

REPORT

Initial review of Air Quality aspects of the Buncefield Oil Depot Explosion

A report produced for the Department for Environment, Food and Rural Affairs, the Scottish Executive, the Welsh Assembly Government and the Department of the Environment in Northern Ireland



AEA/ENV/R/2168 Issue 1
May 2006

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Front cover image by Dave Madle, Netcen



The Buncefield plume photographed from the air – © Chiltern Air Support Unit.

Executive Summary

On Sunday 11th December 2005, there was a major explosion at the Buncefield oil depot near Hemel Hempstead, north of London. Following the explosion, large stocks of refined product including petrol, aviation turbine fuel, diesel and gas oil at the depot remained on fire until Wednesday 14th December, when the last major fires were finally extinguished. A number of smaller fires continued until Thursday 15th December.

The large plume of particles and other pollutants produced by the fires could be seen from many kilometres away, and was also clearly identified in satellite images.

Netcen has estimated that 8,000 tonnes of PM₁₀ particles may have been released during the fire; this is equivalent to approximately 6% of the total annual emissions of this pollutant in the UK (based on 2003 figures from the UK National Atmospheric Emissions Inventory).

This report aims to present and summarise the air quality measurements made during the Buncefield event. It includes results obtained from targeted local monitoring undertaken in and around the plant; this was organised by Defra, Netcen, the Health Protection Agency, the Hertfordshire Fire Brigade and the Met Office. The report also includes measurements from long-term monitoring networks supported by Department for Environment, Food and Rural Affairs (Defra), Devolved Administrations (DAs) and Local Authorities in the southeast of England.

The wide range of pollutants measured and reported here includes particulate matter (PM₁₀, PM_{2.5} and PM₁, particles with a mean aerodynamic diameter of 10 µm, 2.5 µm and 1 µm, respectively), nitrogen oxides (NO_x), carbon monoxide (CO), volatile organic compounds (VOCs), dioxins, furans, hydrocarbons and polycyclic aromatic hydrocarbons (PAHs).

These air quality measurements are supported by modelling studies undertaken by the Met Office; these used atmospheric dispersion models to predict the transport and spread of the plume and to identify the origin of the air contributing to peak measurements. The Met Office carried out a variety of modelling studies during the event; these have subsequently been refined to take into account additional information and estimates of the plume's properties. These current best modelling analyses of the worst-case scenario (all fuel on site burnt) are summarised in Section 6 and examined in detail in Appendix E.

Localised monitoring of particulate matter and VOCs carried out in and around the depot showed that concentrations were elevated when compared to those recorded at nearby monitoring stations, but not markedly.

Likewise, provisional monitoring data from the UK's Automatic Urban and Rural Network (AURN), together with other regional networks in southeast England, did not show any significant increase in ground-level air pollution during the event. With the exception of a few localised and relatively unexceptional peaks, air pollution levels remained low everywhere.

Measurements taken from within the plume by the Facility for Airborne Atmospheric Measurements (FAAM) BAe146-301 research aircraft, operated by the Met Office and Natural Environment Research Council (NERC), showed that the plume was mainly black carbon- soot.

Despite the unprecedented scale of the Buncefield explosion and fire, a wide range of air pollution monitoring undertaken before, during and after the event showed that ground-level concentrations of a range of pollutants remained low to moderate over local, regional and national scales. It appears that the high plume buoyancy and favourable meteorological conditions resulted in the plume being trapped aloft, with minimal mixing to the ground. As a result, there are unlikely to have been widespread air quality impacts at ground level due to the pollutants emitted from the Buncefield fires.

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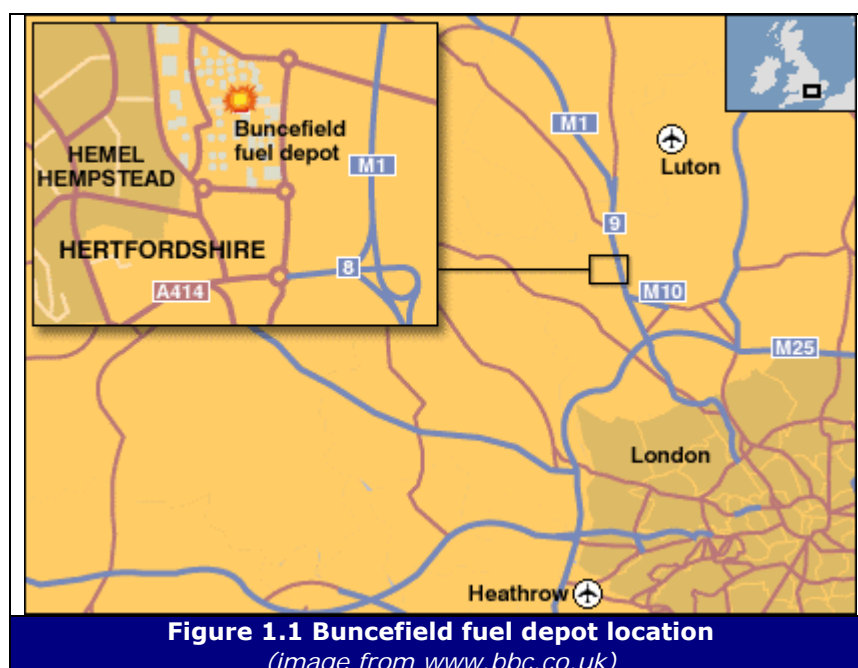
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1 Introduction

At approximately 6:03 am on Sunday 11th December 2005, there was a major explosion and subsequent large-scale fires at the Buncefield oil depot near Hemel Hempstead (see Figure 1.1). This depot is a major distribution terminal storing refined oil and petrol, as well as kerosene supplies for airports across the region, including Heathrow and Luton. The force of the blasts was heard up to 40 miles away and flames rose more than 60 metres into the sky.

By midday on Monday 12th, the fires had been extinguished in 10 out of the 20 tanks affected by the blast. The last of the fires were extinguished on Thursday.



Due to the large scale of the fires and the extensive black smoke plume, independent experts and the media expressed some concern about potential air quality impacts on public health, both in the vicinity of the depot and throughout southern England.

Air quality monitoring and forecasting across the UK, and in particular southeast England, continued as usual with no interruptions. The Automatic Urban and Rural Network (AURN), together with other local networks and monitoring stations in the region, provided valuable information on the impacts and effects of the fire. In fact, hour-by-hour updates on air quality at a range of locations throughout southern England were available throughout the event and its aftermath at the UK's national air quality website at www.airquality.co.uk.

On behalf of Defra and the Devolved Administrations, Netcen also carried out local air quality monitoring around the depot. Sampling was undertaken at a range of locations, both near the depot itself and in the surrounding areas, between December 12th and 14th. When selecting sampling points, the monitoring team attempted each day to target areas of maximum visible impact of the plume.

The Facility for Airborne Atmospheric Measurements (FAAM) BAe146-301 aircraft operated by the Met office and NERC also made detailed *in-situ* observations of the plume on the 13th December.

This report summarises currently available air quality measurements made before, during and after the fires, as well as the results of plume dispersion modelling carried out by the Met Office.

It includes the following sections:

- Timeline of events (**Section 2**)
- Emissions estimates (**Section 3**)
- Network monitoring data, targeted local air quality monitoring and aircraft measurements from within the plume (**Section 4**)
 - Pollutants covered include:
 - PM₁₀, PM_{2.5} and PM₁- particles of mean aerodynamic diameter of 10, 2.5 and 1 µm (micrometers), respectively
 - Nitrogen oxides- NO_x
 - Volatile Organic Compounds –VOCs
 - Dioxins and furans
 - Polychlorinated Biphenyls- PCBs
 - Hydrocarbons and Polycyclic Aromatic Hydrocarbons (PAHs).
- Air mass trajectory analysis (**Section 5**)
- Met Office modelling of the plume (**Section 6**)
- Conclusions (**Section 7**).

An extended series of Appendices provide more detailed insight, measurements and analyses.

2 Timeline of Events

A detailed timeline of the events during the period of the fire from 6:03 am on Sunday 11th until the end of Wednesday 14th December is presented in Figure 2.1. See also Appendix H.

The explosion occurred at 6:03 am, after which the plume rose very rapidly due the high buoyancy generated by the heat of the fire. The plume penetrated the temperature inversion at the top of boundary layer (the lowest part of the atmosphere which is directly influenced by the earth's surface) and was transported into the stable atmosphere above, reaching a height of around 3000m. There was significant wind shear, with north-westerly winds at lower levels and northeasterly winds aloft. This resulted in a fan like appearance of the plume, as shown in Figure 2.2, which could readily be seen in MODIS (MODerate resolution Imaging Spectroradiometer) satellite imagery obtained from NASA's Terra and Aqua satellites.

The anticyclonic conditions of the day resulted in a stable atmosphere; as a result, there was little mixing within the boundary layer, with most of the plume transport occurring in the free troposphere.

During the morning of Monday 12th December, a weak frontal system moved through the area. Following the clearance of the front, there were north-easterly winds at all levels over the source. These resulting in a narrow plume being transported towards the south-west, as shown by the MODIS image from the Aqua satellite at 12:40 pm (Figure 2.3).

On Tuesday 13th December there was considerably more cloud, which reduced the availability of satellite imagery of the plume. The winds were north/north-easterly, resulting in the plume being advected south. The plume was intercepted by the FAAM aircraft, which was able to confirm that the Met Office NAME model forecasts of the plume's position were correct. From Tuesday 13th to Wednesday 14th December, the winds backed round to more northerly.

By Thursday 15th December, only small fires remained at the site. Winds became north-westerly and stronger. The remainder of the plume was therefore transported to the south-east and rapidly dispersed in the moderate winds.

Figure 2.4 illustrates the different plume locations identified by satellite imagery and aircraft observations. Starting from the satellite picture obtained at 11:50 am on 11th December, the increased dispersion is shown by the area delimited by a black line (plume dispersion at 1:35 pm on 11th). The transport of the plume on 12th and 13th December was more linear. The other three lines represent this:

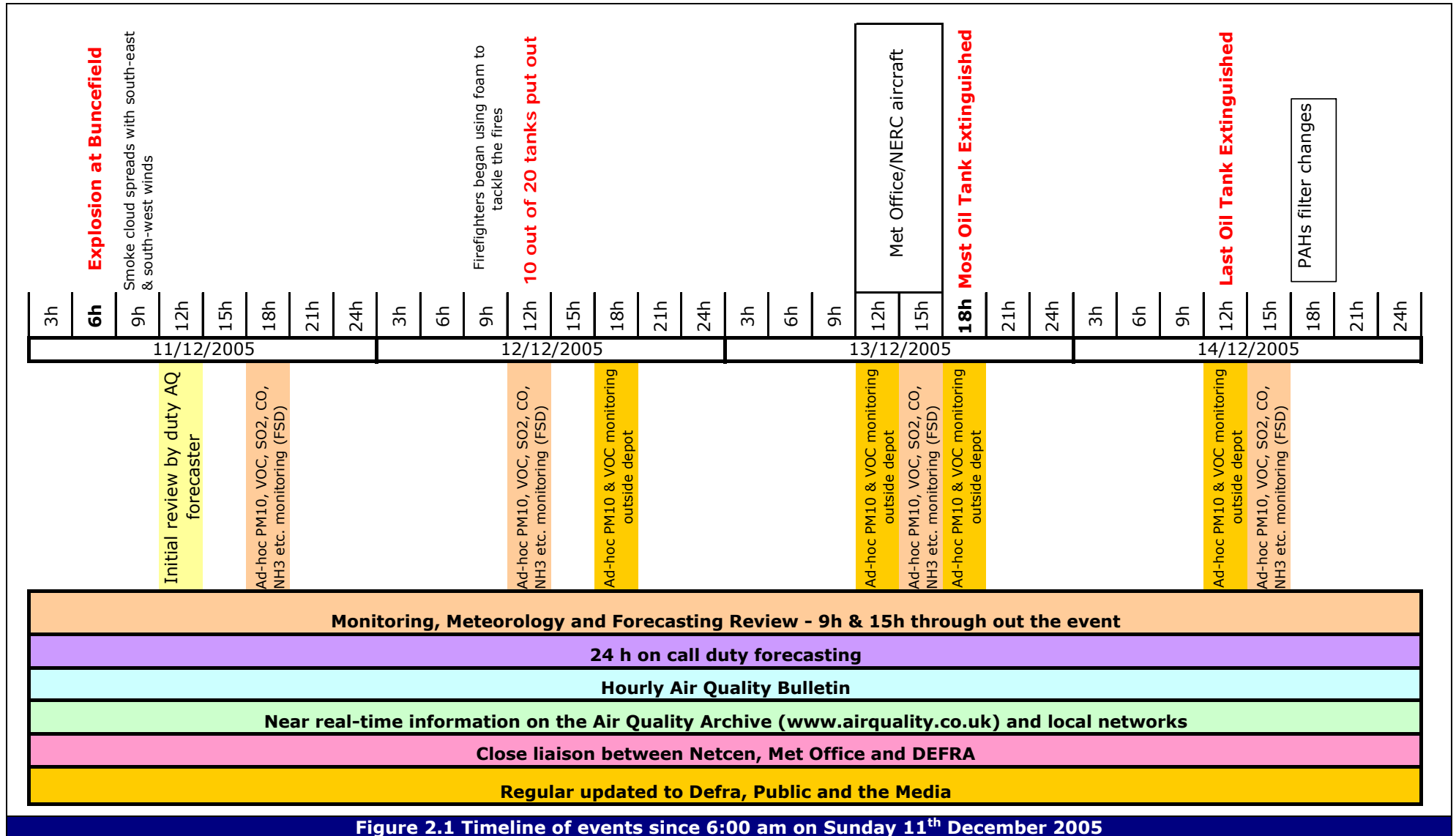
- Blue: at 10:00 am on 12th December
- Purple: at 12:10 pm on 12th December, and
- Green: between 12:00–1:00 pm on 13th December

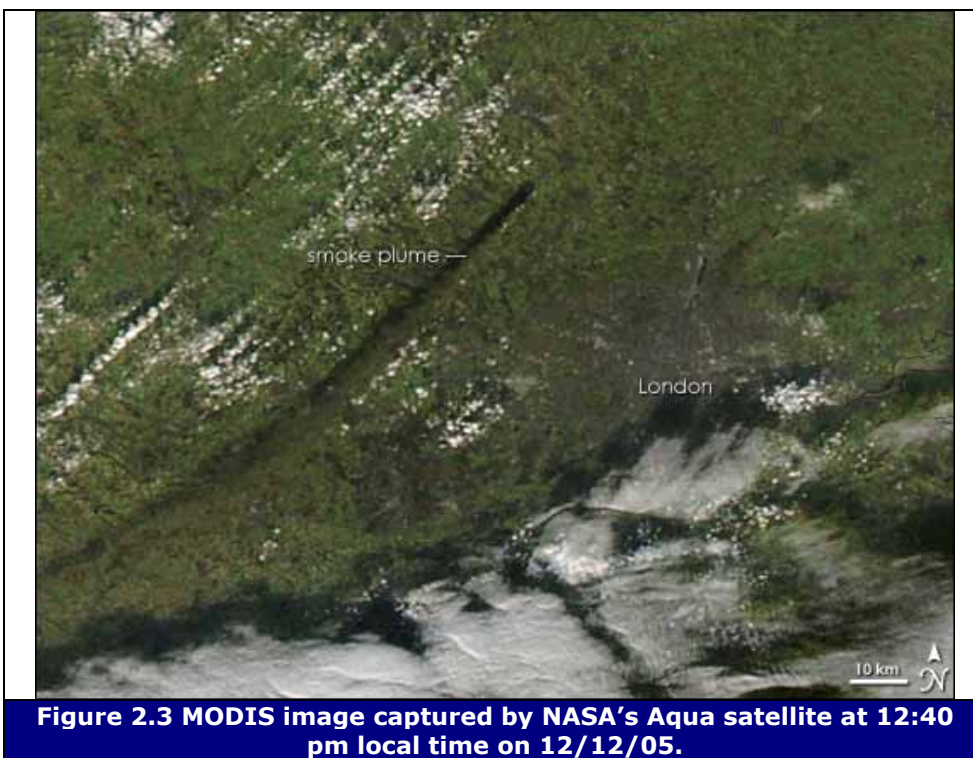
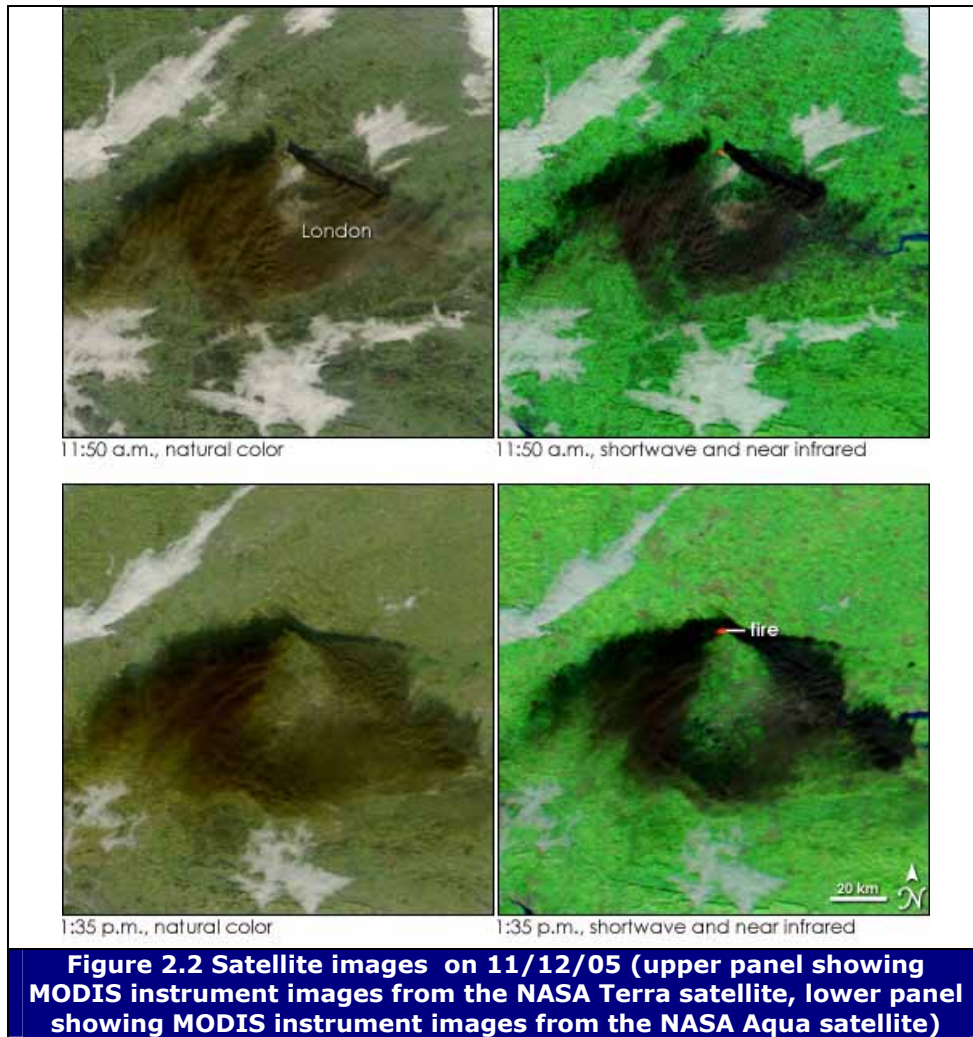
Full details of the plume positioning over the period is given in Section 6 and Appendix E, which detail Met Office NAME modelling of the event.

