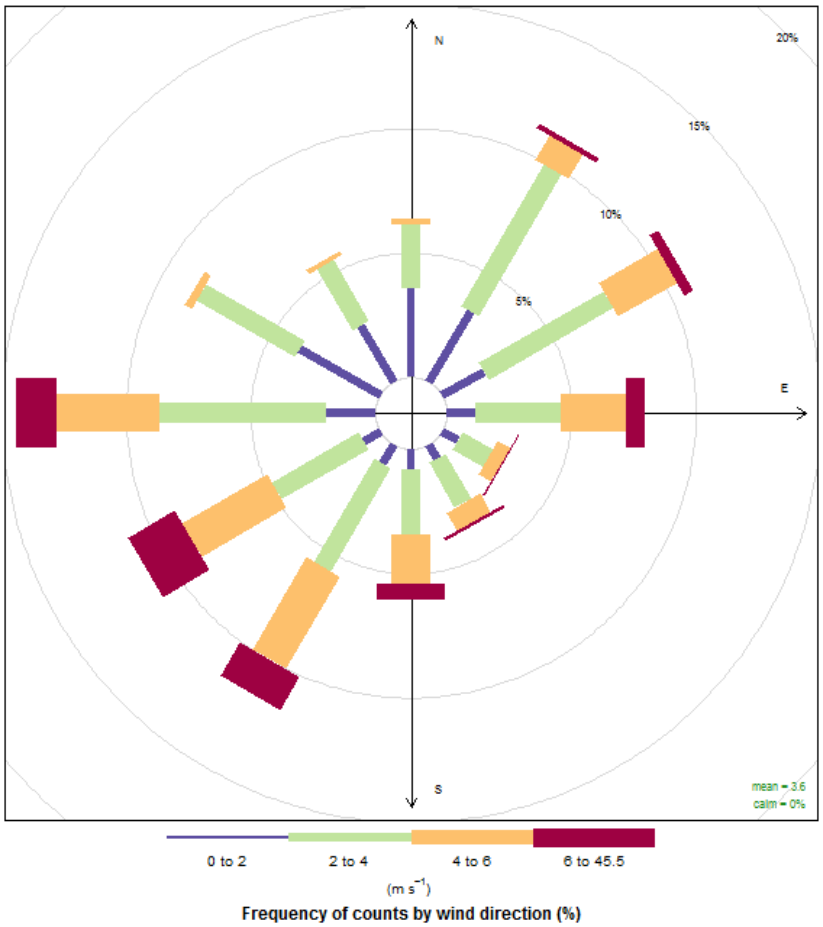


Figure 3-15 to Figure 3-18 show bivariate plots of hourly mean concentrations of NO, NO_2, PM_{10} and $PM_{2.5}$ at LHR2 against the corresponding wind speed and wind direction. Figure 3-19 shows a bivariate plot of ozone concentration at Harlington, plotted using wind speed and direction data from LHR2. These plots should be interpreted as follows:

- The wind speed is indicated by the distance from the centre of the plot; the grey circles indicate wind speeds in 2 m s^{-1} intervals.
- The pollutant concentration is indicated by the colour (as indicated by the scale).

These plots therefore show how pollutant concentrations varied with wind direction and wind speed. No VCM correction has been applied to the PM_{10} data used in these analyses, as the intention was to show patterns rather than absolute values.

The plots do not show distance of pollutant emission sources from the monitoring site. However, in the case of primary pollutants such as NO, the concentrations at very low wind speeds are dominated by emission sources close by, while at higher wind speeds, effects are seen from sources further away.

A small number of extremely high wind speed measurements were recorded between 14:00-20:00 on 20th January (speeds up to 45 ms^{-1}). These were considered unlikely to be genuine and have therefore been removed from the dataset before producing the bivariate plots (to avoid distorting the patterns).

Figure 3-15: Pollution rose for NO at LHR2

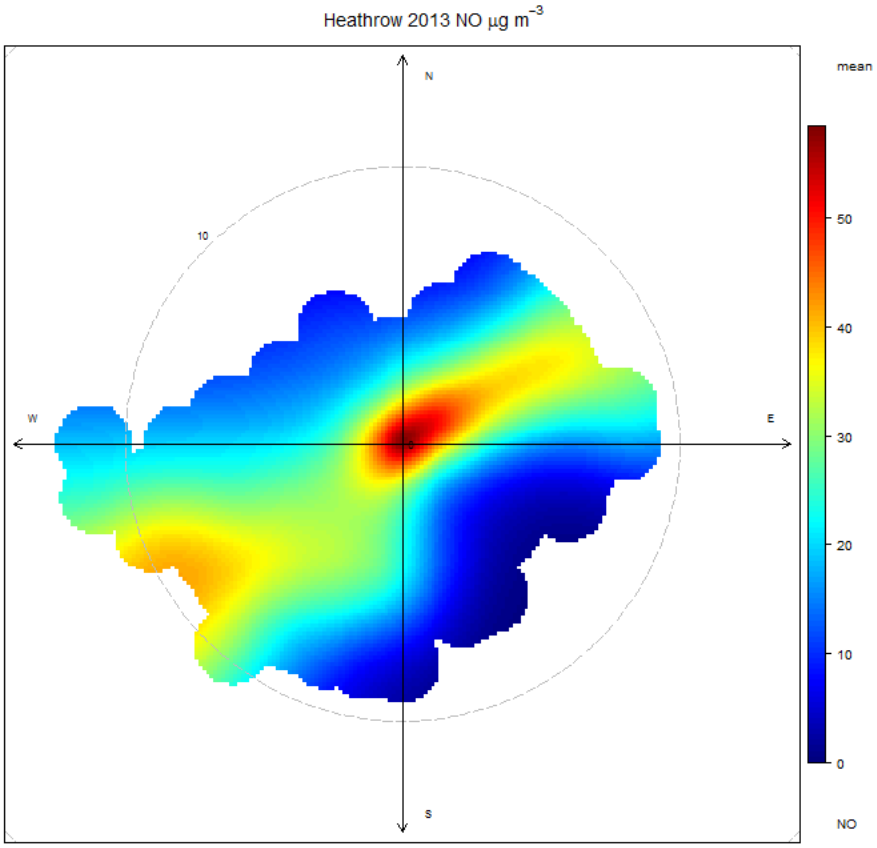


Figure 3-15 shows that the highest concentrations of NO occurred under calm conditions. Such conditions will have allowed NO emitted from nearby sources (vehicles on the northern perimeter road, Bath Road, and within the hotel car parks beside it) to build up, reaching high concentrations. There were also high NO concentrations at greater wind speeds from the south west and the north east.

Figure 3-16: Pollution rose for NO_2 at LHR2

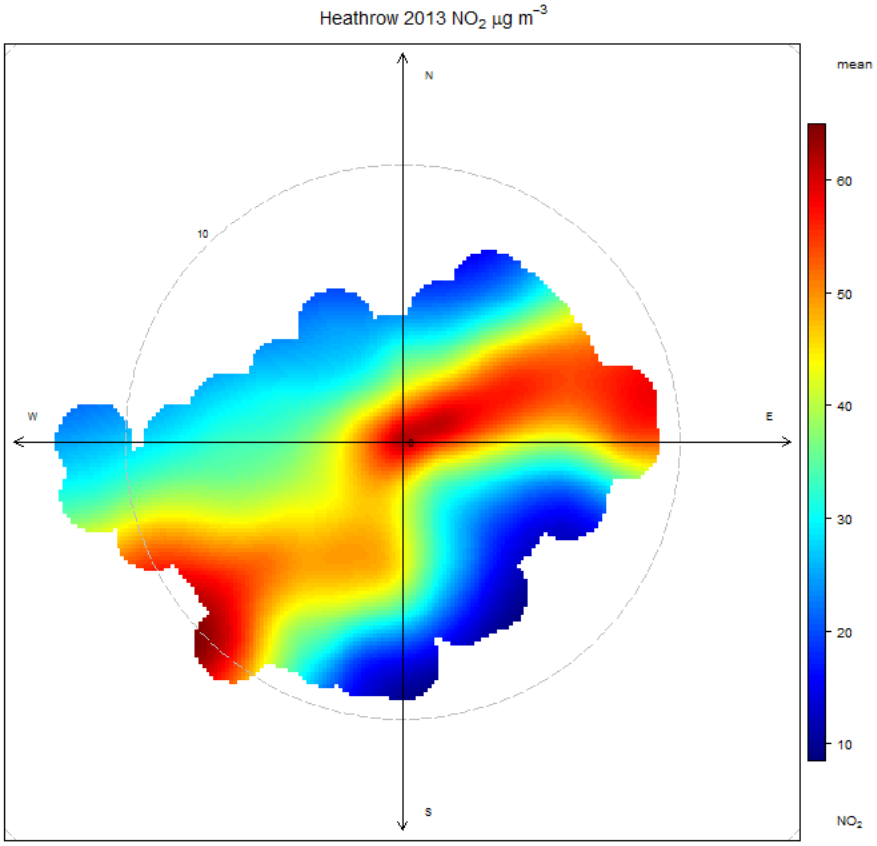


Figure 3-16 shows that the highest concentrations of NO_2 were associated with two sets of conditions. Calm conditions and light winds from the north east brought pollutants from the nearest roads and the built-up area of Harlington. The second area of orange-red is associated with a wind direction of around 240º. However, it is more evident at higher wind speeds, (6-10 ms^{-1}), possibly indicating a source further away. In this direction are the Terminal 5, the central terminal area (CTA) and the M25.

Figure 3-17: Pollution rose for PM_{10} at LHR2 (TEOM data as measured)

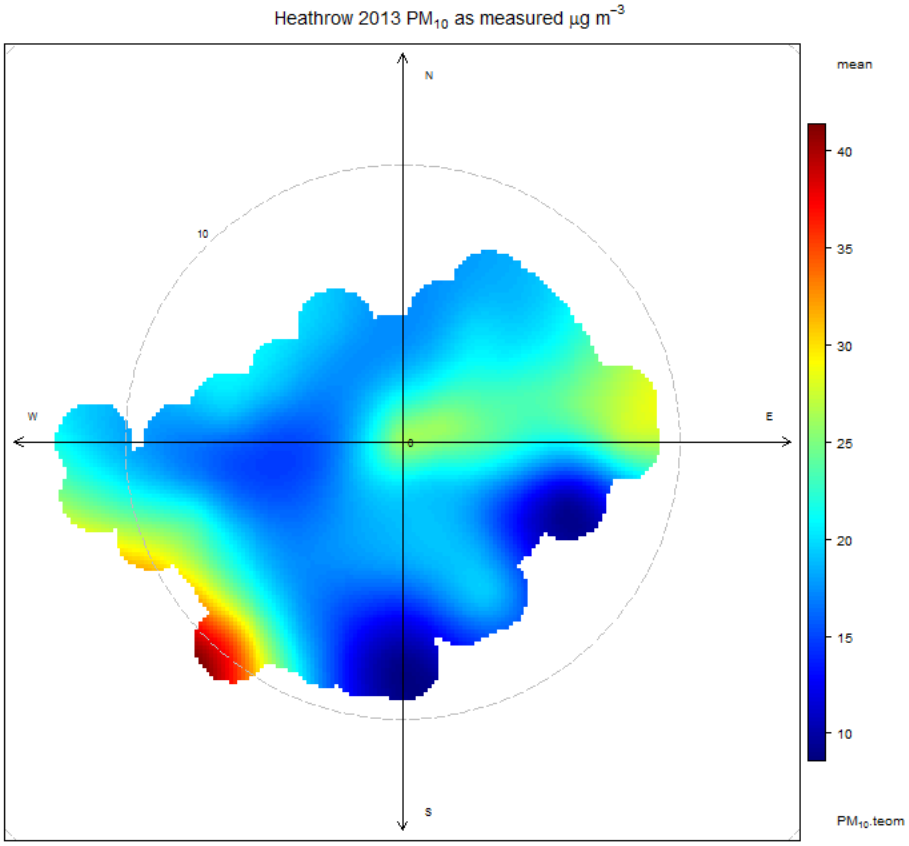


Figure 3-17 (for PM_{10}) is based on TEOM data "as measured", without VCM correction. It shows moderate concentrations occurred under calm conditions very close to the monitoring station. There was also a moderately strong signal from approximately 70 ° at a range of wind speeds. This is similar to the pattern seen for NO_2, suggesting that the two sources might be related. At higher wind speeds, high concentrations also appeared to the south west. As for the oxides of nitrogen, there are numerous sources in this direction such as Terminal 5, the central terminal area (CTA) and the M25.

Figure 3-18: Pollution rose for $PM_{2.5}$ at LHR2

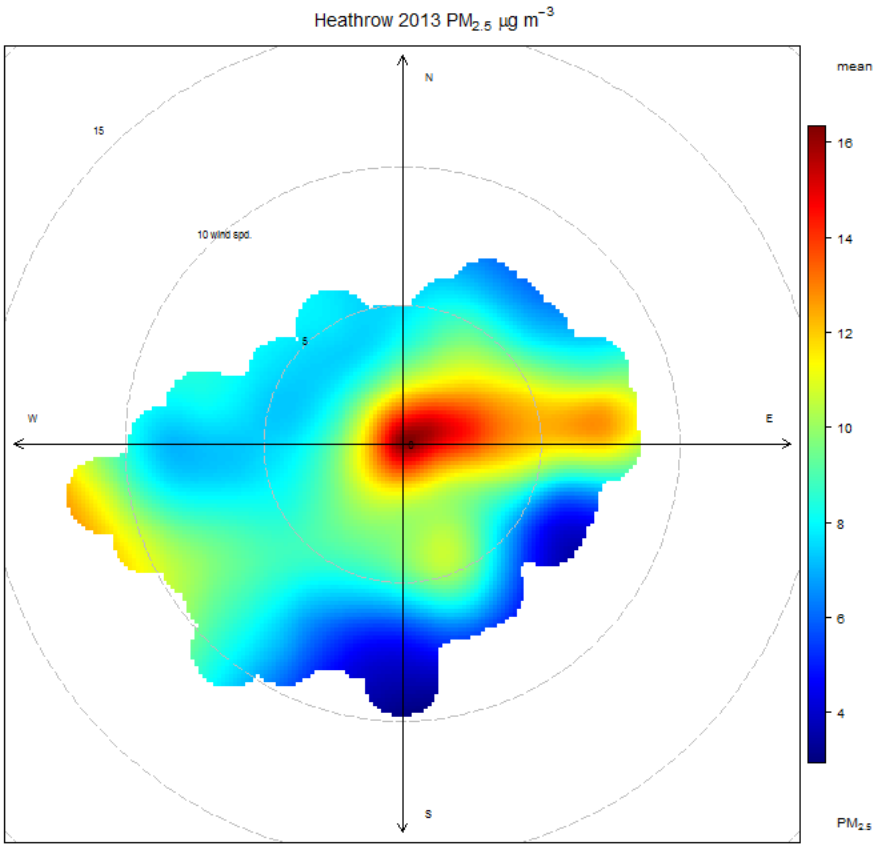
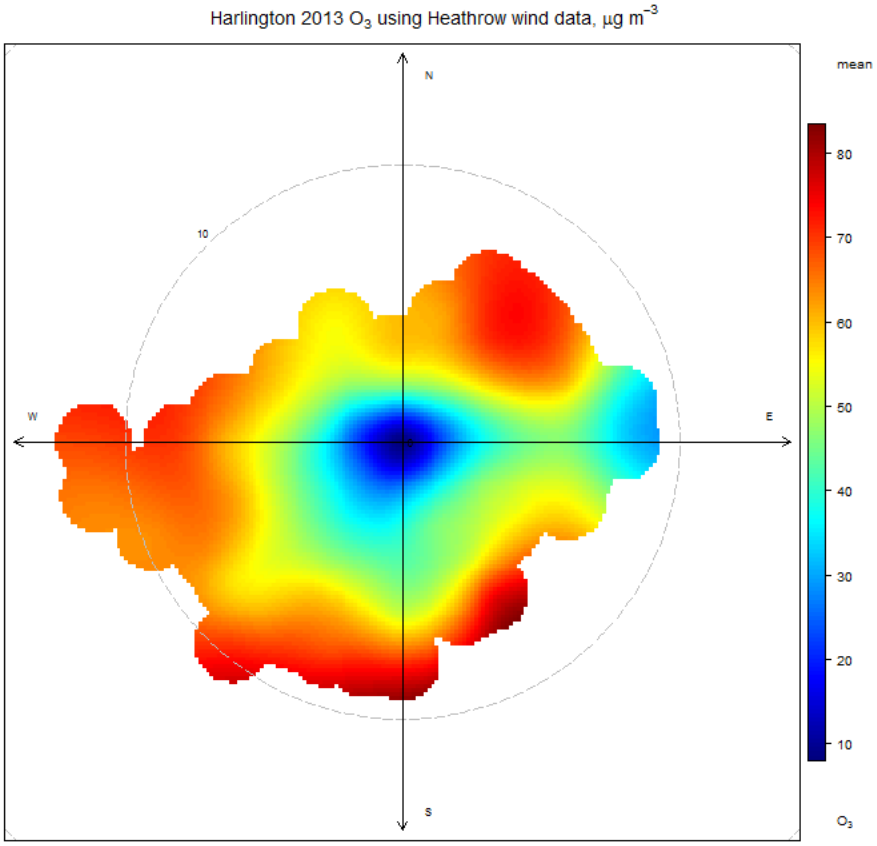


Figure 3-18 shows a similar directional pattern for $PM_{2.5}$ to that seen with PM_{10}. At low wind speeds, there appeared to be a build-up close to the monitoring location, suggesting the same sources were involved for both particulate size fractions. The signatures at higher wind speeds were also similar, although $PM_{2.5}$ showed a lower contribution than was seen for PM_{10} (note that the scales vary between Figures 3-17 and 3-18).