During the fires, national air quality monitoring and daily forecasting of air quality were carried out as usual, with a duty air quality forecaster at Netcen undertaking checks on monitoring data from the AURN and other air quality monitoring networks. The 24-hour forecasting updates at 3:00 pm (see Figure 2.5, Table 2.1 and Table 2.2) were complemented with a 9:00 am forecasting update. Close liaison with the Met Office's Environmental Monitoring and Response Centre (EMARC) was maintained during the event, in order to obtain up-to-date weather reports and the latest information on model predictions of the plume dispersion.

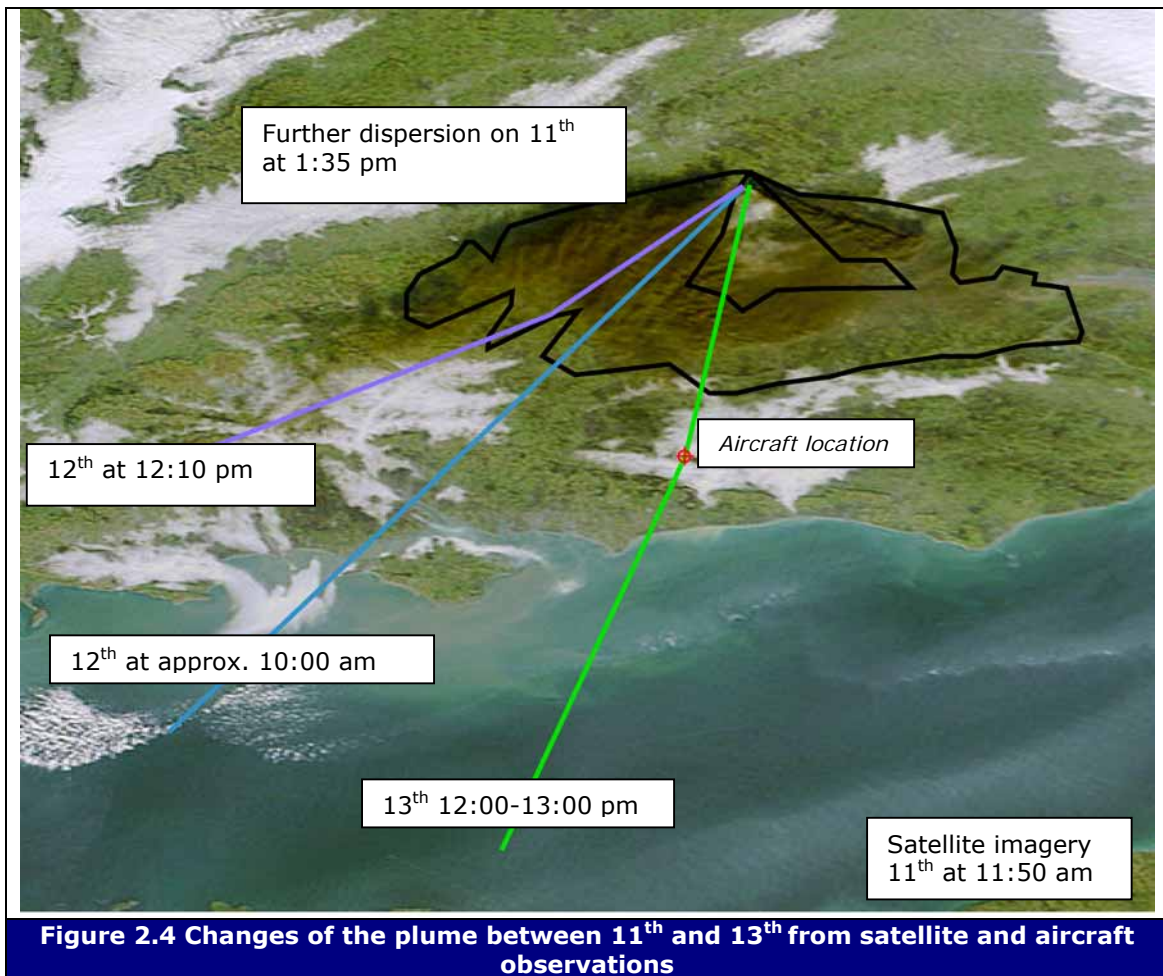
Air quality information in the form of hourly measurements from the AURN and forecasts were published as usual on the UK Air Quality Archive (www.airquality.co.uk) and on Teletext. Data from automatic monitors were published within an hour of measurements being taken¹. The Air Quality Archive usage statistics show a great increase in public interest during the event (see Figure 2.6) Defra was regularly updated with the latest information. The public and the media were also informed through the Air Quality Archive online news and email bulletins, together with personal communications by the Air Quality Forecasting team.

¹ An hour is the usual time lag between a measurement being taken and published on the Internet. This is the inevitable result of the large number of monitoring sites in the network from which data have to be acquired.





Images in Figures 2.2 and 2.3 courtesy of MODIS Rapid Response Project at NASA/GSFC



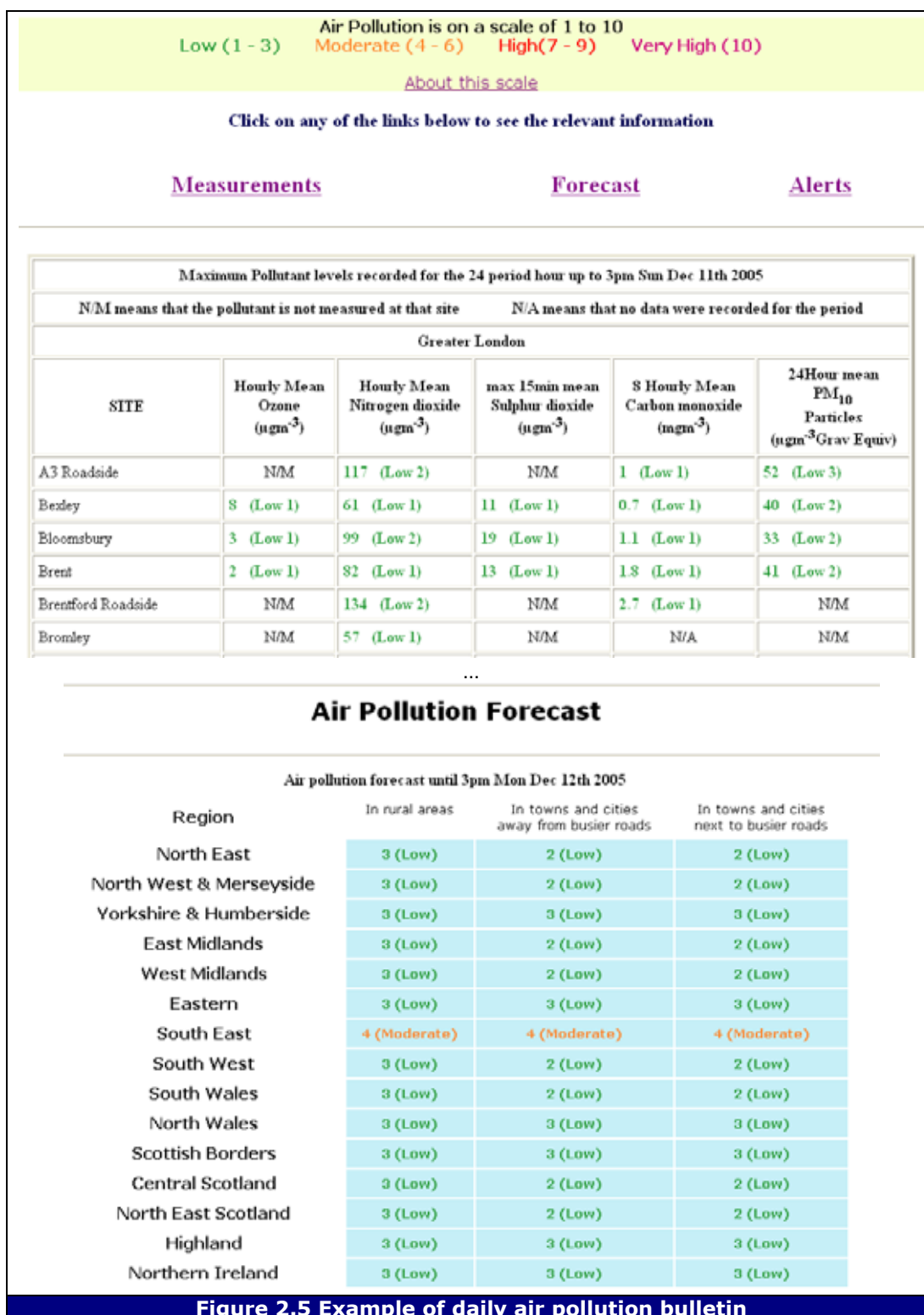


Figure 2.5 Example of daily air pollution bulletin

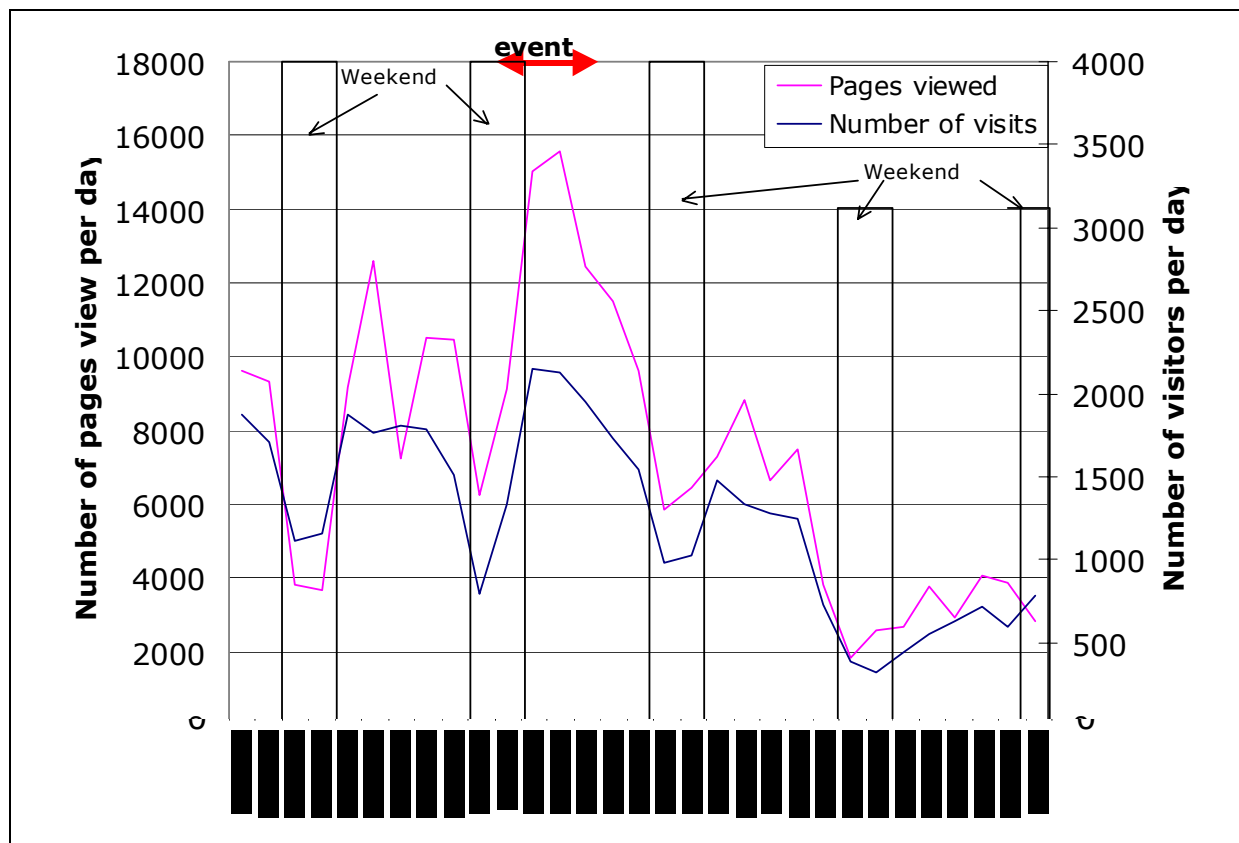


Figure 2.6 UK Air Quality Archive Access Statistics for December 2005

Table 2.1 Air quality forecasting email sent on Monday 12th December	
From: Jaume Targa, Netcen	12/12/2005 14:53:34
To: Air Quality Forecast Recipients	
Subject: Air Quality Forecasting - BUNCEFIELD OIL DEPOT FIRE	

Dear Colleagues,

The national air quality monitoring network has not recorded any high levels of air pollution in Southern England following yesterday's fire at the Buncefield oil depot.

A High Pressure System is currently building up over the UK and will remain, at least, for the next 48 hours. At the moment, the plume has been buoyant enough to punch through the boundary layer. Hence, the lack of monitoring stations measuring moderate/high levels of air pollution.

As you can see from the NOAA picture attached from 11.53 on 12th December 2005, the plume is heading towards Southampton and Weymouth with no risk in grounding. All the pollution from the plume is still trapped above the boundary layer. We're continuing to liaise with the Met Office now and trying to forecast when/if it will ground.

At present, the only chances of pollution grounding are likely to be caused by changes in the buoyancy of the plume. If this does happen, localised pollution events near the depot may be expected.

As a cautionary approach, we have forecast MODERATE levels across Greater London, Eastern and the South East zones.

Yours,

Jaume Targa
Netcen

Table 2.2 Air quality forecasting email on Tuesday 13th

From: Jaume Targa, Netcen To: Air Quality Forecast Recipients Subject: Air Quality Forecasting - BUNCEFIELD OIL DEPOT FIRE	13/12/2005 14:54:00
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Dear Colleagues,

The national air quality monitoring network has still not recorded any high levels of air pollution in the UK following Sunday's fire at the Buncefield oil depot (www.airquality.co.uk).

The High Pressure System over the UK will remain until the end of today. It will be moving towards the Atlantic and a Low Pressure System will be established over the UK by Friday. The weather will remain dry with bright spells for central and eastern areas. Some light showers might be experienced tomorrow, but first heavy rain is expected on Friday. Wind direction is currently north-westerly changing northerly tomorrow.

The plume has been moving towards the south changing to the southeast over the afternoon. This will remain until tomorrow when the winds change again.

Up to now, the plume has kept buoyant enough to penetrate the boundary layer. However, as the fire is put out, the plume might become less buoyant and localised pollution might be measured. The area of risk due to localised pollution is likely to be towards the southeast of the oil depot. Any important regional-transboundary pollution is unlikely, as the plume is dispersing well with high wind speeds above the boundary layer.

At present, the atmospheric conditions are neutral/ stable with some mixing from above the boundary layer. This is unlikely to cause any important pollution event.

Any pollution event is likely to be caused by changes in the buoyancy of the plume. If this does happen, localised impacts near the depot are expected (South-East of the depot).

As a cautionary approach, we have forecast MODERATE levels across Greater London, Eastern and the South East zones. HIGH levels of pollution might arise near the depot.

Yours,

Jaume Targa
Netcen

PS: The current high PM10 levels at Bradford Centre are unrelated to Sunday's event. This is due to localised emissions from construction near to the air quality monitoring site.

3 Estimates of possible emissions

Netcen has estimated the total air pollutant emissions to the atmosphere from the oil fire, both during and after the event. These calculations were useful in order to 1) enable improved modelling of the plume and 2) understand the potential air quality impact of pollutants emitted during the fires.

The total amount of fuel at Buncefield Oil Depot was estimated from information about the terminal capacity provided by the UK Petroleum Industry Association (UKPIA) and Total. Complete information on the actual quantities of fuel at the terminal during the event is not available at this time. These figures are therefore provisional and may need to be revised as more definitive information is made available.

Table 3.1 shows our current best information on the types of fuel, together with an estimate of the total tonnage of each type that was stored at the depot. The initial estimate of the total volume of fuel on site was 105 million litres (82359 tonnes).

Table 3.1 – Estimates of the total fuel (tonnes) at Buncefield oil depot				
Terminal*	Fuel¹	Volume, million litres	Litres per tonne²	Tonnes
HOSL	Petrol	35	1362	25698
HOSL	Petrol	1.7	1361	1267
HOSL	Burning	18	1248	14423
HOSL	Aviation turbine fuel	0	-	0
HOSL	DERV (diesel)	15.8	1203	13113
HOSL	Gas oil	6.5	1187	5476
BPA	Aviation turbine fuel	28	1251	22382
	Total estimate	105	-	82359

* Hertfordshire Oil Storage Terminal (HOSL) & British Pipeline Agency (BPA)

Pollutant emission factors from the UK National Atmospheric Emission Inventory (NAEI at www.naei.org.uk³), together with other published sources, were used to estimate the total emissions arising from the fire at Buncefield oil depot. The quantities of air pollutants emitted were estimated for four possible scenarios for the event:

- 1) 90% of fuel from BPA and 60% of fuel from HOSL lost⁴
- 2) LOW estimate (50% loss of fuel on site assumed)
- 3) MEDIUM estimate (75% loss of fuel on site assumed)
- 4) HIGH estimate (100% loss of fuel on site assumed)

These scenarios attempt to give a picture of the different possible outcomes of the fire, including a more realistic scenario (1) as well as a possible worst-case scenario (4). At the time of writing this report, clear information of the actual quantity of fuel consumed in the blaze is not yet available.