The pollution rose for ozone (Figure 3-19) is based on ozone concentration data from Harlington, combined with wind speed and direction data from the Heathrow LHR site. This should be treated as indicative only, as wind speeds at Harlington are likely to be lower on average than those at the very exposed LHR2 site. The pattern for ozone showed a very different pattern from those seen in previous years. In calm conditions, ozone concentrations remained low, perhaps because NO was not being dispersed and it was therefore able to react with ozone. Low concentrations also occurred at higher wind speeds from the east. The air mass from London is likely to already be ozone depleted, following reactions with emissions in the city. The highest concentrations occurred when the wind direction was from less built-up areas to the north, south and west of Harlington bringing lower concentrations of nitrogen oxides and less opportunity for ozone to react out.

Figure 3-19: Pollution rose for ozone at Harlington (using LHR2 wind data)



3.8 Comparison with other sites in London

Annual mean pollutant concentrations at the four Heathrow sites are compared in Table 3-10 with those measured at other air quality monitoring sites in and around London and the south of England. The sites selected are all part of the UK's national Automatic Urban and Rural Network (AURN) and are as follows:

- London Bexley: a suburban site in a residential area to the south east of London.
- London North Kensington: an urban background site at a school in Kensington, to the west of central London.
- London Bloomsbury: an urban background site in Russell Square, central London
- London Marylebone Road: a kerbside city centre site close to a busy major road: this site measures some of the highest pollutant concentrations in London
- Harwell: a rural site in Oxfordshire, included for comparative purposes.

The PM_{10} statistics from LHR2, Green Gates and Oaks Road shown in this table are VCM-corrected. All AURN monitoring stations make PM_{10} and $PM_{2.5}$ measurements using FDMS instruments rather than unmodified TEOMs, so VCM correction is not necessary in these cases.

All mass units are at 20 °C and 1,013 mb.

Table 3-10: Annual mean pollutant concentrations at Heathrow compared with other sites

Site	Environment type	NO_2 µg m^{-3}	PM_{10} µg m^{-3}	$PM_{2.5}$ µg m^{-3}	O_3 µg m^{-3}
LHR2		48	25	11	-
Harlington		38	20	14	36
Green Gates		33	21	10	-
Oaks Road		34	22	10	-
London Bexley	Suburban background	28	-	16	-
London North Kensington	Urban background	37	n/a*	15	38
London Bloomsbury	Urban background	51	18	15	25
London Marylebone Road	Urban traffic	84	29	20	17
Harwell	Rural background	n/a*	n/a*	n/a*	51

** n/a refers to a data capture below 75%; '–' means that the pollutant was not measured at that location.*

The annual mean NO_2 concentrations at LHR2 and Harlington were comparable to those at the urban background sites, London Bloomsbury and London North Kensington. None of the Heathrow Airport sites had NO_2 concentrations as high as those at London Marylebone, a city centre site beside a congested major road. Annual mean NO_2 concentrations at Green Gates and Oaks Road were higher than those at the suburban London Bexley site. They were comparable with the annual mean at London North Kensington.

The annual mean PM_{10} concentrations at all four Heathrow sites were higher than the mean for London Bloomsbury and lower than the value for London Marylebone Road.

$PM_{2.5}$ concentrations were lower than those for any of the comparison sites. However, this may be due to under-estimation by the TEOM analyser (which for $PM_{2.5}$ cannot be corrected for using the VCM). They were slightly lower than those recorded at London Bloomsbury and London North Kensington, both of which are urban background sites.

Concentrations of ozone tend to be higher in rural areas because of the chemistry of its formation. This is demonstrated by the annual mean recorded at Harwell, which was higher than those at the other sites. The annual mean concentration at Harlington is comparable with that measured at London North Kensington. As expected, it is higher than the annual mean at London Marylebone Road, an urban traffic site.

The number of exceedances of the AQS objective for ozone in 2013 was 11. This is comparable with the number of ozone exceedances at other urban background and rural sites in London and the south east of England (for example 10 days at London North Kensington, 12 days at Reading New Town, 13 days at Southend on Sea and 14 days at Harwell.

3.9 Long-term changes in pollutant concentrations

LHR2 has been in operation for 20 years (having started up in 1993). The other three sites have all been in operation since 2003 or earlier. There is now a considerable amount of data

which can be used to assess how pollutant concentrations have changed over this period. Annual mean concentrations of NOx, NO, NO_2, PM_{10}, $PM_{2.5}$ and O_3 are provided in table form in Appendix 3 and illustrated below in Figures 3-20 to 3-27. Annual means are only shown for years in which data capture was at least 75%.

Figure 3-20: Time series for annual mean NOx

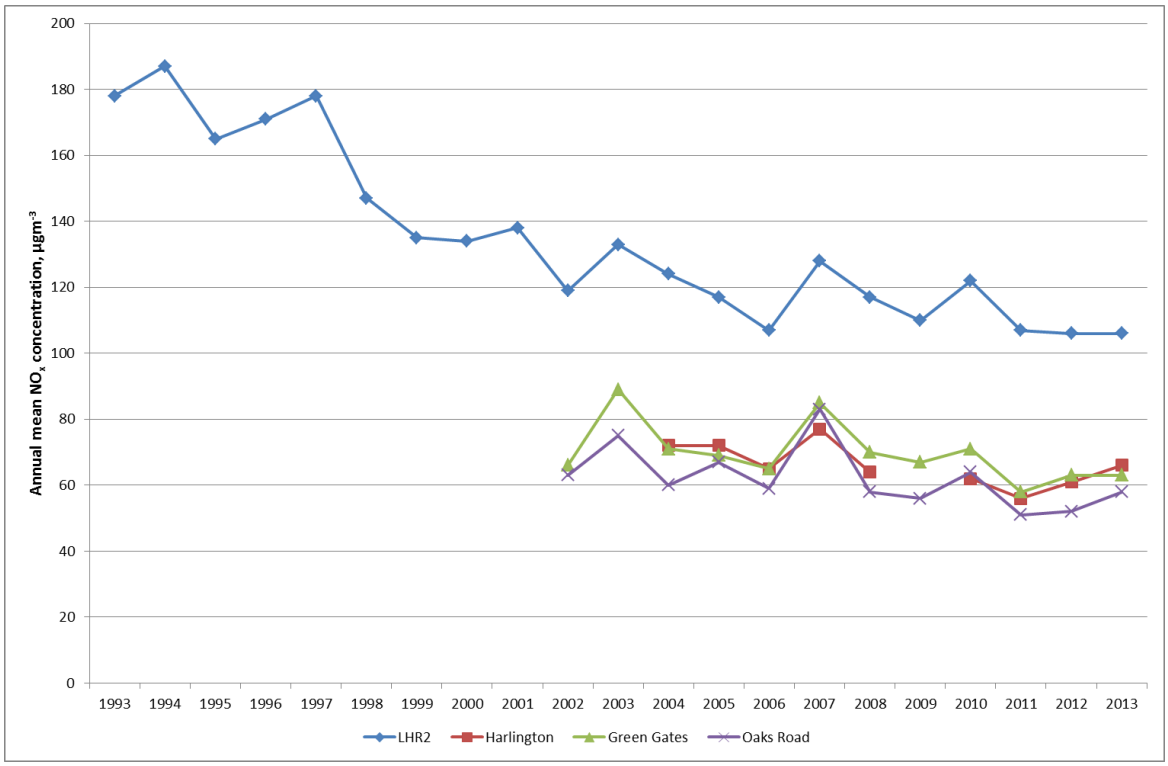
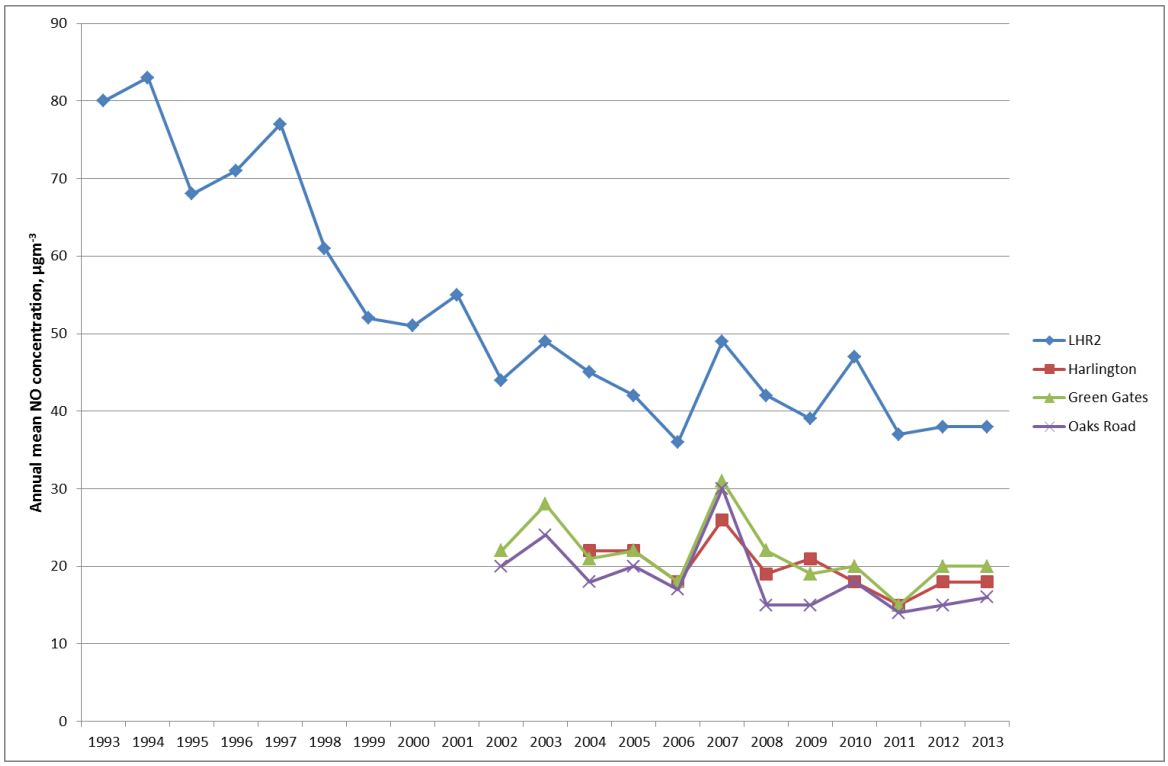


Figure 3-20 shows how annual mean concentrations of total NOx have changed at the four sites, since the first site (LHR2) came into operation. There was a clear decrease throughout the 1990s at this site. Since about 2002, concentrations have fluctuated between approximately 100 µg $m^{-3}$and 130 µg m^{-3}. At the other three sites, a slight decrease in annual mean NOx has occurred over the past decade, although considerable variations have occurred from one year to the next. Trends in annual mean concentrations of NO, illustrated in Figure 3-21, follow similar patterns to those observed for total NOx. (Please note, different scales are used).

Figure 3-21: Time series for annual mean NO



In the case of NO_2 (illustrated in Figure 3-22), there is a downward trend at LHR2, although this is less marked than those seen for NO and NOx and in the previous figures. The annual mean concentrations at Harlington, Green Gates and Oaks Road have fluctuated between 30 µg m^{-3} and 40 µg m^{-3} apart from two peaks at Green Gates in 2003 and 2010.

Figure 3-22: Time series for annual mean NO_2

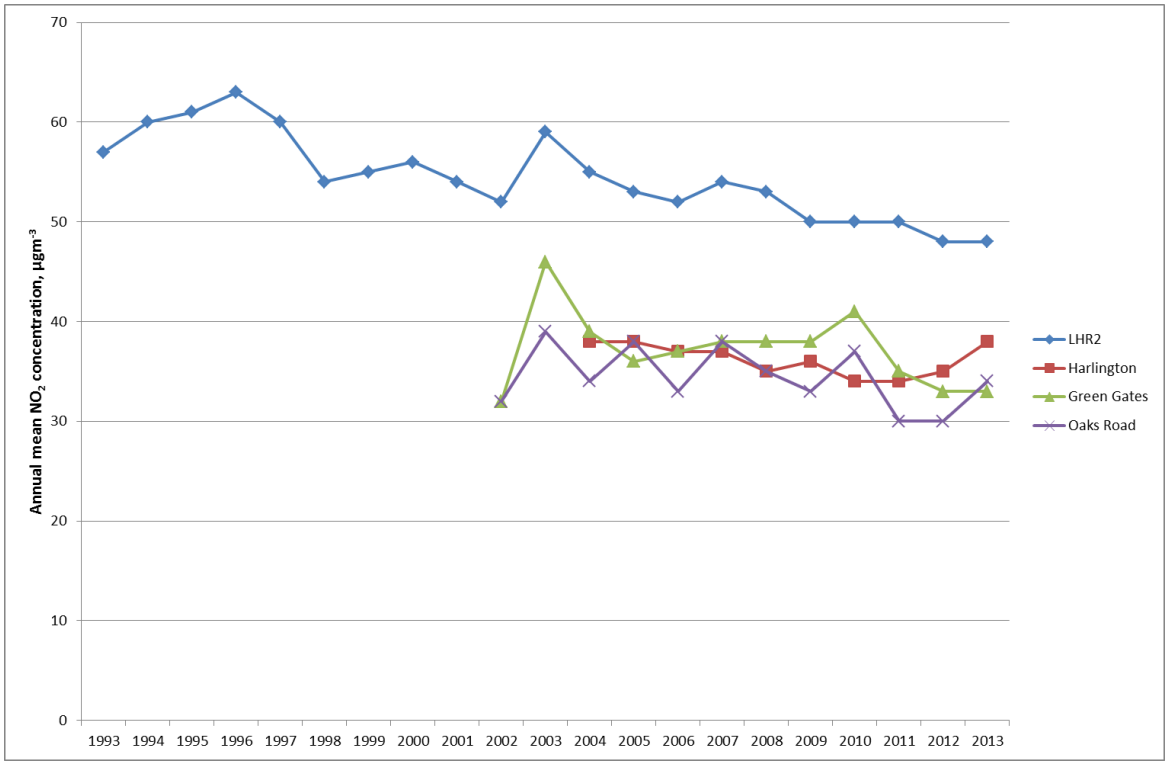
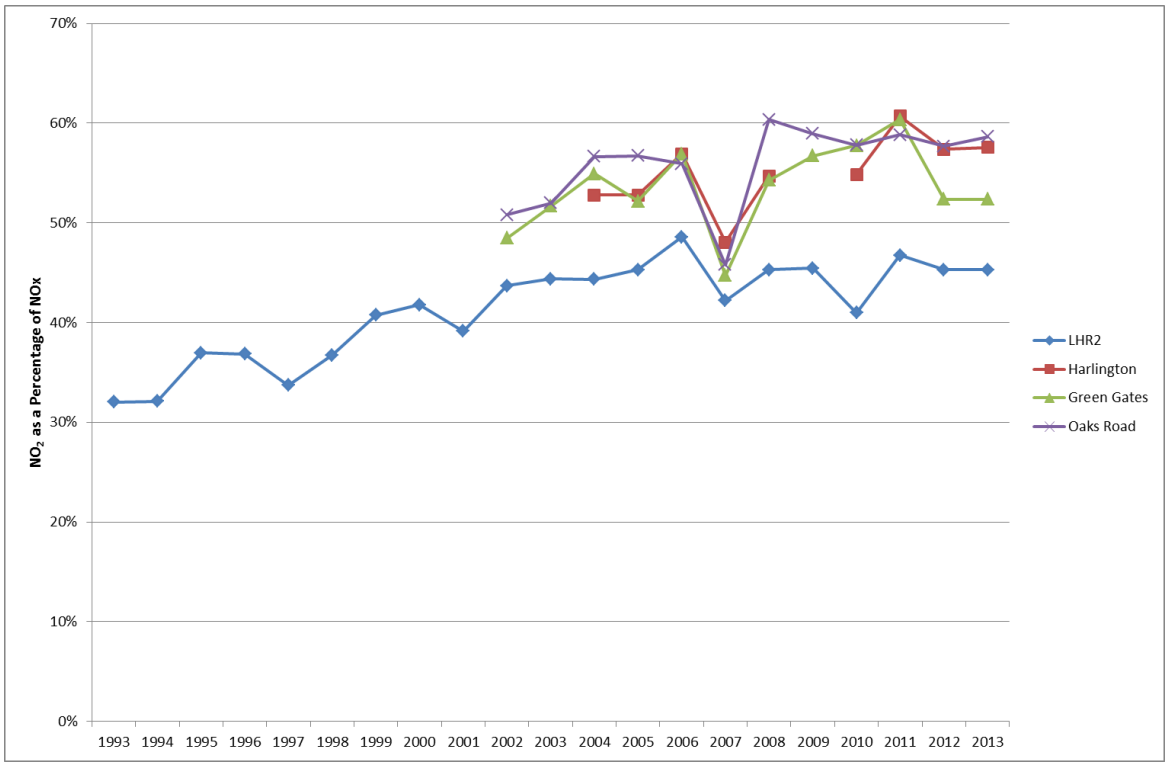


Figure 3-23 shows the annual mean concentration of NO_2 as a percentage of the total NOx. From the early 1990s to about 2006 NO_2 accounted for an increasing percentage of total

NOx at LHR2. Since then, it has fluctuated between 45 % and 50%. The proportion of NOx measured as NO_2 at the other three sites has been consistently higher, but has followed broadly similar yearly variations to those seen at LHR2.