The pollutants selected have air quality standards/objectives (or proposed standards/objectives), are greenhouse gas/global warming pollutants, or were considered to be most relevant for public

¹ Fuel types are as used in the UK National Atmospheric Emission Inventory

² From the Digest of UK Energy Statistics (DUKES) available at: <http://www.dti.gov.uk/energy/inform/dukes/dukes2005/annexa.pdf>

³ <http://www.naei.org.uk/reports.php>

⁴ The HOSL inventory is for both the West & East sections of the terminal. The West terminal was most affected by the fire, while the tanks in the East section remained intact.

health concern. An important factor considered, also, was whether any relevant emission factor data (on pollutants emitted per mass unit of fuel combusted) was available.

The pollutant emissions estimated are as follows:

- Nitrogen dioxide (NO₂) – A UK air quality strategy pollutant
- Particulate matter of mean aerodynamic diameter 10 µm (PM₁₀) – Air quality strategy pollutant
- Particulate matter of mean aerodynamic diameter 2.5 µm (PM_{2.5}) – Proposed air quality strategy pollutant.
- Dioxins – persistent organic pollutant
- Benzo(a)pyrene (B[a]P) - Proposed air quality strategy pollutant and polycyclic aromatic hydrocarbon (PAH) indicator.
- Carbon monoxide (CO) – Air quality strategy pollutant
- Non-methane volatile organic compounds (NMVOC) – ground level ozone precursors
- Benzene – air quality strategy pollutant
- Carbon dioxide (CO₂)– greenhouse gas

Emission estimates were calculated for each scenario by multiplying the quantity of fuel burnt by a pollutant emission factor. In general, emission factors have been applied for 'open-burning' of oil fires. The factors used were obtained from a number of sources and are summarised in Table 3.2. Table 3.3 shows the amount of pollutants emitted and their percentages in relation to UK 2003 total emissions, as reported in the National Atmospheric Emissions Inventory (NAEI).

Table 3.2 Summary of pollutant emission factors		
Pollutant	Emission factor, mg/kg	Source and comment
Nitrogen oxides	651	Derived from Lemieux et al CO emission factor and ratio of NO _x to CO reported by Evans et al
PM ₁₀	170000	Lemieux et al and US Dept of Defence range of PM ₁₀ in total PM
PM _{2.5}	102000	From 60% PM _{3.5} figure of Ross et al.
Benzo(a)pyrene	5	Lemieux et al
Carbon monoxide	30000	Lemieux et al for crude oil
Non-methane volatile organic compounds	1770	Lemieux et al – sum of VOC and carbonyl compounds
Benzene	1022	Lemieux et al
	ng WHO-TEQ/kg ⁵	
Dioxins and furans	2.31 x10 ⁻⁵	World Health Organisation toxic equivalent factors for mammals applied to Lemieux data for speciated dioxin and furan congener groups
References		
Lemieux, P.M. et al. Emissions of organic air toxics from open burning: a comprehensive review. <i>Progress in Energy & Combustion Science</i> , 30 (2004) 1-32		
Evans, D et al. Environmental effects of oil spill combustion. US Dept of Commerce, NIST, National Engineering Laboratory Centre for Fire Research, NISTIR 88-3822, Sept 1987		
Ross et al, Particle and Gas Emissions from an In Situ Burn of Crude Oil on the Ocean <i>J. Air & Waste Manage. Assoc.</i> , 46, 251-259, 1996		
Oil fire health review by US Dept of Defence Deployment Health Clinical Centre		

Carbon dioxide and carbon emission factors are from the NAEI 2004 database. Particulate emissions from uncontrolled oil fires are largely unburnt fuel. CO₂ emissions in Table 3.3 have been modified to account for unburnt fuel in particulate (carbon content of PM estimated to be 95% based on typical fuel analysis and range of 92-100% 'elemental carbon' in oil fire smoke analysis).

⁵ WHO-TEQ – there are many dioxin and furan congeners a number of which are considered hazardous to a greater or lesser extent. Use of toxic equivalence factors allows an assessment of the most significant congeners on a consistent basis. The toxic equivalence factors are published by the World Health Organisation.

The emission estimates indicate that PM₁₀, PM_{2.5} and B[a]P emissions represented the greatest relative proportion of corresponding national emissions. Estimated PM₁₀ and PM_{2.5} emissions were between 4 to 8.5% of total UK annual emissions, while B[a]P emissions were between 5 and 10%. The emissions for other pollutants like NO₂ and dioxins would be around 40 tonnes and 1.5 WHO-TEQ g, (0.003% and 0.6% of total UK annual emissions, respectively).

Pollutants	Scenario				Units	UK Total (2003)		Scenario (%)			
	1	2	3	4				1	2	3	4
NO_x	37.2	27.3	40.9	54.6	Tonnes	1570	kTonne	0.0024	0.0017	0.0026	0.0035
PM₁₀	8249.5	6054.8	9082.2	12109.6	Tonnes	141	kTonne	5.8507	4.2942	6.4413	8.5884
PM_{2.5}	4949.7	3632.9	5449.3	7265.7	Tonnes	86.9	kTonne	5.6958	4.1805	6.2708	8.3610
Dioxins	1.32	0.97	1.45	1.93	g-TEQ g	259	g-TEQ g	0.5087	0.3734	0.5601	0.7468
B[a]P	285.4	209.5	314.3	419.0	kg	4034	kg	7.0761	5.1936	7.7903	10.3871
CO	1712.7	1257.0	1885.6	2514.1	Tonnes	2768	kTonne	0.0619	0.0454	0.0681	0.0908
NMVOC	101.0	74.2	111.2	148.3	Tonnes	1089	kTonne	0.0093	0.0068	0.0102	0.0136
Benzene	58.3	42.8	64.2	85.6	Tonnes	13.6	kTonne	0.4290	0.3149	0.4723	0.6298
CO₂	0.144	0.105	0.158	0.211	Mtonne						
C	39.2	28.7	43.1	57.5	kTonne	152324	kTonne	0.026	0.019	0.028	0.038

There are a number of uncertainties associated with the emission estimates. These include:

- Uncertainty of emission factors and relevance of emission factors to the fuels and circumstances of the Buncefield fire. We note that there remains some uncertainty in the volume of fuel stored on site and therefore likely to have burnt. For example, the Buncefield Investigation progress report states that over 35 million litres of fuel was on site on 11/12/05 (Buncefield investigation team, 2006)¹.
- The emission factors used are from a variety of sources for uncontrolled burning, some of which may not be applicable to combustion of refined fuel products in pools.
- The range of emission factors for some pollutants is also comparatively large. For example, emission factors for particulate emissions from oil fires of between 4 and about 17% of the fuel mass were found in the literature.

Nevertheless, the figures summarised in Table 3.3 remain – at the time of preparing this report – our best estimates of the total quantities of air pollutants emitted during the Buncefield incident.

¹ Please see <http://www.buncefieldinvestigation.gov.uk/index.htm>



Figure 3.1 Inside the depot during the fires © the Hertfordshire Constabulary



Figure 3.2 Devastated tanks after the fires © the Hertfordshire Constabulary

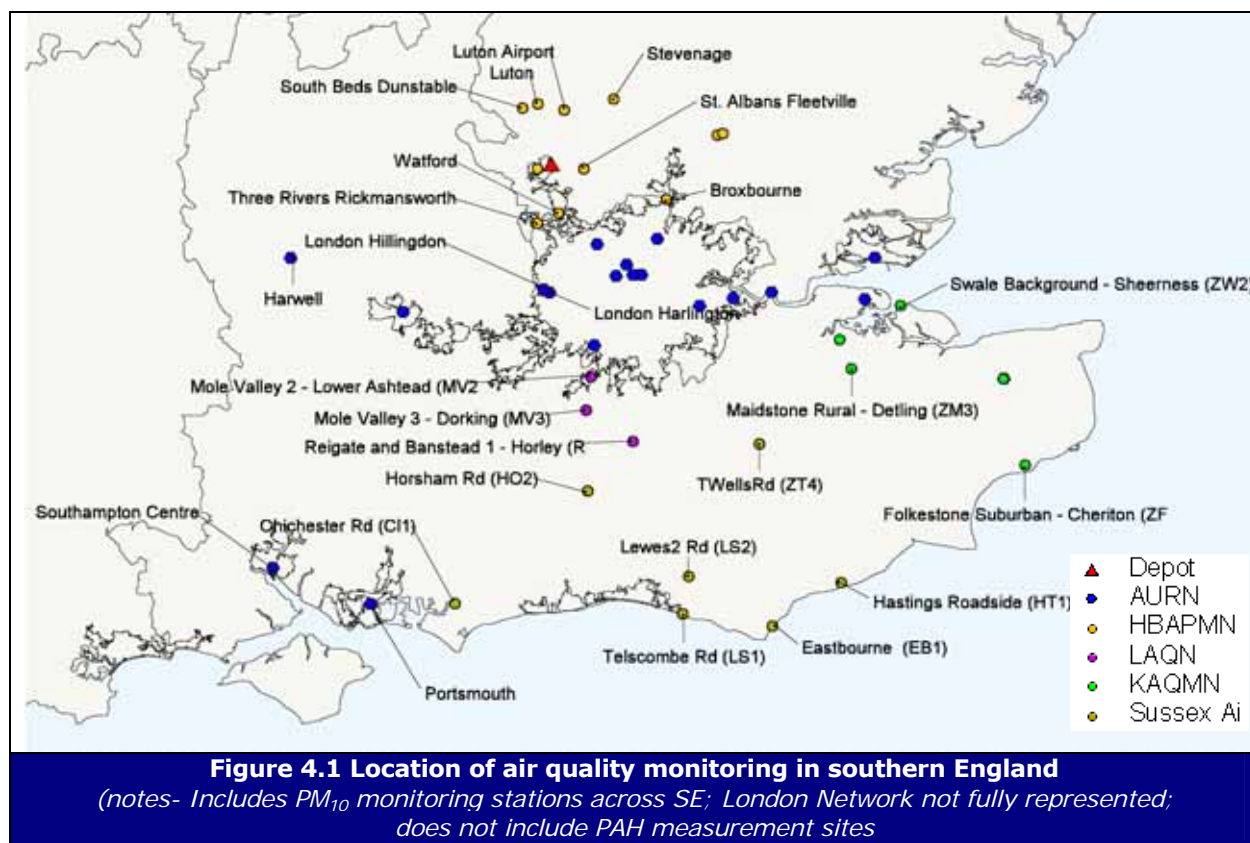
4 Air Quality Monitoring

Hourly automatic air quality monitoring in the UK's national Automatic Urban and Rural Network (AURN) continued as usual and without interruption during the period of the incident. Pollutants measured include: particulate matter (both PM₁₀ & PM_{2.5}), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), carbon monoxide (CO) and ozone (O₃). Results were disseminated in near real-time through the UK Air Quality Archive at www.airquality.co.uk.

Regional air quality monitoring networks near Hemel Hempstead and in south-east England also continued to monitor during the incident; King's College Environmental Research Group (ERG) increased the frequency of updates on these networks to hourly during the course of the incident (www.londonair.org.uk). See Appendix H.

Targeted local monitoring was also carried out within the oil depot and the surrounding area by i) Netcen on behalf of Defra, and ii) the Fire Brigade's Scientific Advisors (Bureau Veritas) and the Health and Safety Laboratories (HSL) on behalf of Health Protection Agency- see Appendix H. Moreover, the Met office/NERC FAAM aircraft made extensive measurements from within the plume on 13th December 2005.

Figure 4.1 shows the locations of fixed automatic network monitoring stations in southeast England that were operational during the incident.



4.1 MONITORING NETWORKS

Across southeast England, the AURN, as well as other local networks, operate continuously to provide near real-time air quality data and information to the public and authorities. Monitoring of air pollutants across England, Greater London and - in particular - near Hemel Hempstead continued uninterrupted during the fires. The different networks across England provided up-to-

date hourly measurements to the public through their respective websites, as noted above. AURN measurements were also made available to the media, as well as through TV Teletext services and a freephone telephone service at 0800 55 66 77.

Please note that all analyses reported here are based on provisional monitoring results (i.e. data have still to be verified through the comprehensive Quality Assurance and Quality Control -QA/QC- and ratification processes applied in UK national networks). Nevertheless, these measurements provide our most reliable indicator of potential public exposure to the plume from the fires.

4.1.1 Automatic Urban and Rural Network (AURN)

4.1.1.1 Air Quality Index

The UK Air Quality Index (AQI) is used to report hourly air quality concentrations. This index provides a simple measure of how clean or polluted the air is, together with an indication of possible health impacts. Appendix C illustrates how the AQI is calculated, as well as showing the possible health effects associated with each band: Low, Moderate, High and Very High.

AURN measurements did not show any instance during the Buncefield incident with PM₁₀ levels of Moderate or above that were attributable to the fire. Table 4.1 summarises the stations across England that measured an AQI of moderate or above between 9th and 16th December 2005. Of the sites featuring in this table, Bradford Centre site was affected throughout this period by localised construction work; Camden Kerbside and London Marylebone are located close to major roads (less than 1 metre from the kerb) and are therefore substantially affected by local transport sources. Haringey Roadside measured Moderate levels due to PM₁₀, but this was before the event.

None of the AQI moderate, high or very high events featuring in Table 4.1 therefore appear related to the Buncefield incident. All other AURN stations recorded low levels of pollution throughout.

Table 4.1 Stations measuring AQI Moderate or above between 9th and 16th December 2005			
Station	Date	Max hourly mean ($\mu\text{g m}^{-3}$)	Air Quality Index
<i>Bradford Centre</i>	09/12/05	66	Moderate
<i>Bradford Centre</i>	10/12/05	63	Moderate
<i>Bradford Centre</i>	12/12/05	57	Moderate
<i>Bradford Centre</i>	13/12/05	97	High
<i>Bradford Centre</i>	14/12/05	97	High
<i>Bradford Centre</i>	15/12/05	130	Very High
<i>Bradford Centre</i>	16/12/05	129	Very High
<i>Camden Kerbside</i>	12/12/05	54	Moderate
<i>Camden Kerbside</i>	13/12/05	60	Moderate
<i>Camden Kerbside</i>	14/12/05	59	Moderate
<i>Camden Kerbside</i>	15/12/05	50	Moderate
<i>Haringey Roadside</i>	10/12/05	52	Moderate
<i>London Marylebone Road</i>	09/12/05	55	Moderate
<i>London Marylebone Road</i>	10/12/05	67	Moderate
<i>London Marylebone Road</i>	11/12/05	62	Moderate
<i>London Marylebone Road</i>	12/12/05	51	Moderate

Figure 4.2 shows the 24-hour running mean PM₁₀ measurements for all stations in England⁶ between 9th and 16th December 2005. Apart from the roadside stations shown in Table 4.1, all other stations recorded low levels of air pollution. This figure presents monitored concentrations across different sites and against the 24-hr running mean air quality statistic on which UK Air Quality Indices are based (dotted red line).

⁶ Figure 4.2 excludes data from the Bradford Centre station as it would obscure the rest of the data.

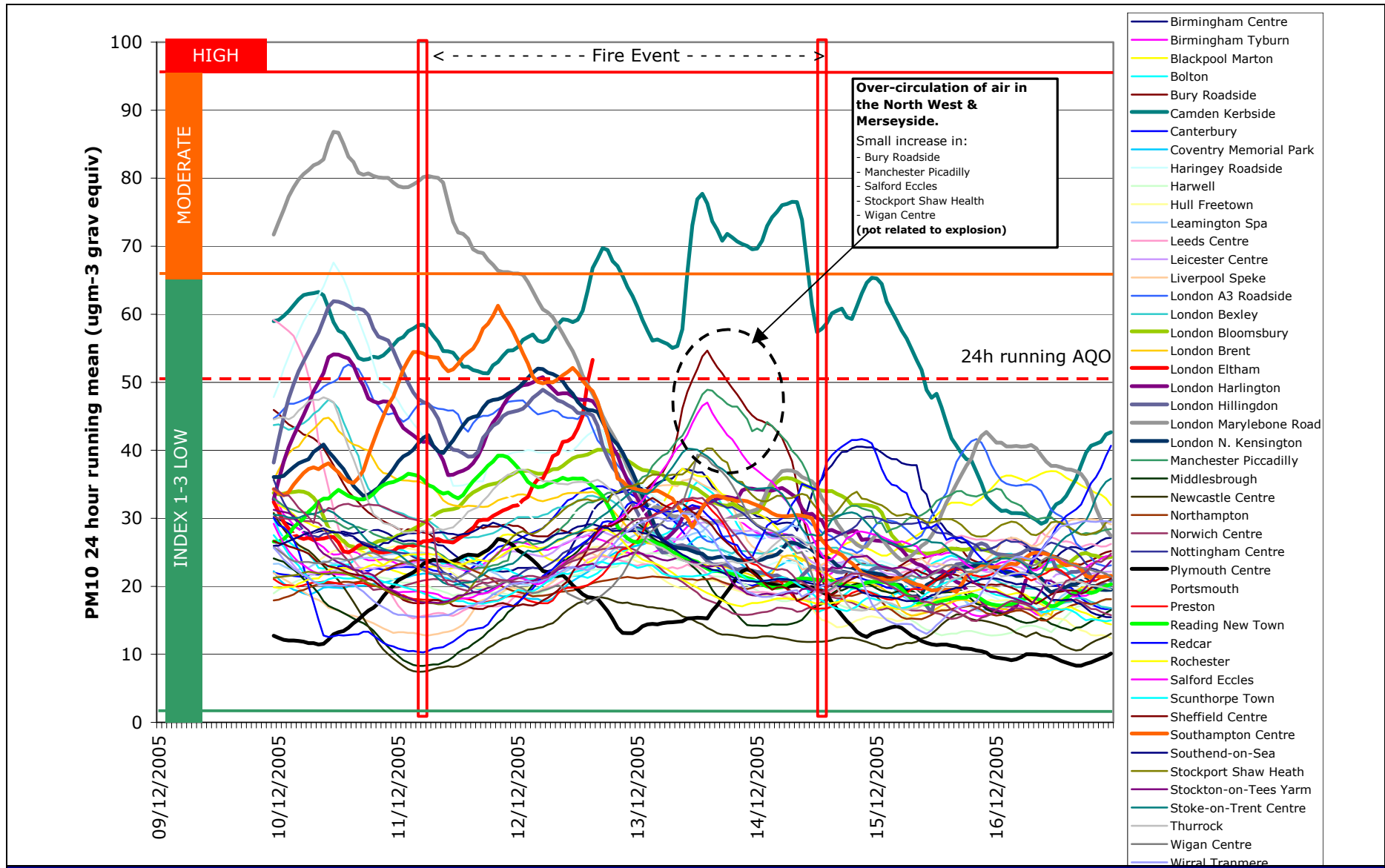


Figure 4.2 Provisional PM₁₀ 24 hour running mean and air quality index for stations across the UK (data excludes Bradford Centre)

4.1.1.2 Air Quality Data

Particulate Matter (PM₁₀) concentrations measured in the AURN have been used as an indicator to assess ground-level air quality impacts of the Buncefield fire. Levels of nitrogen dioxide (NO₂), sulphur dioxide (SO₂), carbon monoxide (CO) and ozone (O₃) were not apparently affected by the fire and remained low during the event.