Figure 3-23: Time series for NO_2 as a percentage of total NOx



An increasing trend in the proportion of NO relative to NOx has been observed in the UK as a whole. The Air Quality Expert Group[4] considered this may be due to an increase in the proportion of total NOx emitted as NO_2 resulting from an increased proportion of diesel cars and more prevalent use of catalytically regenerative particulate traps on buses).

Figure 3-24 illustrates how annual mean PM_{10} concentrations have changed since monitoring began in 1995.

Earlier reports in this series, for years up to and including 2010, have assessed long-term changes on the basis of the annual mean as measured by the TEOM, multiplied by a factor of 1.3. This was formerly used as an indicative estimate of gravimetric equivalent. However, the use of this factor is no longer recommended and the VCM should be used wherever possible. Therefore, in reports for 2011 onwards, the annual mean PM_{10} data for previous years have been retrospectively VCM-corrected, as far back in time as possible. The earliest year for which this has been possible is 2004. Figure 3-24 shows VCM-corrected data from 2004 onwards. For years prior to this, uncorrected TEOM data are shown.

Although there is no clear trend, VCM-corrected PM_{10} concentrations appear to have increased since 2008 at LHR2, Green Gates and Oaks Road. At Harlington, concentrations have increased since 2010, although the results for 2011 and 2012 should be interpreted with caution because of low data capture rates. The annual mean for 2013 is definitely higher than that measured in 2010.

Figure 3-24 also shows the mean result from three urban non-roadside monitoring sites in London and its surrounding area: London Bloomsbury, London North Kensington (gravimetric method) and Thurrock. Only data since 2009 are included, as this is the point at which all TEOM analysers in the AURN were upgraded to FDMS. Again there are no clear trends in recent years but the average result is consistent with those from the Heathrow sites.

Figure 3-24: Time series for annual mean PM_{10} (TEOM until 2003, VCM-corrected TEOM from 2004 onwards)

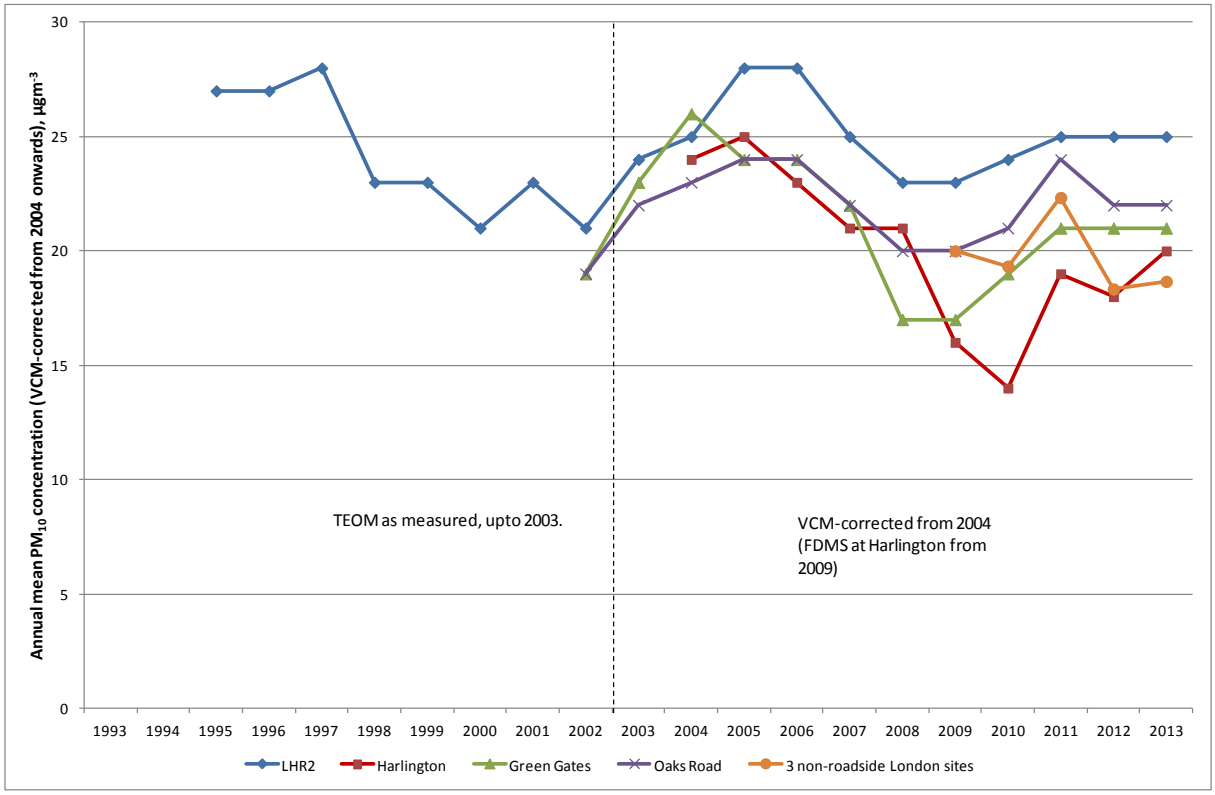
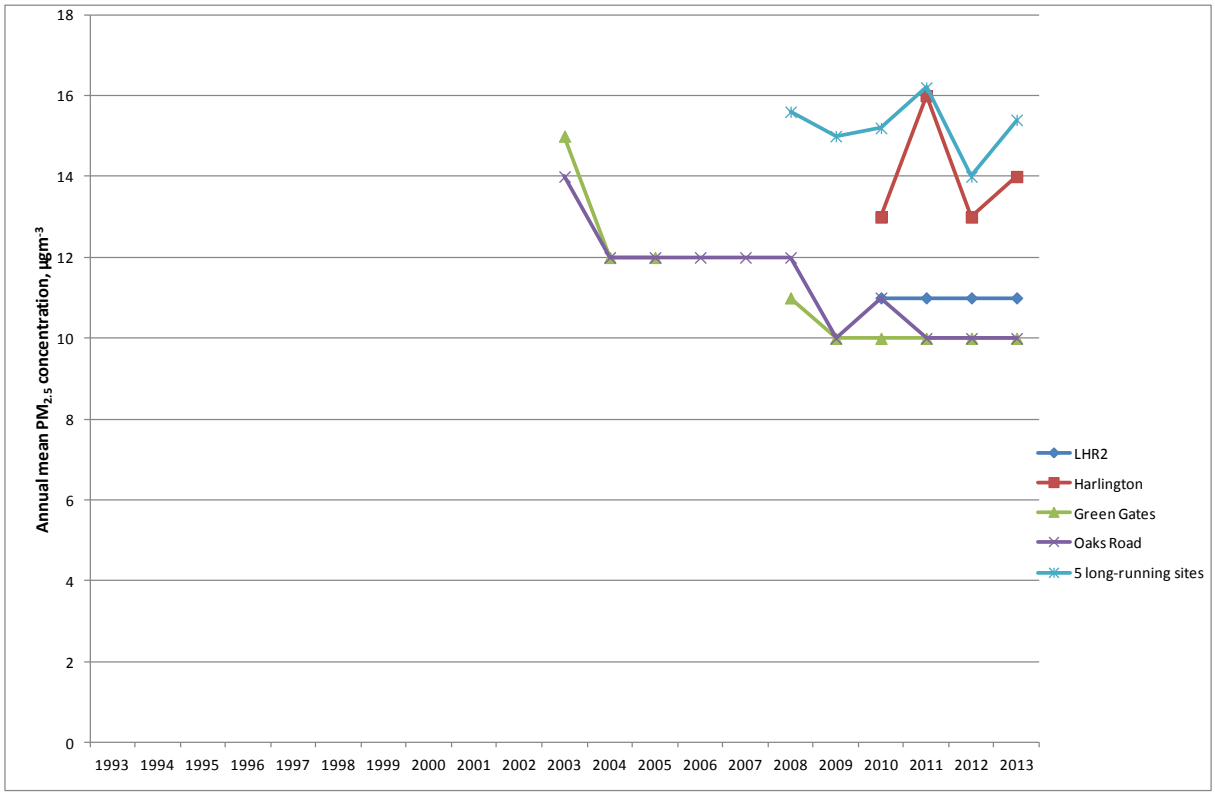


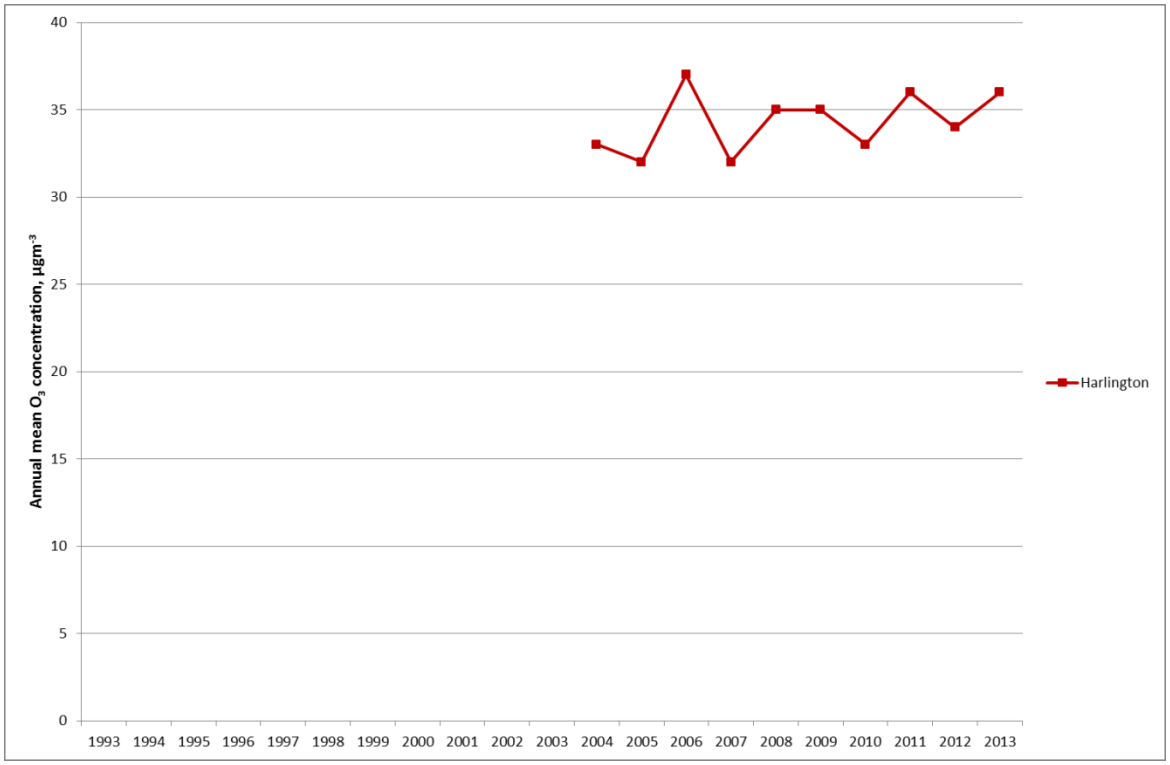
Figure 3-25 shows how annual mean concentrations of $PM_{2.5}$ have changed over time. For Green Gates and Oaks Road, where trends can be observed over several years, concentrations have decreased. Also shown is the mean result from five urban non-roadside monitoring sites in London that have all measured $PM_{2.5}$ since 2008. These are: London Bexley, London Bloomsbury, London Eltham, London North Kensington, London Teddington and London Westminster. The mean from these five sites shows a similar pattern to London Harlington.

Figure 3-25: Trends in annual mean $PM_{2.5}$



Ozone was only measured at Harlington, as illustrated in Figure 3-26. Although a slight upward trend can be detected, the change in concentrations has only been slight and there has been considerable variation from year to year. Ozone at ground level is known to be "scavenged" from the air by NO (with which it reacts): so the slight decrease seen in NO concentration (Figure 3-21) is consistent with the slight increase in ozone concentration evident in Figure 3-26.

Figure 3-26: Trends in annual mean ozone at Harlington



3.10 Relationship with airport activity

As discussed in section 3.5.1, ambient concentrations of oxides of nitrogen and particulate matter measured at the four Heathrow sites were typically higher in winter and lower in summer. This pattern has been observed consistently in previous years. It is important to note that emissions from the airport (and associated sources such as road traffic) are an important contributor to local concentrations of NO_2 and PM_{10}. However, the seasonal variations show that ambient pollutant concentrations around the airport are driven by meteorological factors rather than local emissions.

Although the seasonal variations can be attributed to weather conditions, it is also useful to look for relationships between long-term trends in airport activity and pollutant concentrations. Figure 3-27 shows daily mean aircraft transport movements (ATMs) for each month during 2013. As in most previous years, ATMs remained relatively constant throughout the year, with a slight increase in summer.

Figure 3-27: Average number of transport movements per day at Heathrow, 2013

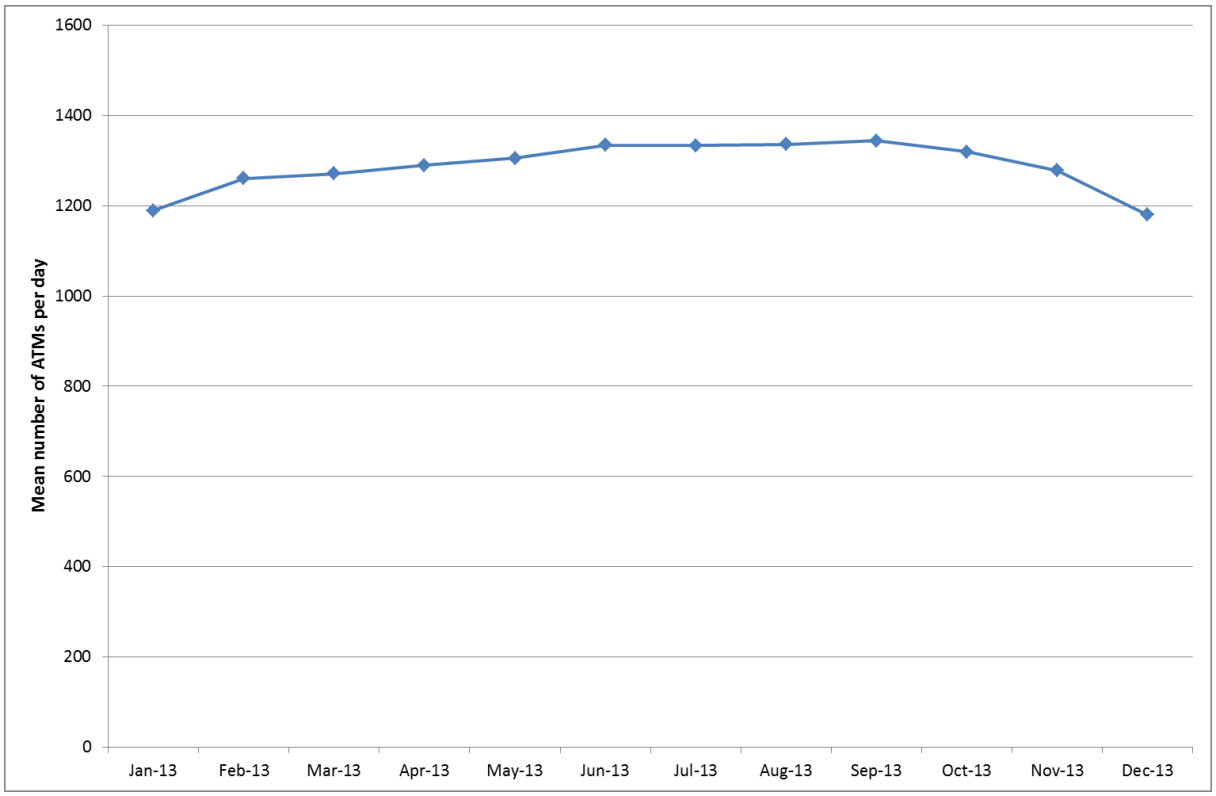


Figure 3-28 shows annual mean NOx concentrations at the four monitoring sites, together with annual total ATMs. ATMs rose steadily at Heathrow from 1995 to 2007, after which there was a decline until 2011. Since then, ATMs have remained steady at around 470,000. Local ambient concentrations in NOx have fluctuated over the same period, but there is no obvious relationship between NOx concentrations and airport activity. (However the airport activities will contribute to NOx concentrations in the area.)