Particulate Matter PM₁₀ data are monitored in the AURN using the TEOM (Tapered Element Oscillating Microbalance) instrument that provides 15-minute mean measurements¹. As shown in Figure 4.1, there were a number of fixed monitoring stations measuring PM₁₀ near the depot, as well as downwind of the fire.

With the exceptions described in the previous section, PM₁₀ levels across the UK were classed as Low between 9th and 16th December 2005. Fifteen-minute mean and hourly concentrations will clearly provide a better way of identifying short-lived incidents of plume grounding than 24-hourly means. However, 24-hourly running means offer a better indication of potential public health impacts.

Figure 4.3 shows the 15-minute mean PM₁₀ concentrations at a number of locations across England. Levels at the Bradford Centre site clearly stand out. However, these were directly linked to stone cutting arising from local construction work and are clearly not attributable to the Buncefield fire; in fact, these transient peaks had been occurring for several months before, during and after the Buncefield event. Other elevated concentrations were measured at Camden Kerbside and Marylebone Road; these were both due to traffic related emissions. Figure 4.4 shows the same data without Bradford Centre and using an expanded scale to show greater detail.

Please note that annual PM₁₀ time series graphs for these and a number of AURN monitoring stations are provided in Section 4.2. These figures provide useful information on Buncefield period measurements when examined within a broader annual context.

With the exception of the monitoring stations discussed above, the majority of the 15-minute PM₁₀ concentrations recorded in the AURN during the event were well below 100 µg m⁻³. The highest 15-minute PM₁₀ value measured was 133 µg m⁻³ at Southampton Centre on 11th December at 8:15 pm. Hourly PM₁₀ concentrations illustrated in Figure 4.5 show that none of the sites recorded levels exceeding 150 µg m⁻³, whilst the majority of the hourly averages remained well below 100 µg m⁻³.

Hourly PM₁₀/NO₂ concentration ratios for some AURN monitoring sites have been calculated and graphed. These ratios are used to identify whether a peak is due to an unusual event or just an increase in pollution from a local source. For a roadside site, it would be expected that any increase in PM₁₀ concentrations would be proportional to any corresponding increase in NO₂ concentrations; this is because both pollutants have a common source- traffic. If the PM₁₀/NO₂ ratio increases substantially, however, it may be concluded that the PM₁₀ source is different from the NO₂ source.

PM₁₀/NO₂ ratios have therefore been used to try to identify the likely origin of the PM₁₀ peaks measured during the incident. Appendix B examines ratios for several AURN stations, including Southampton Centre and Marylebone Road. None of the ratios appear to have changed during the time period; this suggests that these relatively small peaks were not linked to the Buncefield event.

Additional NAME modelling analyses have been carried out by the Met Office to determine the origin of the air contributing to Southampton Centre's 15-minute PM₁₀ peak. These analyses, included in full in Appendix E, show that the 15-minute peak in PM₁₀ concentrations measured at this location was not due to the fire at Buncefield.

In conclusion, there was no evidence of plume grounding from AURN air quality measurements. Pollutant levels were all within normal ranges. Moreover, air origin maps from NAME modelling did not support the view that small localised peaks in AURN PM₁₀ levels had originated from the Buncefield oil depot.

In Section 4.1.2, we examine corresponding data from non-AURN monitoring stations operational in Southern England at the time.

¹ The TEOM instrument is widely used in UK and worldwide. It is based on the real-time measurement of oscillations in a tapered element microbalance; as the element becomes progressively loaded with deposited particles, its resonant frequency changes. Measuring this provides a reliable indication of ambient particle concentrations.

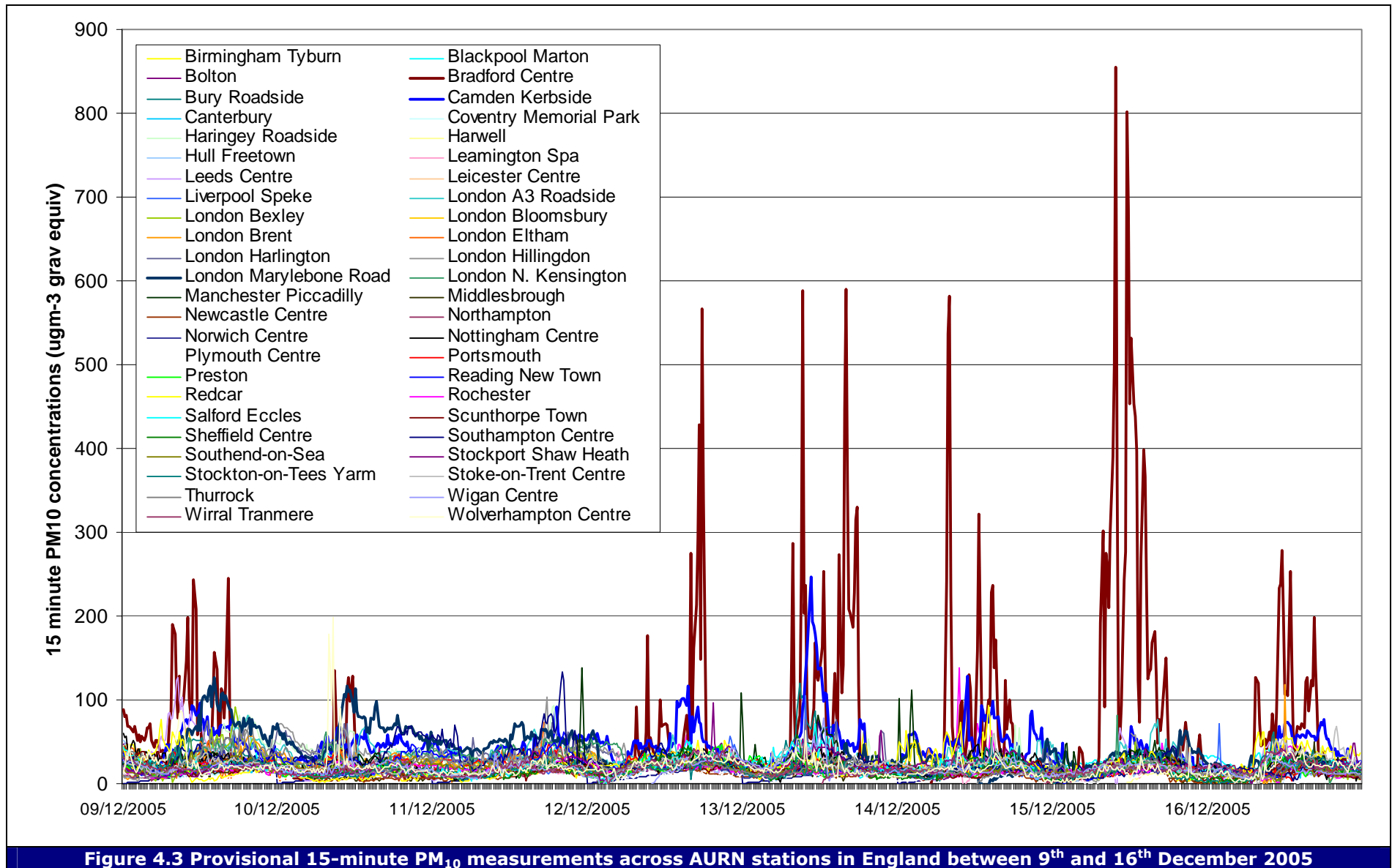


Figure 4.3 Provisional 15-minute PM₁₀ measurements across AURN stations in England between 9th and 16th December 2005

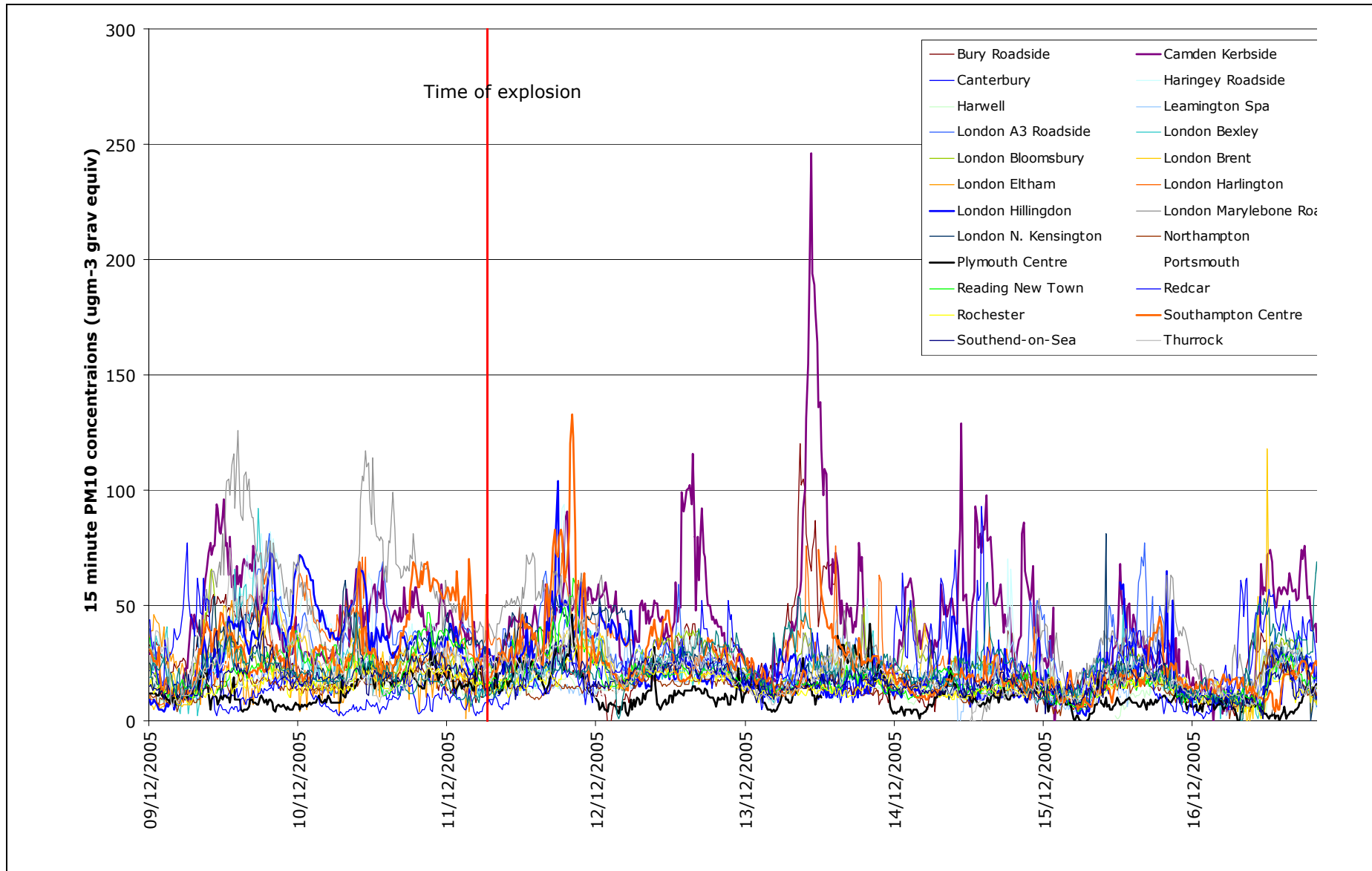
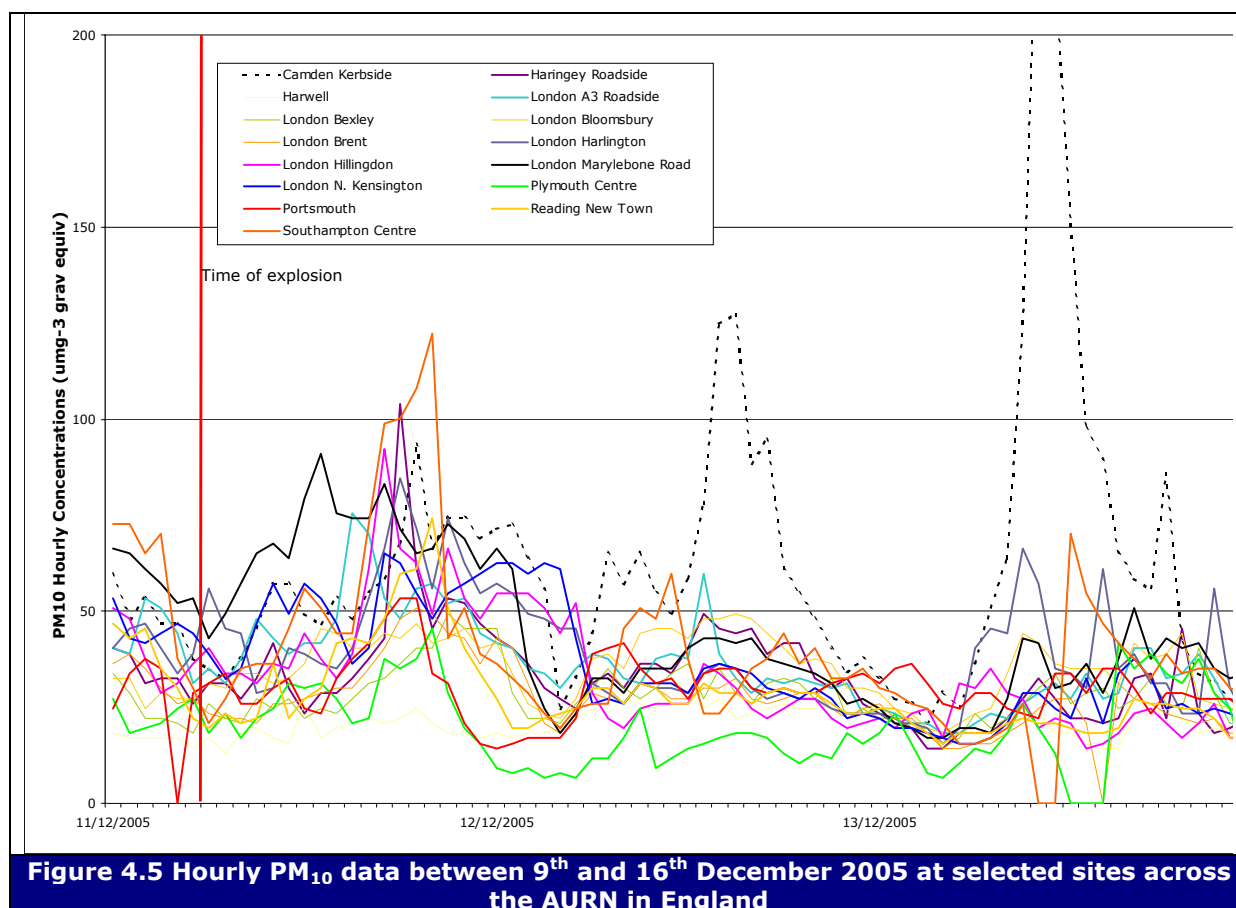


Figure 4.4 15-minute mean PM₁₀ measurements between 9th and 16th December 2005 at selected sites across the AURN in England



4.1.2 Local Networks

In addition to data from the AURN, measurements from local air monitoring networks have been analysed in this report. These include:

- Herts & Beds Air Pollution Monitoring Network (HBAPMN) www.hertsbedsair.org.uk
- London Air Quality Network (LAQN) www.londonair.org.uk
- Kent Air Quality Monitoring Network (KAQMN) www.kentair.org.uk
- Sussex Air www.sussex-air.net

4.1.2.1 HBAPMN

As can be seen in Figure 4.1, the HBAPM Network surrounds Buncefield oil depot. Figure 4.6 shows the 15-minute mean PM₁₀ concentrations at six background stations in this local network. The highest two values measured were 133 µg⁻³ at 8:30 pm on 11th December at St Albans Fleetville and 98 µg⁻³ at 5:30 am on 12th December at Three Rivers Rickmansworth station. These levels are not particularly high and are, in fact, similar to those measured before the event (Section 4.2). They are also typical of measurements at AURN stations during the period. Please note there is a decrease in background levels after the 12th, due to changes in weather conditions and air mass origins (Section 5).

4.1.2.2 LAQN, KAQMN and Sussex Air

PM₁₀ levels were also measured at monitoring stations in the LAQN, KAQMN and Sussex Air networks. Figure 4.7 shows the 15-minute mean PM₁₀ concentration measurements at all stations measuring PM₁₀ across these networks (excluding most of London’s sites). The highest peaks were measured on 11th December. Horsham Roadside measured a 15-minute mean PM₁₀ concentration of 290 µg⁻³ at 10:45 pm, Lewes 2 Roadside recorded a peak 15-minute mean PM₁₀ concentration of 217 µg⁻³ at 7:15 pm; the corresponding maximum 15-minute mean PM₁₀ concentration at Mole Valley Urban Background site was 156 µg⁻³ at 4:15 pm.

It should be emphasised that these levels are the **highest** measured across these networks during the incident. Nevertheless, as shown in Figure 4.8, they were not particularly high in absolute terms, resulting in an Air Quality Index of Moderate for a very short time only. In fact, pollution levels were within normal ranges for the time of year and prevailing meteorology (see Section 4.2).

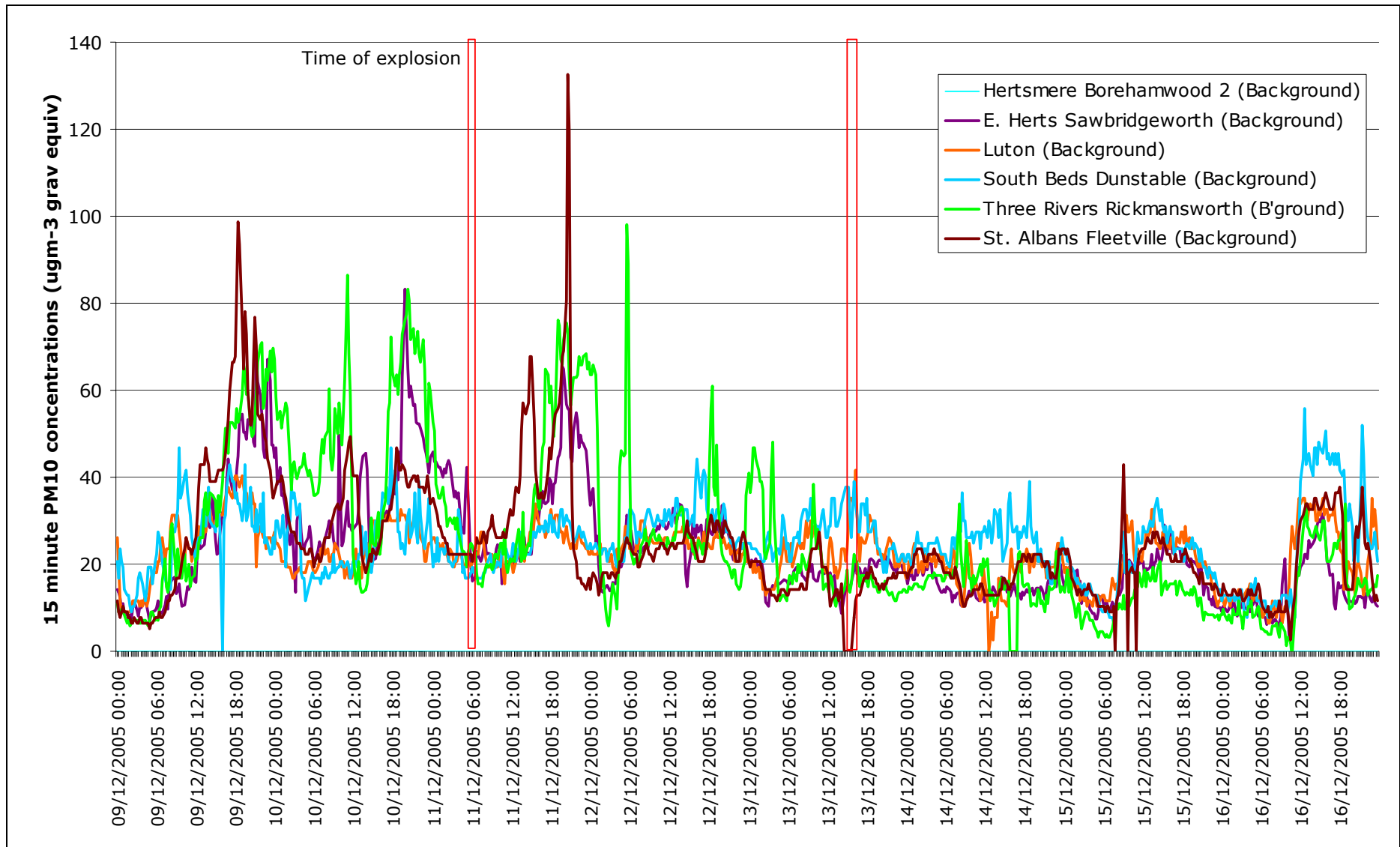


Figure 4.6 Fifteen minute PM₁₀ concentrations across background stations in the HBAPMN (provisional data)

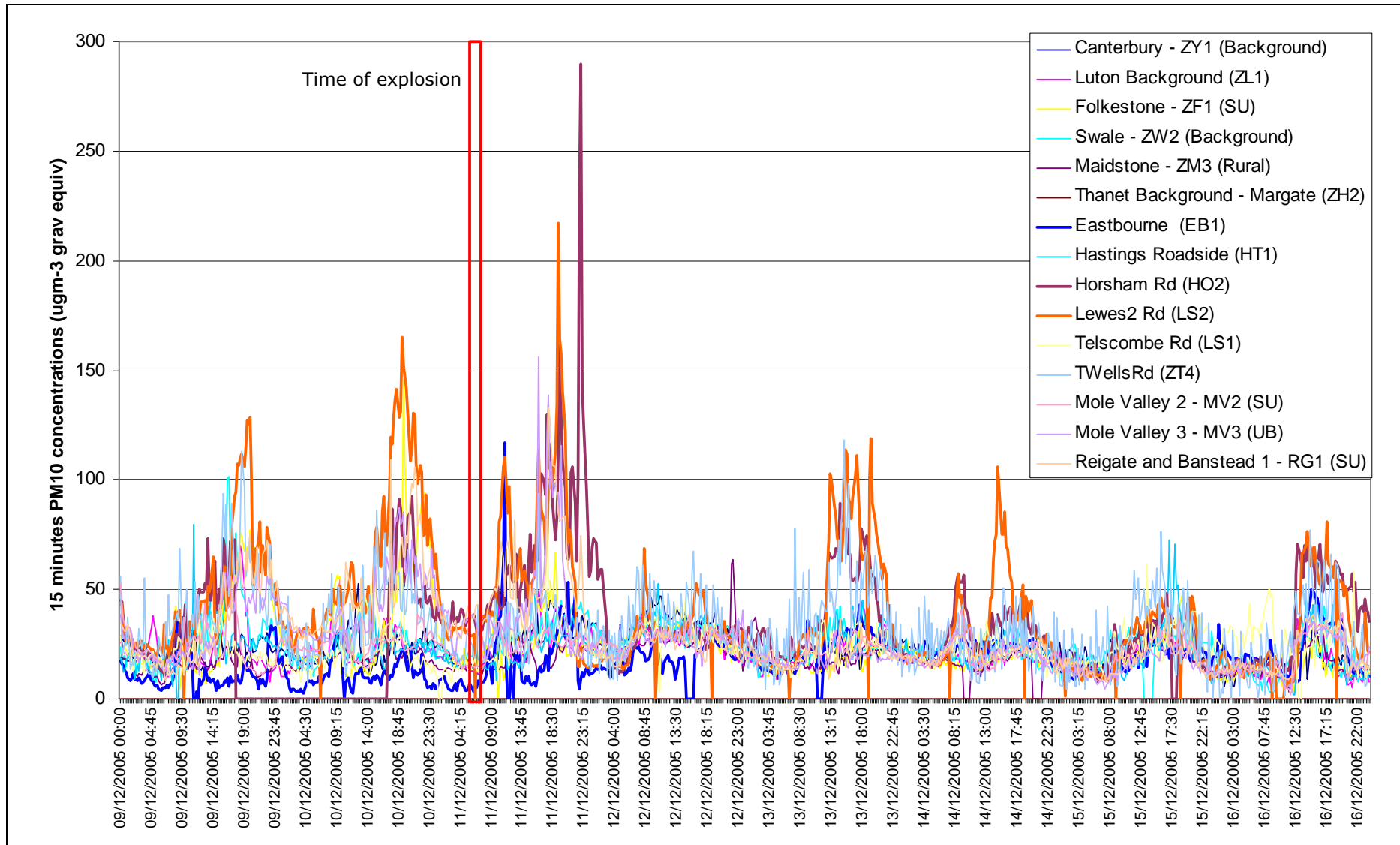


Figure 4.7 Fifteen minute mean PM₁₀ concentrations across selected sites in the Kent Air Quality Monitoring Network & Sussex Air Network (provisional data)

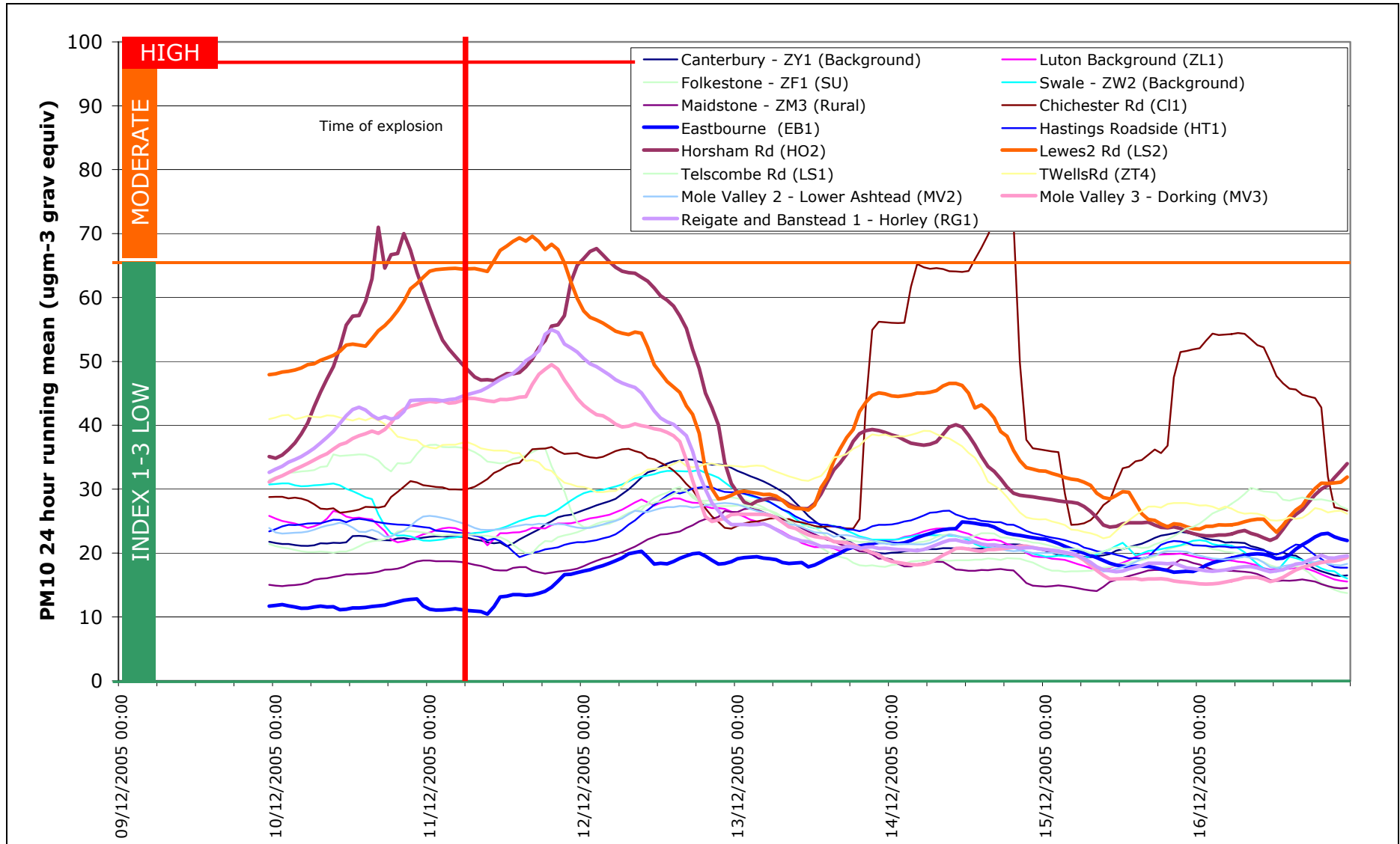


Figure 4.8 PM₁₀ 24-hour running mean and air quality index for selected stations LAQN, KAQMN and Sussex Air

Examining the measured PM₁₀/NO₂ ratios at the Horsham Roadside site (see Figure 4.9), it appears that the peak in PM₁₀ concentrations on the 11th is not directly related to the traffic emissions and may therefore be of a different origin. Assuming that the data are not faulty, it would appear that the elevated peak is related to another source. This could, of course, include grounding of the plume from the Buncefield fires. This may also be the case for Lewes Roadside (Figure 4.10), but the evidence here is less clear.

NAME back map analyses carried out by the Met Office to determine the origin of the air contributing to Horsham's 15-minute PM₁₀ peak are included in Appendix E. These demonstrate that the Buncefield oil depot plume could have contributed to the peak in PM₁₀ concentrations at Horsham Roadside.

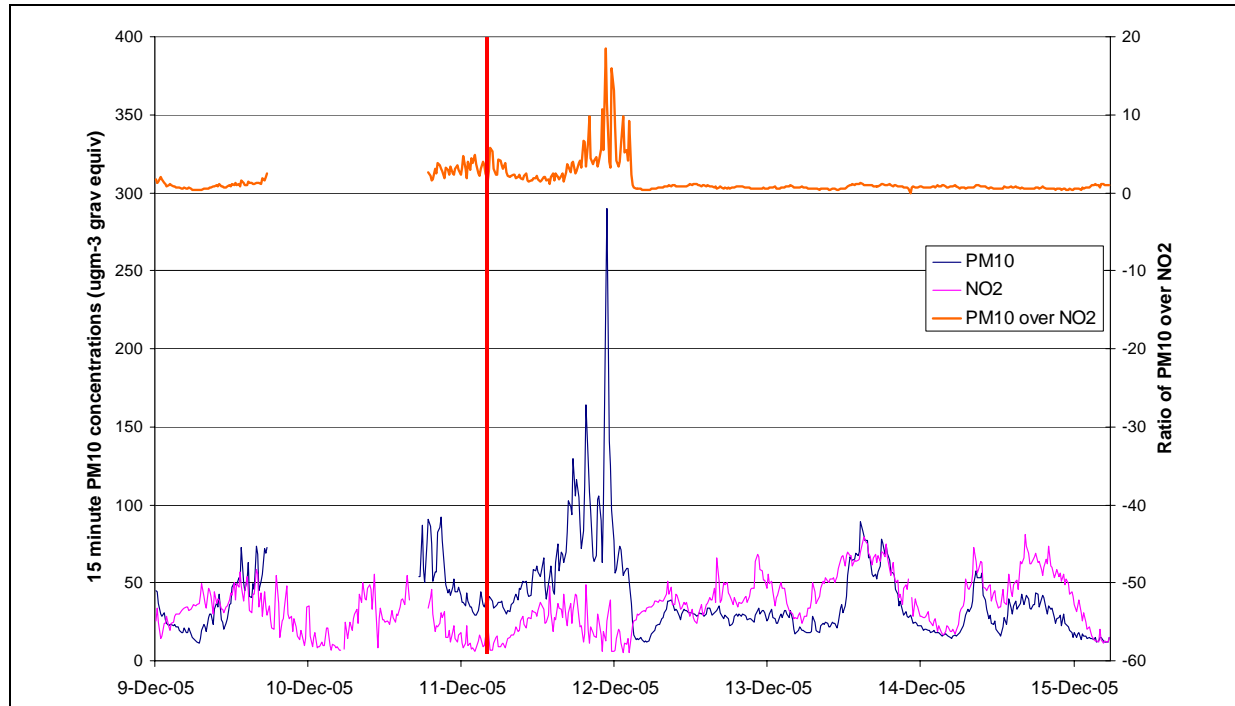


Figure 4.9 Horsham Roadside PM₁₀ and NO₂ relationship between 9th and 15th Dec 2005

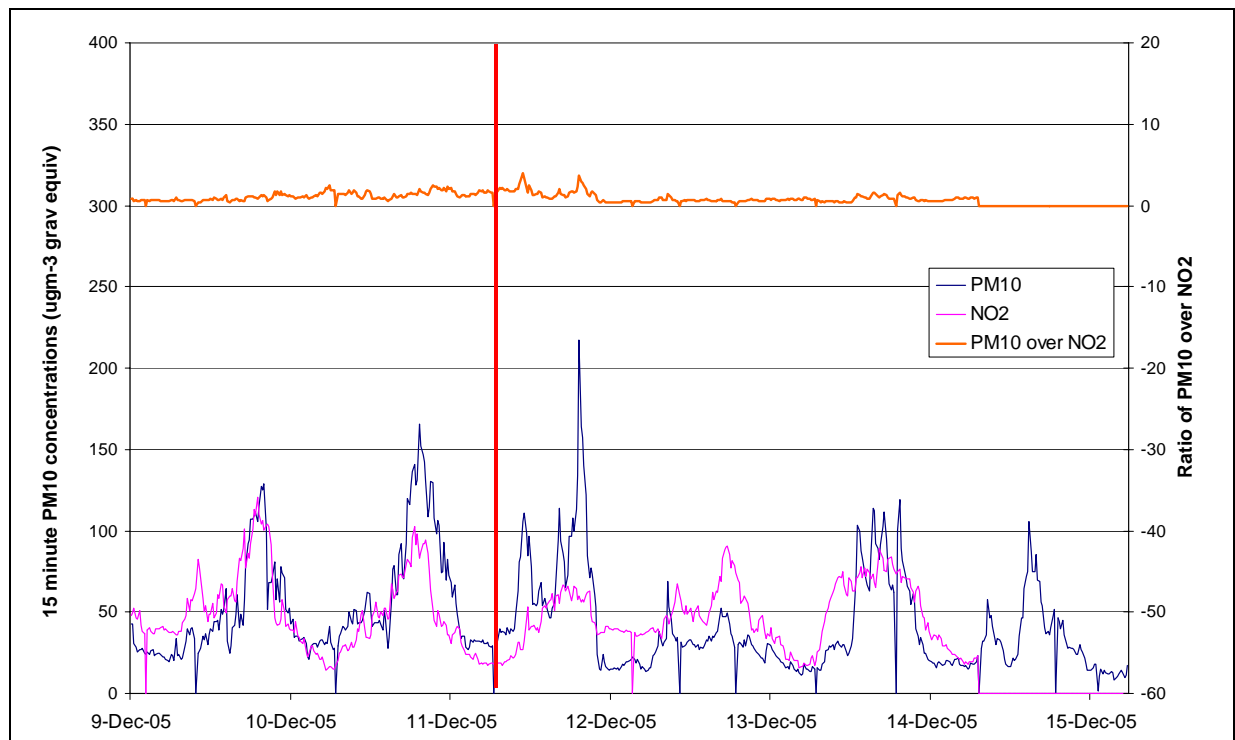
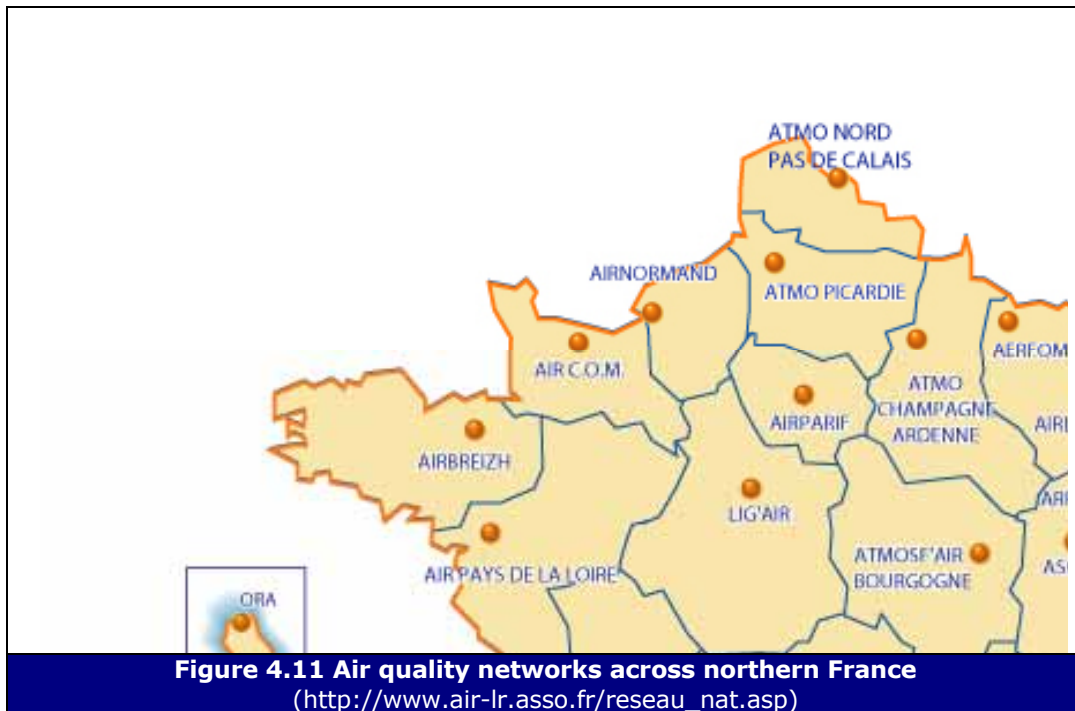


Figure 4.10 Lewes 2 Roadside PM₁₀ and NO₂ relationship between 9th and 15th Dec 2005

4.1.3 Monitoring Networks in France

There are several local monitoring networks across northern France continuously measuring air pollution. Provisional data from these networks have been used to assess if the Buncefield fire had any trans-boundary impact. In particular, data from the following four networks have been reviewed (Figure 4.11):

- Air Pays de la Loire
- Air Normand
- Air C.O.M.
- Airbreizh



Hourly mean PM₁₀ concentrations between 9th and 16th December 2005 for stations from the four networks across north-west France are summarised in Appendix E. The highest hourly values were measured at Caen and Cherbourg before the event. After 11th December, the highest values were measured at Le Havre, Caen and Cherbourg. However, these levels are below 100 µg m⁻³ and the UK AQI remained Low across the networks.