Figure 3-28: Time series for annual ATM and annual mean NOx concentrations

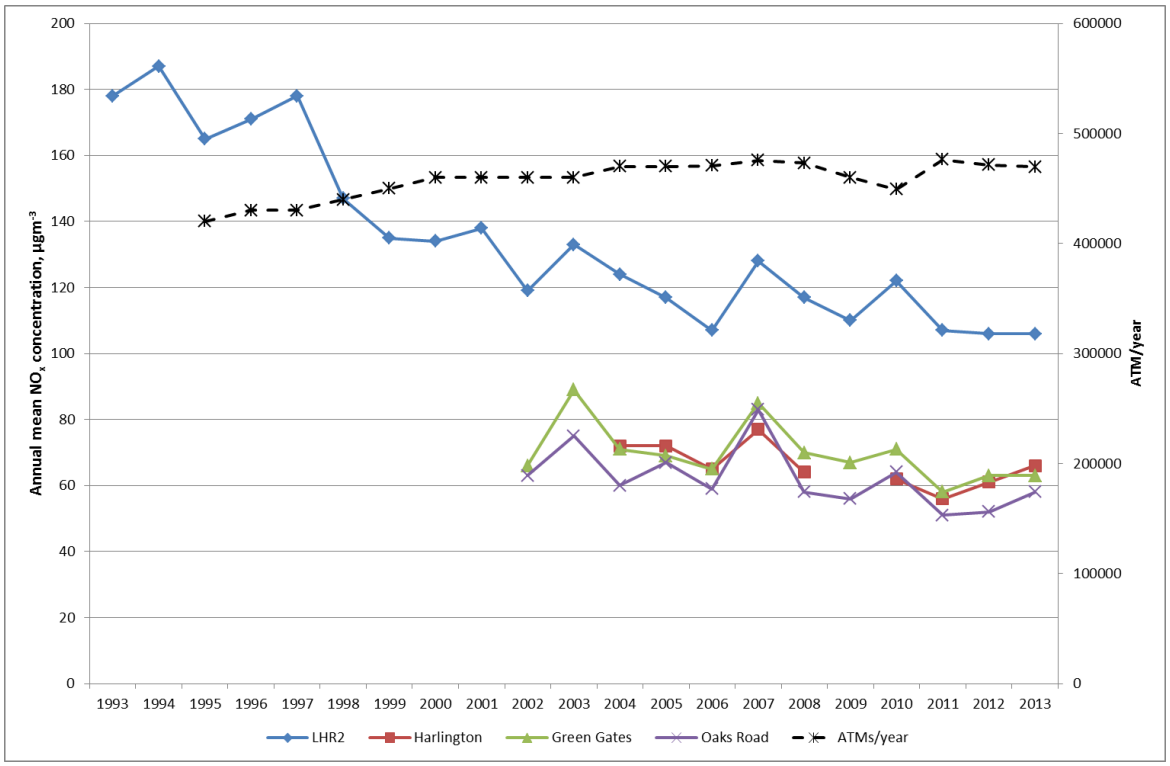
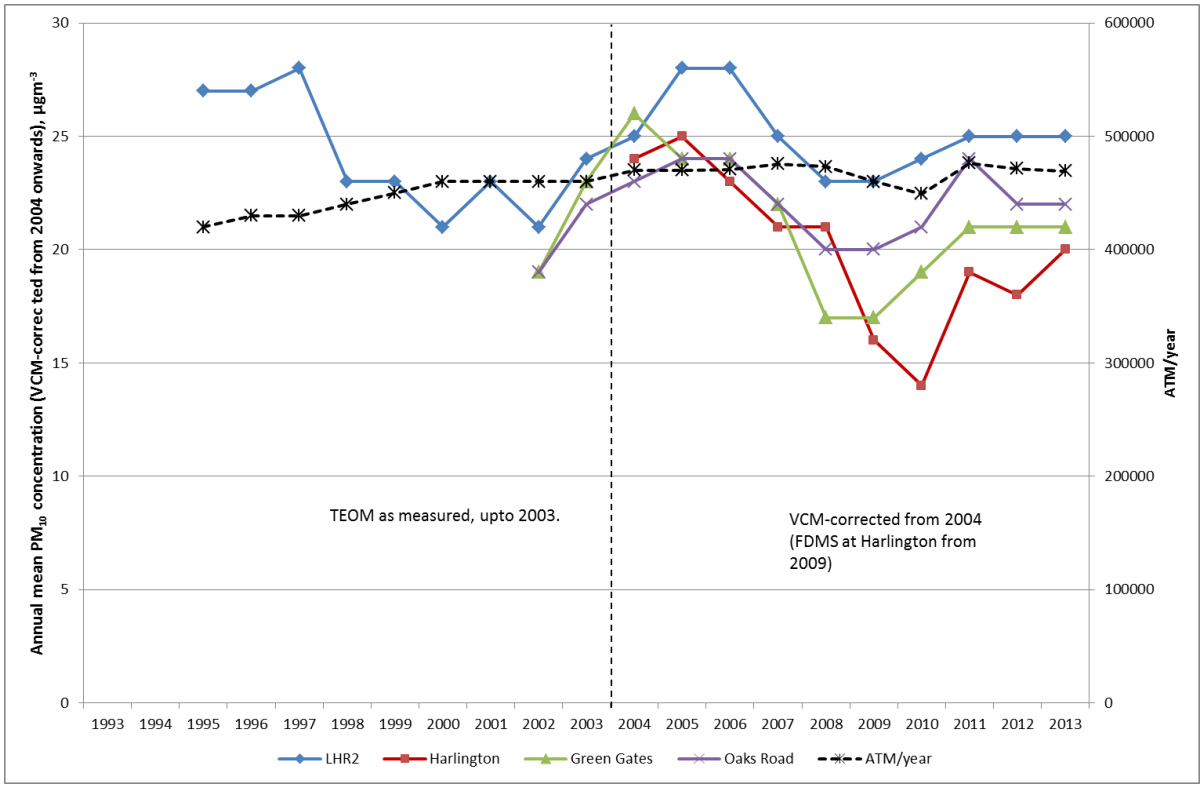


Figure 3-29 shows the same comparison for PM_{10}, with no clear relationship being apparent between annual mean PM_{10} and changes in air transport movements. This does not mean that the airport is not a major contributor to local ambient PM_{10}, but suggests that variations in ambient PM_{10} concentrations are also dependent on other factors.

Figure 3-29: Time series for annual ATM and annual mean PM_{10} concentrations



4 Conclusions

Oxides of nitrogen and particulate matter (as PM_{10} and $PM_{2.5}$) were monitored throughout 2013 at four sites around Heathrow Airport (LHR2, London Harlington, Green Gates and Oaks Road). Ozone was measured at Harlington. Benzene was indicatively monitored using diffusion tubes at LHR2. The conclusions of the 2013 monitoring programme are summarised below.

1. Data capture of at least 90 % was achieved for all pollutants monitored at LHR2, Green Gates and Oaks Road. This target was achieved at Harlington for all pollutants except NO and NO_2, for which the data capture was 86 %.
2. Oxides of nitrogen were monitored at all four sites. No sites exceeded the AQS objective of 200 µg m^{-3} for hourly mean NO_2 more than the 18 permitted times per year during 2013.
3. One site, LHR2, exceeded the annual mean AQS objective of 40 µg m^{-3} for NO_2 in 2013, with an annual mean of 48 µg m^{-3}, although the EU limit values and AQS objectives do not apply at the LHR2 site, because it is within the airport boundary where there is no public exposure. LHR2 has consistently exceeded this objective since monitoring began. The other three sites did not exceed this objective.
4. All four sites met the AQS objective for 24-hour mean PM_{10}. Where measurements were made using the TEOM instrument, the PM_{10} data were converted to gravimetric equivalent using the King's College Volatile Correction Model (VCM).
5. All four sites met the annual mean AQS objective of 40 µg m^{-3} for PM_{10}, again after correction, where applicable, to gravimetric equivalent using the VCM.
6. Ozone was measured at Harlington only. This site exceeded the AQS objective for ozone on 11 days during 2013, which is more than the permitted maximum of 10 days per calendar year. Harlington has exceeded the objective before, the most recent occurrences being in 2006, 2008, 2009 and 2011. Many other sites in the south east of England also exceeded this objective in 2013.
7. Diffusion tube measurements at LHR2 indicate that this site met the AQS objective for benzene.
8. Seasonal variations in pollutant concentrations at all sites were similar to those observed in previous years and at other urban background sites. Both NO and NO_2 exhibited higher concentrations during the winter months. PM_{10} and $PM_{2.5}$, which have both primary and secondary components, showed a much less pronounced seasonal pattern. Ozone levels were highest during the spring and summer, as is typical.
9. The diurnal patterns of concentrations of all pollutants were similar to those observed at other urban monitoring sites. Peak concentrations of NO, NO_2 and particulate matter coincided with the morning and evening rush hour periods, and levels of ozone peaked in the afternoons.
10. Several periods of elevated PM_{10} concentration (daily mean concentration in the Defra "Moderate" band) occurred during 2013. As in previous years, other urban background monitoring sites in London and the south east of England showed a similar pattern of elevated PM_{10} concentrations during the above periods. This indicates that the higher concentrations measured at Heathrow reflected regional variations in PM_{10} concentration, rather than any emission sources specific to the airport.
11. Ozone concentration (measured at Harlington only) went into the "Moderate" band on 11 days in 2013.
12. Meteorological measurements at LHR2 allowed the effect of wind direction and speed to be investigated. Bivariate plots of NO concentration and wind data showed that

concentrations of the primary pollutant NO at LHR2 were typically highest in calm conditions, indicating that the main sources of NO were nearby. The pattern was similar for NO_2, but with a strong signal also appearing from the south west. The patterns for PM_{10} and $PM_{2.5}$ showed contributions from sources on a bearing of approximately 70 ° at a range of wind speeds. In the case of PM_{10} there were also contributions from the south west at higher wind speeds.