NAME modelling analyses were carried out by the Met Office to determine the origin of the air contributing to the peaks on 11th December at Le Havre and Cherbourg; these are included in Appendix E. These analyses show that the Buncefield plume did not contribute to the measured PM₁₀ peaks at these locations.

During the Buncefield event, there was no evidence from the monitoring networks of pollution in northern France that had been transported from the Buncefield fires.

4.1.4 PAH network

Apart from the AURN and other local networks measuring the most common pollutants such as PM₁₀, there are other continuously operating networks in the UK, including the PAH (Polycyclic aromatic hydrocarbons) and Hydrocarbon Networks. Results from these are presented below.

The polycyclic aromatic hydrocarbon (PAH) monitoring network provides measurements of PAH concentrations at 24 sites across the UK. PAHs are a group of chemicals consisting solely of carbon and hydrogen that are emitted during combustion processes, particularly when these are incomplete. Routine samples are taken over 14-day periods and are combined to provide quarterly average concentrations for 34 individual PAHs. The air quality objective for PAHs is expressed in terms of an annual average of a representative compound- benzo[a]pyrene. Three of the network

sites are in the southeast of England; at Brent (Kingsbury High School), London (Victoria Street) and Bromley (Crystal Palace Parade).

Data from the PAH Network were made available shortly after the fire. Initial analyses of these data are presented in a letter report from Peter Coleman (Netcen) to Martin Meadows (Defra), included in Appendix F. This report found that, during the week in which the Buncefield oil depot was burning, the concentrations of dioxins and PAHs rose at the three Greater London sites (Brent, London Victoria Street and Bromley).

The report noted, however, that this increase in concentrations during the fire did not follow that expected geographically from the proximity of the individual sites to the fire – levels at Brent increased most, whilst levels at Bromley increased more than those at Victoria Street. The increase in individual compounds was not consistent between sites, moreover. The report concluded that further dispersion modelling, together with analysis of additional samples from the PAH network, would be required to confirm whether the recorded increase in PAH and dioxin concentrations resulted from plume grounding in London or could merely reflect normal temporal variability in concentrations of these pollutants.

Additional analyses were then carried out on earlier and later samples from the three London sites. (Appendix G). In view of the short-term peaks in PM₁₀ discussed below at Horsham and Lewes, the contemporary samples from the Hove site were also analysed for PAHs.

These later analyses also indicate that PAH measurements were not influenced by the Buncefield incident. Measurements of PM₁₀ and nitrogen dioxide at London Brent do not follow the trend in Benzo[a]pyrene concentrations, and show no significant signal during the period of the incident. Increased individual PAH and dioxin concentrations were seldom observed; those that did occur, did not appear to be related to the proximity of the measurement site to the incident.

The analysis of filters taken by the aircraft show low concentrations of PAHs and dioxins, below those measured at the sampling sites. Hence, while the smoke from the Buncefield fire may have increased concentrations of PAHs and dioxins at the four South East England PAH network sites, this increase was no greater than the ongoing variability in PAH concentrations. Overall, a PAH 'signal' due to the fire cannot be demonstrated, therefore.

4.1.5 Hydrocarbon Networks

The UK Ambient Automatic Hydrocarbon Air Quality Network consists of five monitoring stations, each measuring between six and twenty-nine hydrocarbon compounds. Three of the sites - Glasgow, Cardiff and Harwell - use Environnement VOC71M analysers to report 1,3 butadiene and the BTEX aromatic compounds. The remaining two sites - Eltham and Marylebone Road - both in London, use Perkin Elmer ozone pre-cursor analysers to report the full range of hydrocarbon species on the European Union's 4th Daughter Directive list¹.

Marylebone Road in London is the closest site in the Hydrocarbon Network to Hemel Hempstead. Figure 4.12 shows hourly concentrations of some selected hydrocarbons at Marylebone Road. These levels are within the normal range for this site.

Figure 4.13 shows the ratio of all measured aromatic compounds to benzene. These ratios are used to identify any unusual event in the data. The graph may help to highlight a different source of pollution to those usually affecting the site and could therefore indicate Buncefield plume grounding. The ratios to benzene are fairly stable, but the measurement at 3:00 pm on 11th December stands out. This sample shows elevated toluene, xylenes and trimethylbenzenes. Benzene, all other VOCs, PM and inorganic data did not rise during this hour, however.

This is the only unusual measurement noted in the Hydrocarbon Network during the event. The elevated compounds are the same as those also observed in grab samples taken near the depot (see Section 4.3.2); this may indicate a relationship. However, there are a number of alternative and more local sources of such short-term changes in the VOC profile, such as fuel evaporation or paint fumes.

¹ Directive 2004/107/EC of the European Parliament and of the Council of 15 December 2004 relates to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air. More detailed information, in particular in relation to PAHs and benzo[a]pyrene may be found at: <http://europa.eu.int/eur-lex/lex/LexUriServ/LexUriServ.do?uri=CELEX:32004L0107:EN:HTML>

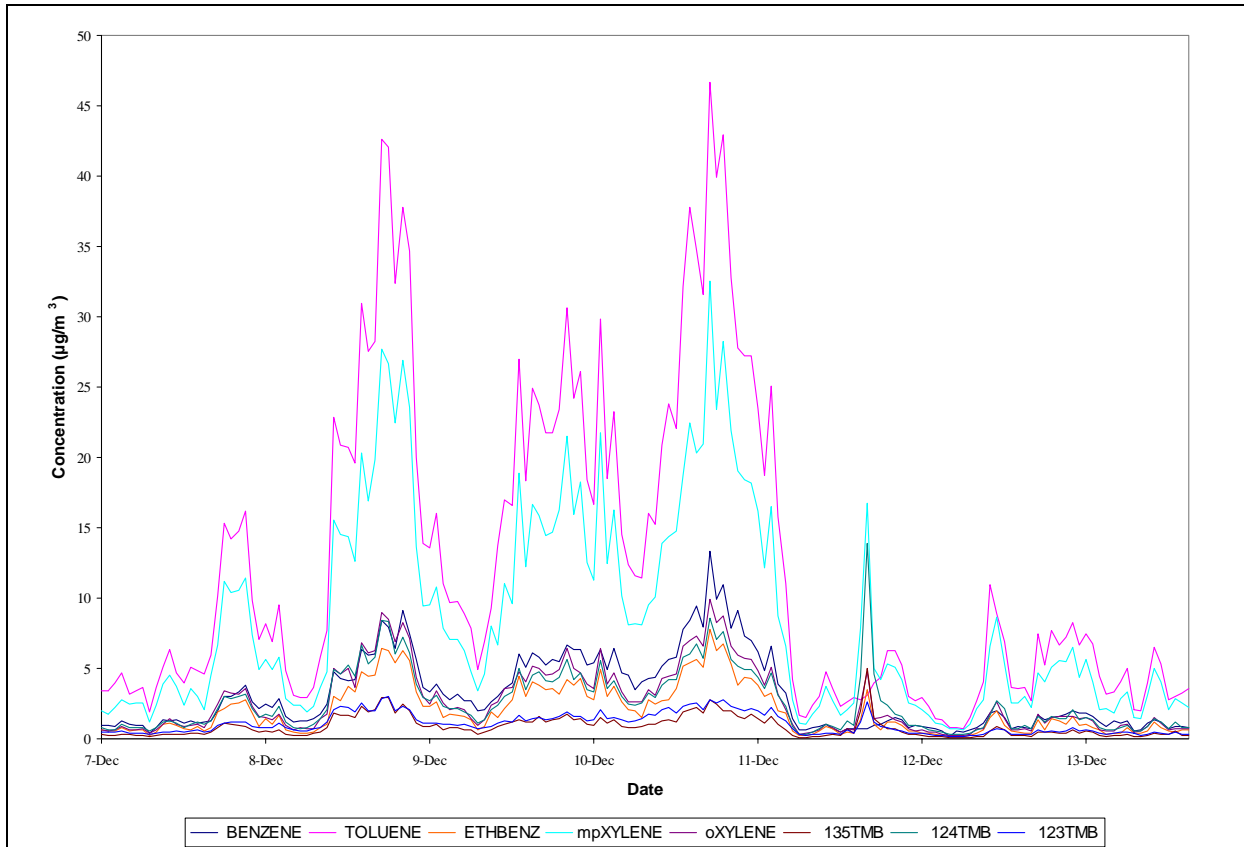


Figure 4.12 Hourly concentrations of selected hydrocarbons at London Marylebone Road

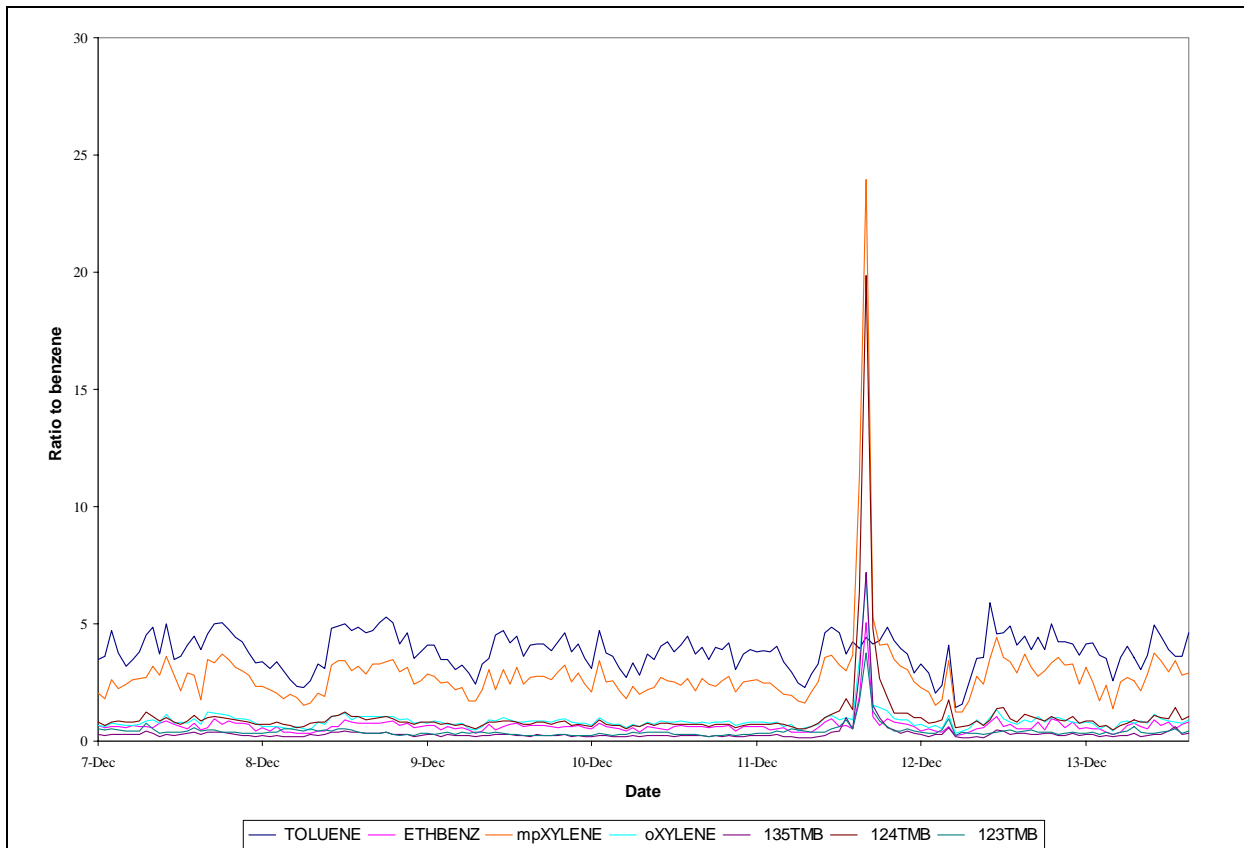


Figure 4.13 Ratios of all aromatic compounds to benzene at London Marylebone Road

4.2 AIR QUALITY MEASUREMENTS DURING BUNCEFIELD SET IN A BROADER TIMEFRAME

4.2.1 Annual time series comparison

As noted in the previous sections of this report, monitoring undertaken in a number of UK networks during the week following the Buncefield oil depot explosion did not highlight – with the exception of the Horsham, Lewes Roadside Marylebone Road measurements discussed previously – any significantly elevated air pollution concentrations. In this section, we illustrate and re-enforce this observation by examining the measurements in the broader context of the year as a whole.

The data presented in Figures 4.14a and b are from a range of networks. We have, in particular, selected monitoring sites discussed in previous sections; this makes the graph easier to interpret than were we to graph all datasets. Data from sites in the UK Automatic Urban and Rural Network (AURN) for 2005 have been fully ratified by Netcen. Where data capture statistics were below 75%, sites were omitted from the analysis. Also presented are monitoring data from locations in close proximity to the Buncefield oil depot. These sites were part of the Sussex Air Quality Steering Group Network (<http://www.sussex-air.net/>) and the Hertfordshire & Bedfordshire Air Pollution Monitoring Network (<http://www.hertsbedsair.org.uk/hertsbeds/asp/home.asp>).

Figure 4.14a shows the daily average PM₁₀ concentrations at selected sites throughout 2005. It confirms the unexceptional magnitude of the measurements recorded during the Buncefield week. The only data that stand out from this analysis are those for Bradford Centre. As already discussed, however, these are directly attributable to local construction work, including stone cutting, in the immediate vicinity of the monitoring hut. PM₁₀ peaks are, in fact, seen at this site before and after the Buncefield event, and continue to this time.

Please note that, in order to filter some of the day-to-day statistical ‘noise’ from these graphs, we repeat the analysis in Figure 4.14b, but this time using 1-week (168-hour) running averages.

4.2.2 A comparison with Bonfire Night

Figure 4.15 compares PM₁₀ concentrations measured throughout the AURN during the Buncefield incident with those recorded during a range of recent Bonfire Night weeks. Bonfire Night particle concentrations depend critically on weather conditions and timing, and therefore vary markedly from year to year. The graphed Bonfire night events (1995, 2001, 2005) have been selected as being typical of high, medium and low-intensity events of this type, respectively.

Please note that the running 24-hour average metric plotted here conforms to the Defra Health bandings for PM₁₀. Note, also, that the data graphed are network averages over the whole of the AURN (for sites with >75% data capture).

Although the different time series in Figure 4.15 are not strictly comparable, because they do not cover the same time periods or the same geographical scale (Bonfire Night being nationwide and Buncefield more localised), they nevertheless serve broadly to demonstrate the magnitude of the Buncefield event when compared against recent Bonfire Nights. It is clear that the Buncefield event was associated with PM₁₀ concentrations similar to those observed during Bonfire Night 2005. However, as the result of favourable meteorological factors, the 2005 event did not exhibit any significant increase in particle levels above background.

Figure 4.14a Daily average time series PM₁₀ concentrations (TEOM, $\mu\text{g m}^{-3}$), 2005

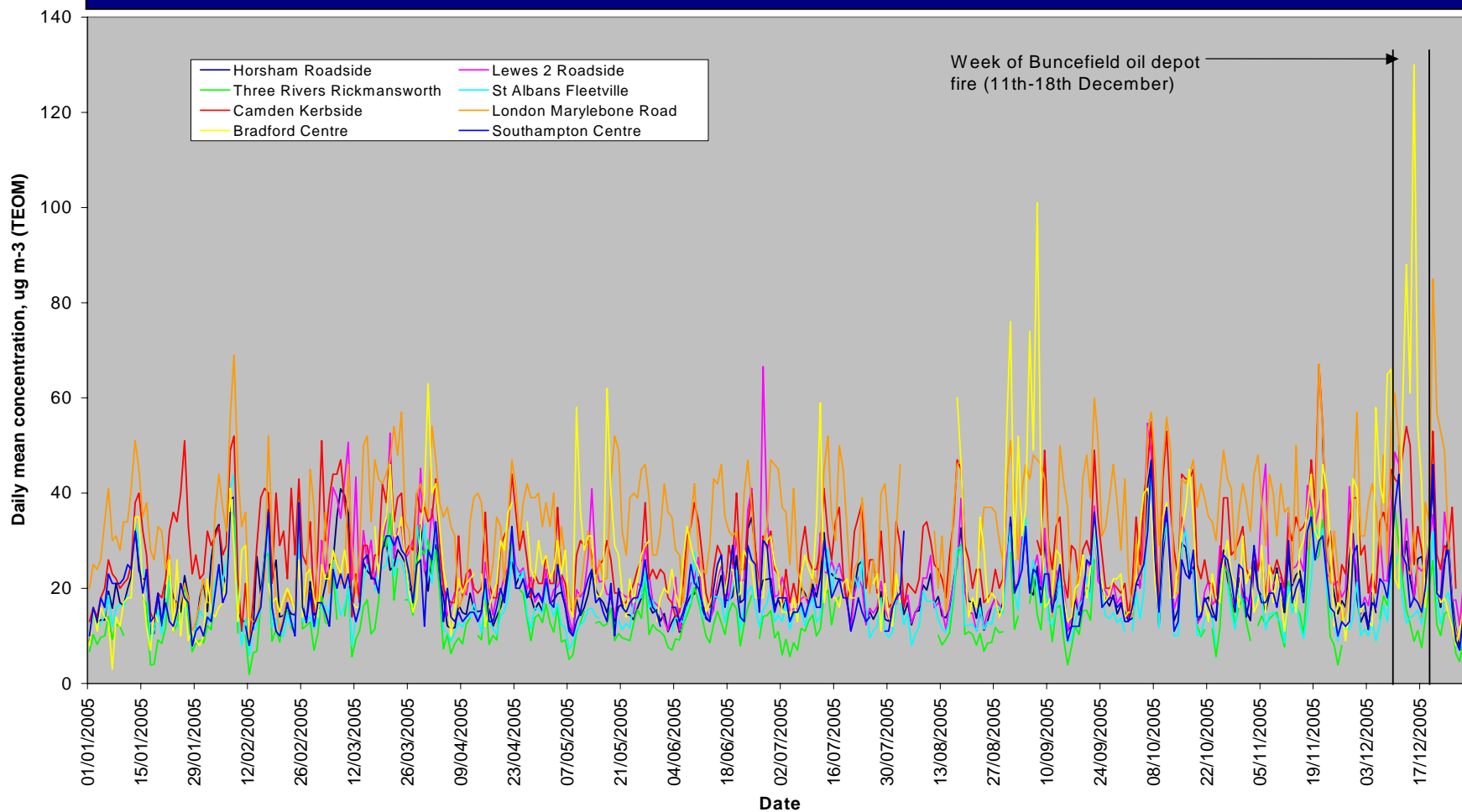


Figure 4.14b Running 168-hour average time series PM₁₀ concentrations (TEOM, μgm⁻³), 2005

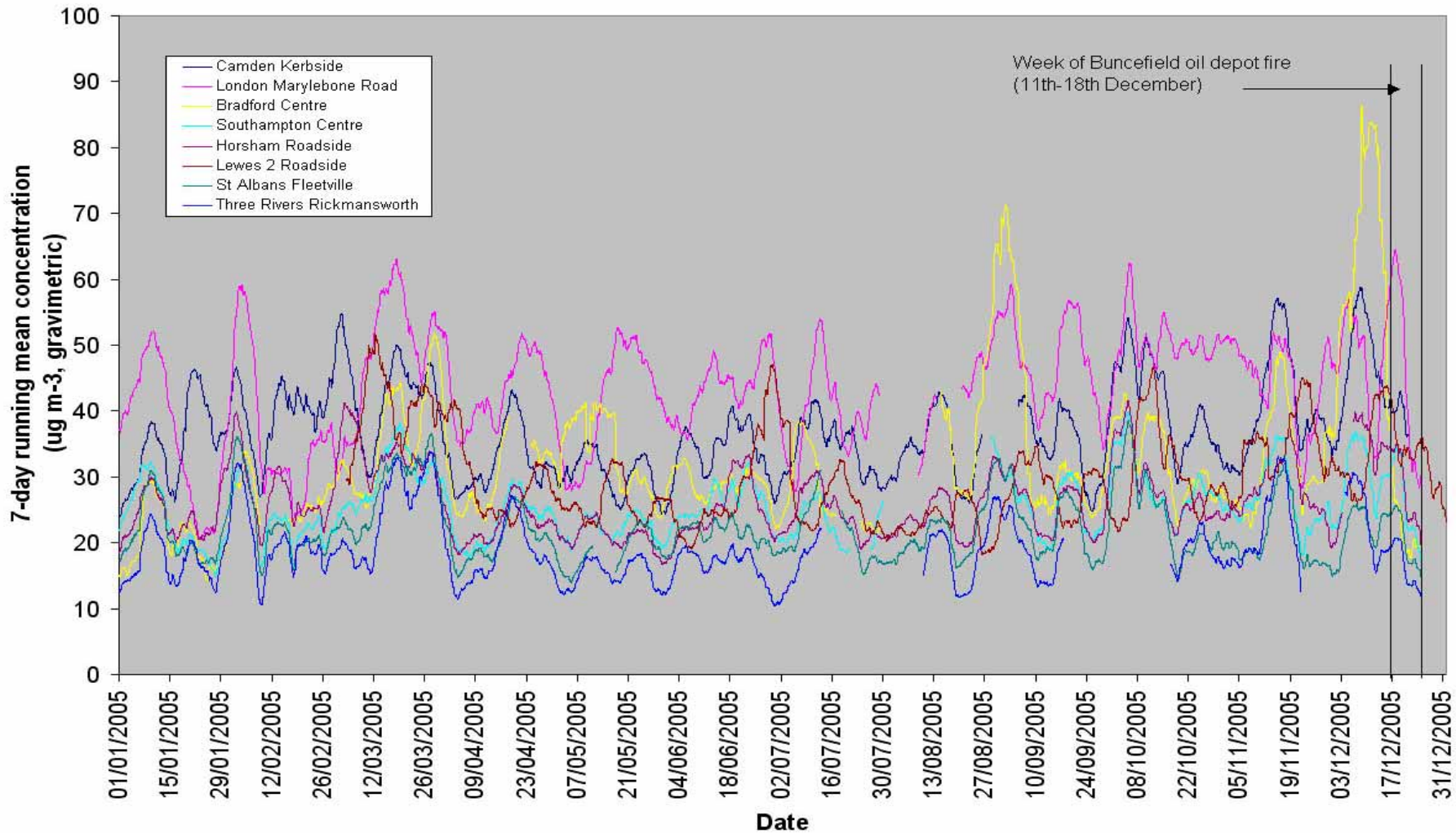
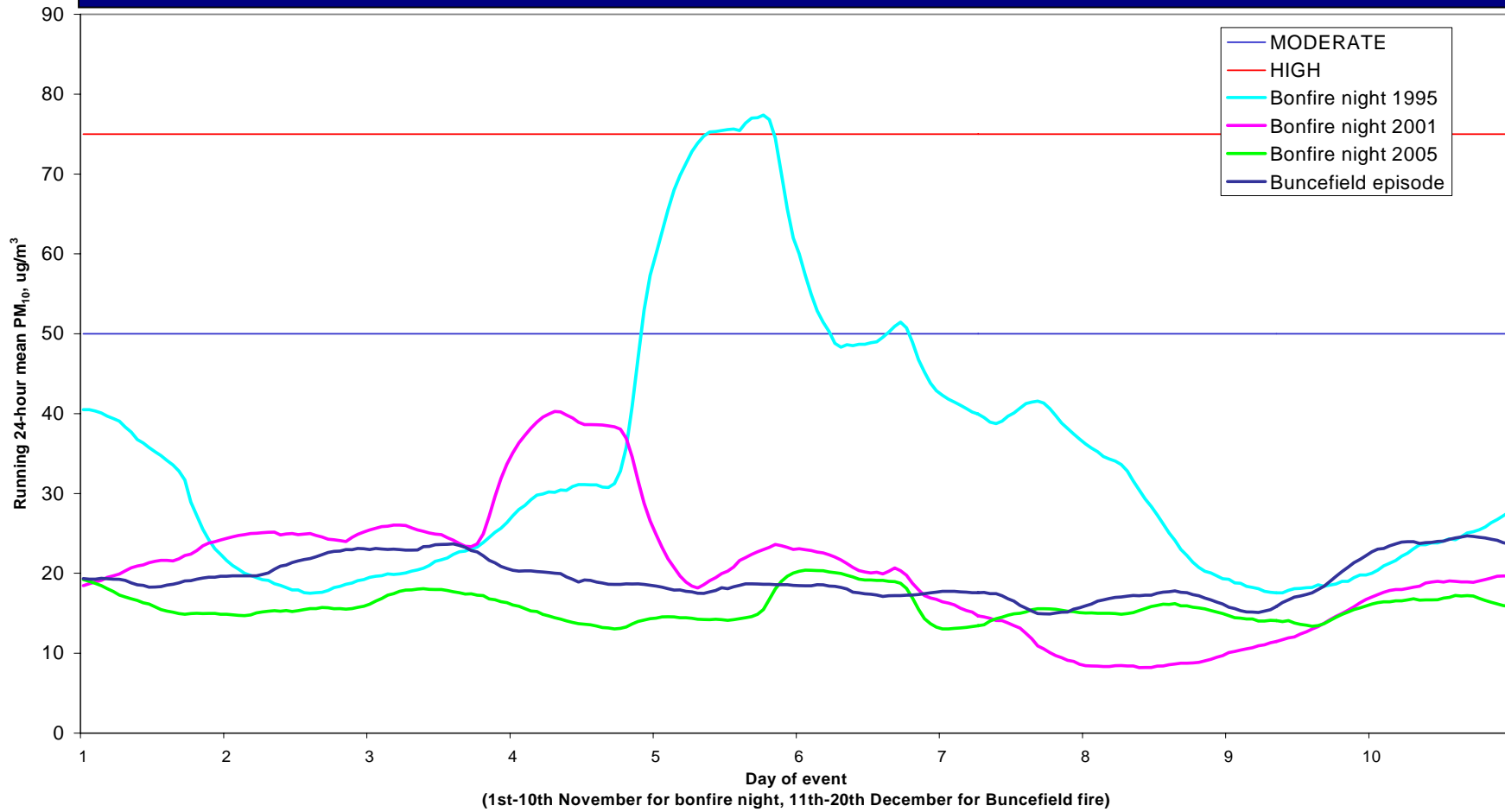


Figure 4.15 Running 24-hr average PM₁₀ concentrations (µgm⁻³, TEOM) in the Automatic Urban and Rural Monitoring Network during the Buncefield fire and during Bonfire Night



4.3 TARGETED LOCAL MONITORING

Apart from data from the well-established permanent monitoring networks presented in Section 4.1, targeted local monitoring was carried out around the oil depot and surrounding areas by i) Netcen on behalf of Defra and the DAs and ii) by the Fire Brigade's Scientific Advisors (Bureau Veritas) and HSL on behalf of the HPA (see Appendix H). The Met Office/NERC FAAM aircraft also made extensive measurements from within the plume on 13/12/05.

During the fire, Netcen carried out targeted monitoring of particulate matter and VOCs both inside and outside of the oil depot. Measurements between 12th and 14th December included:

- Particulate matter using a Grimm particulate sampler.
- Grab sampling for VOCs.
- Monitoring by the Fire Brigade's Scientific Advisors (Bureau Veritas) and HSL on behalf of the HPA for CO, CO₂, SO₂, particulate matter, hydrocarbons and VOCs

Figure 4.16 shows the exact locations of the Netcen targeted monitoring.

4.3.1 Particulate Matter in Buncefield

Using a Grimm particulate sampler, Netcen obtained particulate matter measurements from the oil depot site and surrounding areas. A portable dust analyser (GRIMM 1.101) was used to gauge concentrations of particulate matter. The GRIMM dust monitor is capable of simultaneously measuring in real time the Inhalable, Thoracic and Alveolic dust masses.

This monitoring targeted the areas of maximum visible impact of the plume, aiming to measure the likely highest concentrations at ground level. Figure 4.16 shows the location of the different sample points. Indicative measurements of PM₁₀, PM_{2.5} and PM₁ are shown in Figures 4.17 to 4.20.

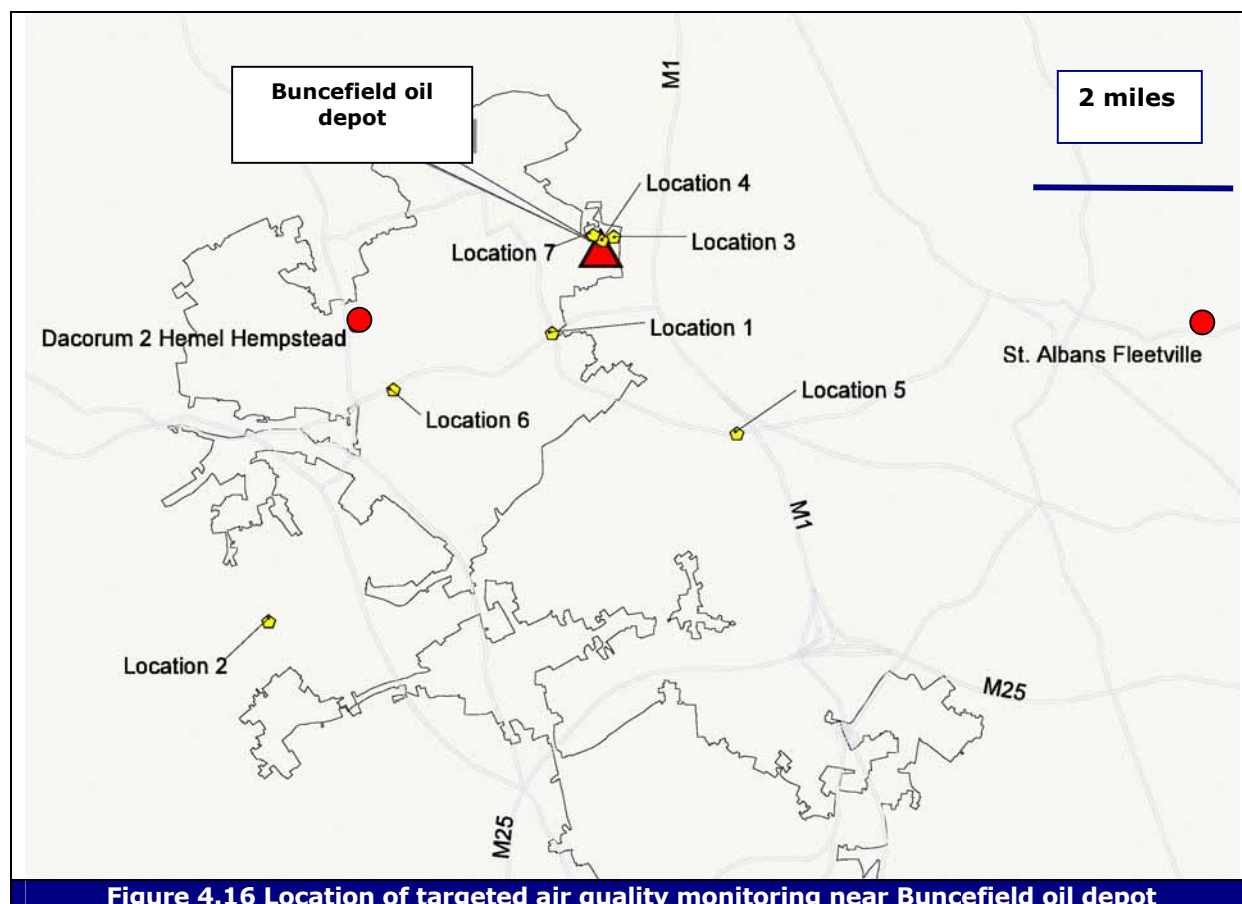


Figure 4.16 Location of targeted air quality monitoring near Buncefield oil depot

PM₁₀

One-minute averages were obtained, giving a high temporal resolution. The maximum indicative PM₁₀ one-minute mean measurement was 985 $\mu\text{g m}^{-3}$ on 12/12/05 at 6:08 pm at location 1. The

maximum 15-minute mean indicative measurement was 340 $\mu\text{g m}^{-3}$ on 13/12/05 at 2:15 pm at location 4 (See Figure 4.20).

PM_{2.5}

The maximum indicative one-minute mean PM_{2.5} measurement was 801 $\mu\text{g m}^{-3}$ at location 4 on 13/12/05 at 2:18 pm. The corresponding peak 15-minute mean indicative measurement was 318 $\mu\text{g m}^{-3}$ at location 4 on 13/12/05 at 2:30 pm (See Figure 4.20).

PM₁

The maximum indicative one-minute mean PM₁ measurement was 522 $\mu\text{g m}^{-3}$ at location 4 on 13/12/05 at 2:21 pm. The maximum 15-minute mean indicative measurement was 210 $\mu\text{g m}^{-3}$ at location 4 on 13/12/05 at 2:15 pm (See Figure 4.20).

To put these measurements made in the vicinity of the Buncefield depot in context, they are lower than those typical of near-roadside environments or during Bonfire Night. See Section 4.2 for further exploration of this point.