13. Annual mean concentrations of pollutants at the four Heathrow sites in 2013 were comparable with those measured at other suburban and urban background monitoring sites in London.
14. Long-term data from this monitoring programme indicate that annual mean concentrations of the primary pollutant NO have decreased, although they have fluctuated around a more constant level in recent years. A decrease is also observed in annual mean concentrations of NO_2 at LHR2, although the pattern is less marked at the other sites. PM_{10} has shown a slight increase. The proportion of total NOx measured as NO_2 has increased.
15. Neither seasonal patterns, nor long-term trends, in pollutant concentration at the Heathrow sites showed any obvious relationship to monthly or annual aircraft transport movements. Although the airport is likely to be a significant contributor to local air pollution, ambient concentrations are also influenced by meteorological and other factors.

5 Acknowledgements

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6 References

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Appendices

Appendix 1: Quality assurance and quality control

Appendix 2: Daily air quality index bandings

Appendix 3: Annual mean pollutant concentrations 1993-2013

Appendix 1 – Quality assurance and quality control

Ricardo-AEA operates air quality monitoring stations within a tightly controlled and documented quality assurance and quality control (QA/QC) system. Elements covered within this system include: definition of monitoring objectives; equipment selection; site selection; protocols for instrument operation calibration; service and maintenance; integrity of calibration gas standards; data review; scrutiny and validation. Ricardo-AEA's audit calibration procedures are UKAS accredited to ISO 17025. These procedures are documented in Ricardo-AEA's Automatic Urban and Rural Network (AURN) QA/QC manual[8].

All gas calibration standards used for routine analyser calibration are certified against traceable primary gas calibration standards at Ricardo-AEA's Gas Standards Calibration Laboratory. The calibration laboratory operates within a specific and documented quality system and has UKAS accreditation for calibration of the gas standards used in this survey.

An important aspect of QA/QC procedures is the regular 6-monthly intercalibration and audit check undertaken at every monitoring site. This audit has two principal functions, firstly to check the instruments and the site infrastructure, and secondly to recalibrate the transfer gas standards routinely used on-site, using standards recently checked in the calibration laboratory.

In line with current operational procedures within the Defra AURN, full intercalibration audits take place at the end of winter and summer. At these visits, the essential functional parameters of the monitors, such as noise, linearity and, for the NOx monitor, the efficiency of the NO_2 to NO converter are fully tested. In addition, the on-site transfer calibration standards are checked and re-calibrated if necessary, the air intake sampling system is cleaned and checked and all other aspects of site infrastructure are checked.

All air pollution measurements are reviewed daily at Ricardo-AEA by experienced staff. Data are compared with corresponding results from AURN monitoring stations and with expected air pollutant concentrations under the prevailing meteorological conditions. This review process rapidly highlights any unusual or unexpected measurements, which may require further investigation. When such data are identified, attempts are made to reconcile the results against known or possible local air pollution sources or local meteorology, and to confirm the correct operation of all monitors. In addition to checking the data, the results of the daily automatic instrument calibrations are examined to identify any possible instrument faults. Should any faults be identified or suspected, arrangements are made for Ricardo-AEA personnel or equipment service contractors to visit the site as soon as possible.

At the end of every quarter, the data for that period are reviewed to check for any spurious values and to apply the best daily zero and sensitivity factors; and also to account for information which only became available after the initial daily processing. At this time, any data gaps are filled with data from the data logger back-up memory, to produce a data record that is as complete as possible.

Finally, the data are re-examined on an annual basis, when information from the six-monthly intercalibration audits can be incorporated. After completion of this process, the data are fully validated and finalised, for compilation in the annual report.

Appendix 2 – Daily air quality index bandings

Table A2-1: Air pollution bandings and descriptions

Band	Index	Health descriptor
Low	1 to 3	Effects are unlikely to be noticed even by individuals who know they are sensitive to air pollutants.
Moderate	4 to 6	Mild effects, unlikely to require action, may be noticed amongst sensitive individuals.
High	7 to 9	Significant effects may be noticed by sensitive individuals and action to avoid or reduce these effects may be needed (e.g.reducing exposure by spending less time in polluted areas outdoors). Asthmatics will find that their 'reliever' inhaler is likely to reverse the effects on the lung.
Very High	10	The effects on sensitive individuals described for 'High' levels of pollution may worsen.

Table A2-2: Boundaries between index points for each pollutant

Band	Index	O_3 Daily max running 8-h mean (µg m^{-3})*	NO_2 Hourly mean (µg m^{-3})	SO_2 15 minute mean (µg m^{-3})	$PM_{2.5}$ Daily mean (µg m^{-3})	PM_{10} Daily mean (µg m^{-3})
	1	0-33	0-67	0-88	0-11	0-16
Low	2	34-66	68-134	89-177	12-23	17-33
	3	67-100	135-200	178-266	24-35	34-50
	4	101-120	201-267	267-354	36-41	51-58
Moderate	5	121-140	268-334	355-443	42-47	59-66
	6	141-160	335-400	444-532	48-53	67-75
	7	161-187	401-467	533-710	54-58	76-83
High	8	188-213	468-534	711-887	59-64	84-91
	9	214-240	535-600	888-1,064	65-70	92-100
Very High	10	241 or more	601 or more	1,065 or more	71 or more	101 or more

Appendix 3 – Annual mean pollutant concentrations 1993-2013

Table A3-1: Annual mean concentrations of NOx, µg m^{-3}

	LHR2	Harlington	Green Gates	Oaks Road
1993	178			
1994	187			
1995	165			
1996	171			
1997	178			
1998	147			
1999	135			
2000	134			
2001	138			
2002	119		66	63
2003	133		89	75
2004	124	72	71	60
2005	117	72	69	67
2006	107	65	65	59
2007	128	77	85	83
2008	117	64	70	58
2009	110	-	67	56
2010	122	62	71	64
2011	105	56	58	51
2012	106	63	61	52
2013	106	66	63	58

Table A3-2: Annual mean concentrations of NO, µg m^{-3}

	LHR2	Harlington	Green Gates	Oaks Road
1993	80			
1994	83			
1995	68			
1996	71			
1997	77			
1998	61			
1999	52			
2000	51			
2001	55			
2002	44		22	20
2003	49		28	24
2004	45	22	21	18
2005	42	22	22	20
2006	36	18	18	17
2007	49	26	31	30
2008	42	19	22	15
2009	39	21	19	15
2010	47	18	20	18
2011	37	15	15	14
2012	38	18	20	14
2013	38	18	20	16

Table A3-3: Annual mean concentrations of NO_2, µg m^{-3}

	LHR2	Harlington	Green Gates	Oaks Road
1993	57			
1994	60			
1995	61			
1996	63			
1997	60			
1998	54			
1999	55			
2000	56			
2001	54			
2002	52		32	32
2003	59		46	39
2004	55	38	39	34
2005	53	38	36	38
2006	52	37	37	33
2007	54	37	38	38
2008	53	35	38	35
2009	50	36	38	33
2010	50	34	41	37
2011	50	34	35	30
2012	48	33	33	30
2013	48	38	33	34

Table A3-4: Annual mean concentrations of PM_{10}, µg m^{-3}

Year	LHR2	Harlington	Green Gates	Oaks Road
1995	27 (35)			
1996	27 (36)			
1997	28 (36)			
1998	23 (30)			
1999	23 (29)			
2000	21 (27)			
2001	24 (29)			
2002	21 (28)		19 (25)	19 (25)
2003	24 (31)		23 (30)	22 (29)
2004	25	24	26	23
2005	28	25	24	24
2006	28	23	24	24
2007	25	21	22	22
2008	23	21	17	20
2009	23	16	17	20
2010	24	14	19	21
2011	25	-	21	24
2012	25	18	21	22
2013	25	20	21	22

Yellow shading indicates TEOM (as measured) with TEOM x 1.3 in brackets.
Aqua shading indicates VCM-corrected TEOM data.
Orange shading indicates FDMS data (from April 2009) at Harlington.

Table A3-5: Annual mean concentrations of $PM_{2.5}$, µg m^{-3}

	LHR2	Harlington	Green Gates	Oaks Road
2003			15	14
2004			12	12
2005			12	12
2006			-	12
2007			-	12
2008			11	12
2009			10	10
2010	11	13	10	11
2011	11	16	10	10
2012	11	13	10	10
2013	11	14	10	10

Table A3.6: Annual mean concentrations of O_3, µg m^{-3}

	LHR2	Harlington	Green Gates	Oaks Road
2004		33		
2005		32		
2006		37		
2007		32		
2008		35		
2009		35		
2010		33		
2011		36		
2012		34		
2013		36		

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