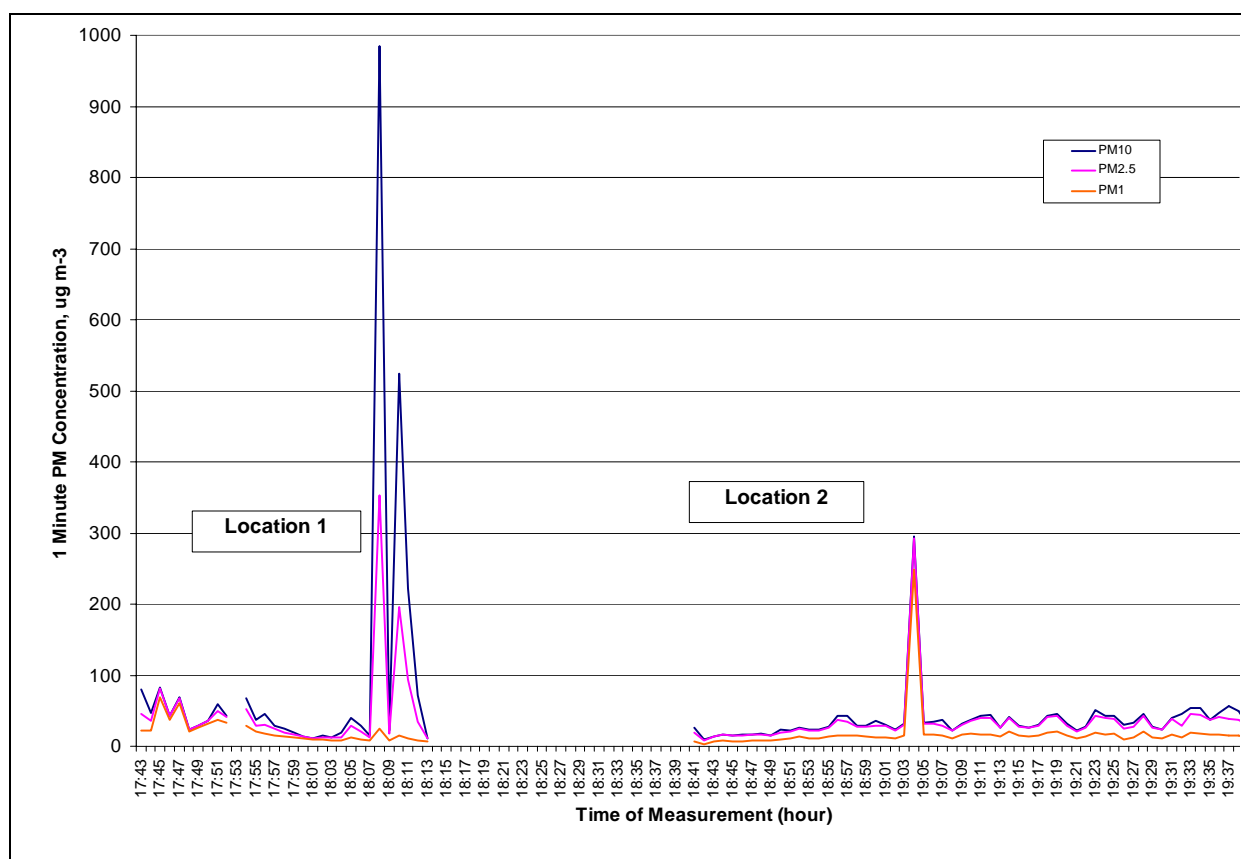


Figure 4.17 One minute mean PM concentrations at locations 1 and 2 on 12/12/05

(Gaps in graphs due to movement of equipment from one location to another)

4.3.2 Volatile Organic Compounds (VOCs)

Netcen also measured VOCs within and outside the oil depot. These were derived from grab sampling, with the samples collected in stainless steel canisters of 1.6 litre volume. The internal surfaces of the canister had been electro polished and passivated by the SUMMA process in order to ensure their inertness. The sampling technique meets the requirement of the USEPA method TO-14A. Air samples in the stainless steel canisters were analysed using a gas chromatograph fitted with flame ionisation detectors (GC/FID).

This monitoring was carried alongside PM sampling (detailed above) between 12th and 14th December. Figure 4.21 shows all the 30-second mean measurements at the six different locations where VOCs were measured (3, 4 and 7 in the oil depot and 1, 5 and 6 outside) - see Figure 4.16 for exact locations.

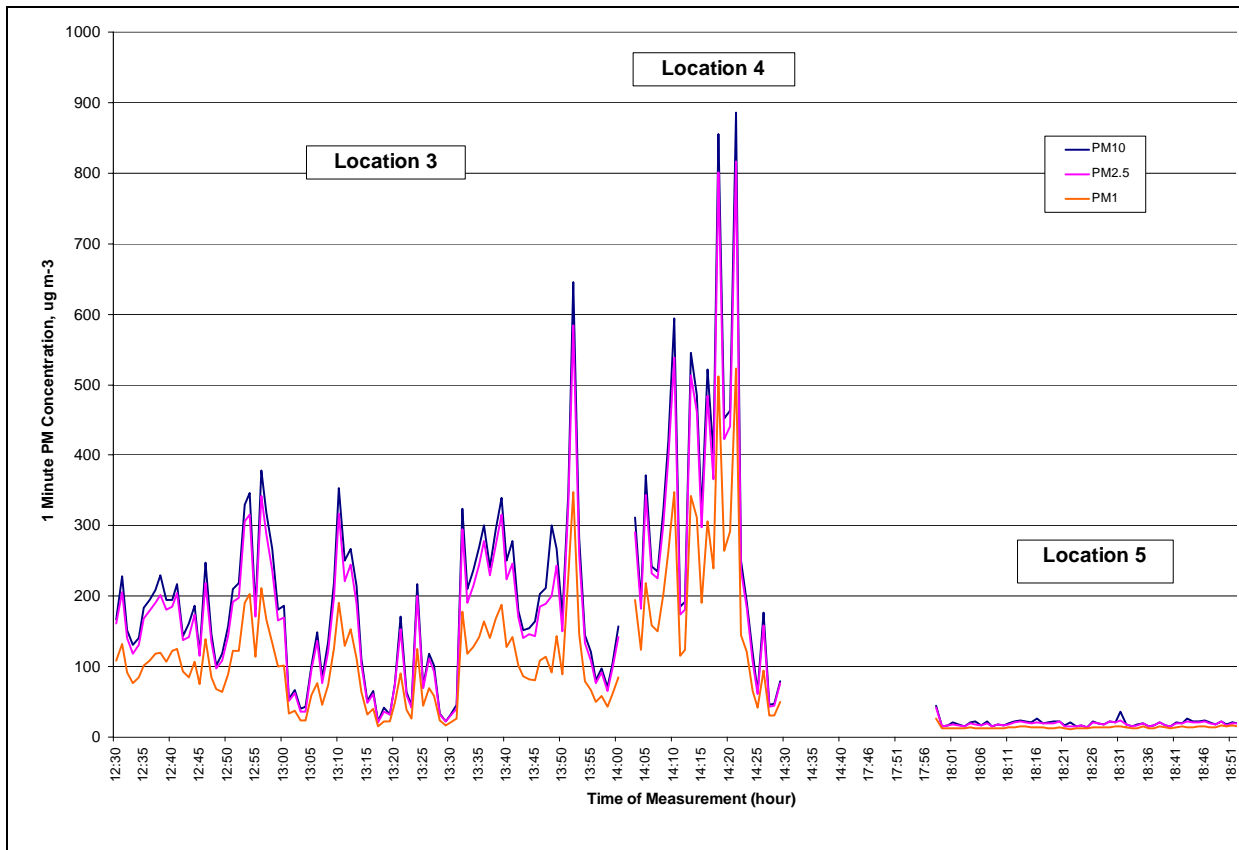


Figure 4.18 One minute mean PM concentrations at locations 3, 4 and 5 on 13/12/05

(Gaps in graphs due to movement of equipment from one location to another)

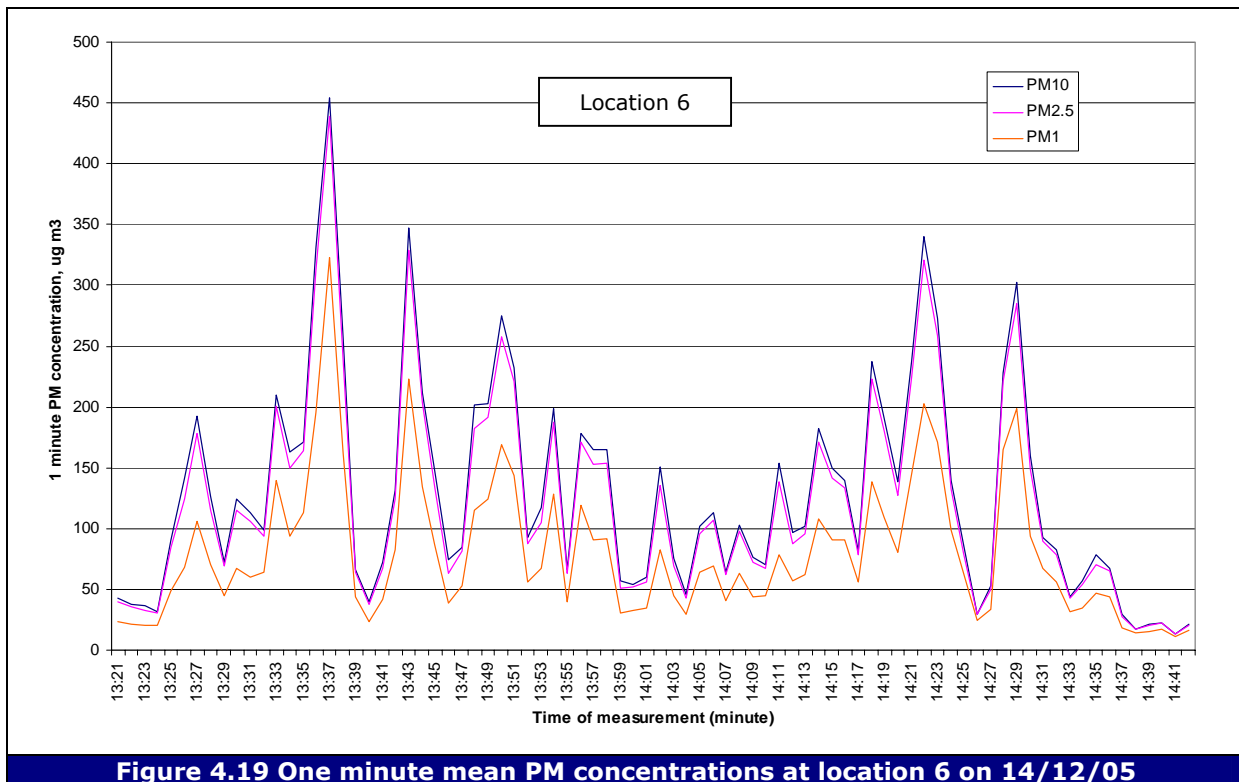


Figure 4.19 One minute mean PM concentrations at location 6 on 14/12/05

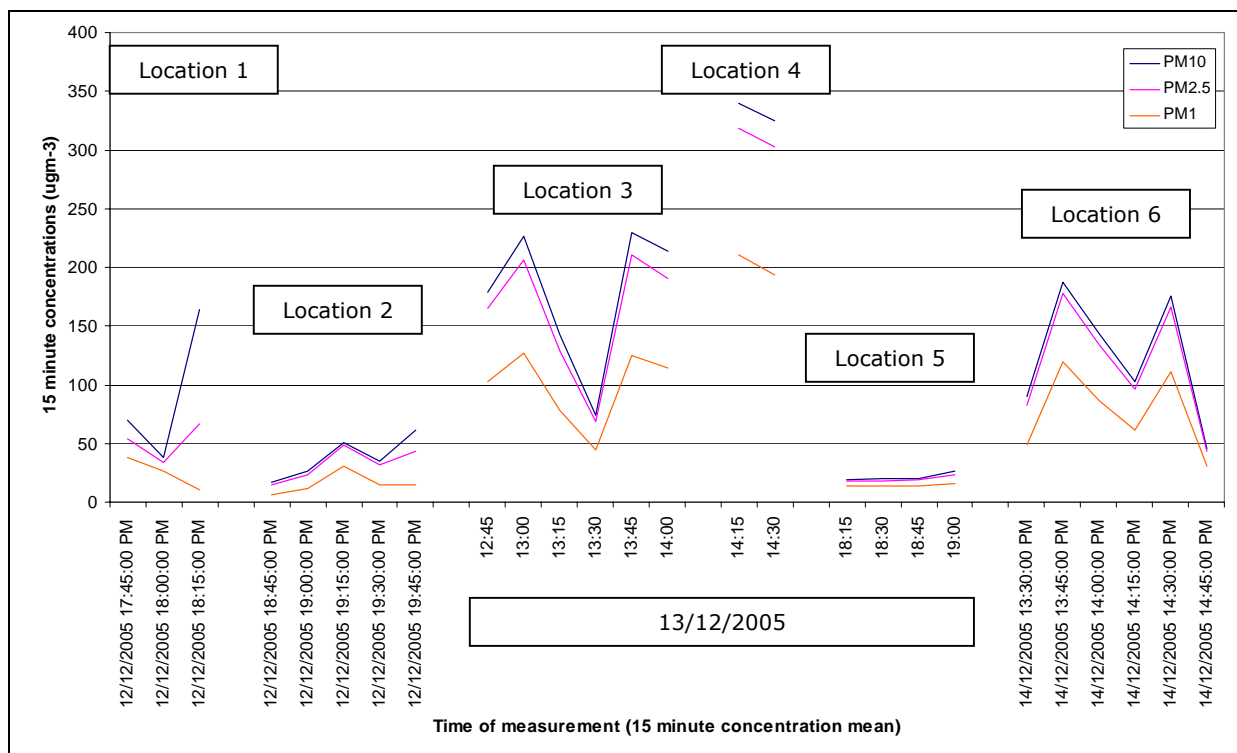


Figure 4.20 15-minute mean PM concentrations between 12/12/05 and 14/12/05

(Gaps in graphs due to movement of equipment from one location to another)

As can be seen in Table 4.2, none of the measured VOC concentrations exceeded any of the short term Environmental Assessment Levels (EALs) for air for the protection of human health¹. To provide perspective, Figure 4.22 compares the maximum 30 second mean VOC concentrations obtained from grab sampling between 12th and 14th December with maximum hourly measurements at Marylebone Road in 2003 and across the UK Hydrocarbon Network in 2000.

For example, the highest recorded toluene grab-measurements around Buncefield were of the order of 700 µgm⁻³. By way of comparison, the EAL for this species is 8000 µgm⁻³.

It may be noted that in Table 4.2 we are comparing 30-second mean measurements from the incident with hourly measurements; we would, of course, normally expect peak 30-second mean measurements to be higher than corresponding hourly measurements due to the shorter averaging period. With the exception of a few pollutants, however, the levels measured at Hemel Hempstead during the Buncefield incident are much lower than those recorded at Marylebone Rd or, indeed, across the hydrocarbon network.

Compared to the usual levels measured across the Hydrocarbon Network, there were increased levels of m_p-xylene, oxylene, ethylbenzene, 1,2,3 trimethylbenzene, 1,2,4 trimethylbenzene and 1,3,5 trimethylbenzene surrounding the oil depot (see Figure 4.22). However, these levels are well below the EAL of 37500 µgm⁻³ for the trimethylbenzene and 66200 µgm⁻³ for m_p-xylene. High levels of these species are typical of unburnt fuel, indicating that the origin of the pollution is likely to have been evaporative releases from the fuel in the tanks, rather than from the plume itself.

¹ In order to fulfil its emissions regulatory role, the UK Environment Agency has developed environmental criteria known as environmental assessment levels (EALs) for different environmental media (air, water and land) for use within the H1 assessment methodology framework (Guidance on Environmental Assessment and Appraisal of Best Available Technology –BAT). A hierarchical approach has been used to develop EALs. For air, existing standards and guidelines are used as EALs; however, as there are only a limited number of appropriate values, EALs for most substances have been derived from occupational exposure values by the application of a simple safety factor. It should be emphasised that EALs are not protective of Human Health; they are simply guidelines derived from occupational standards.

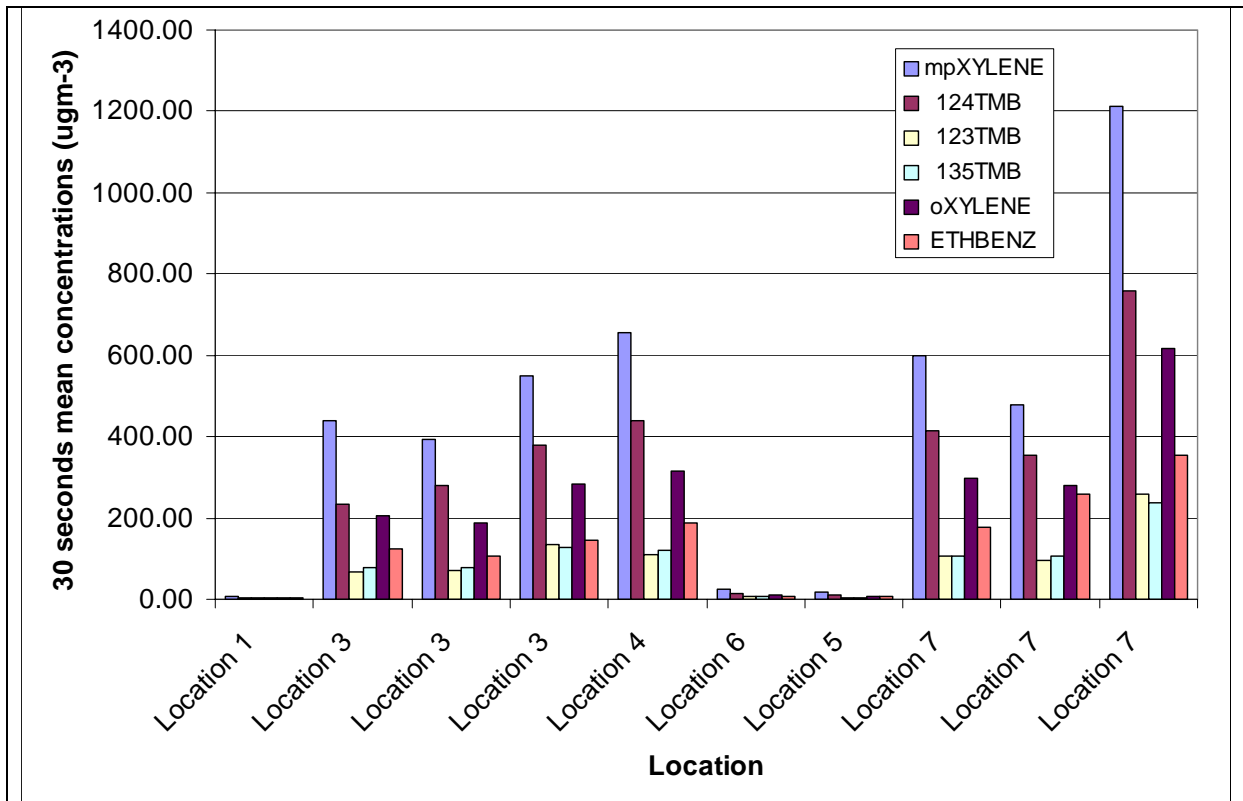


Figure 4.21 30 second mean concentration levels of m+p-xylene, o-xylene, ethylbenzene and three trimethylbenzenes

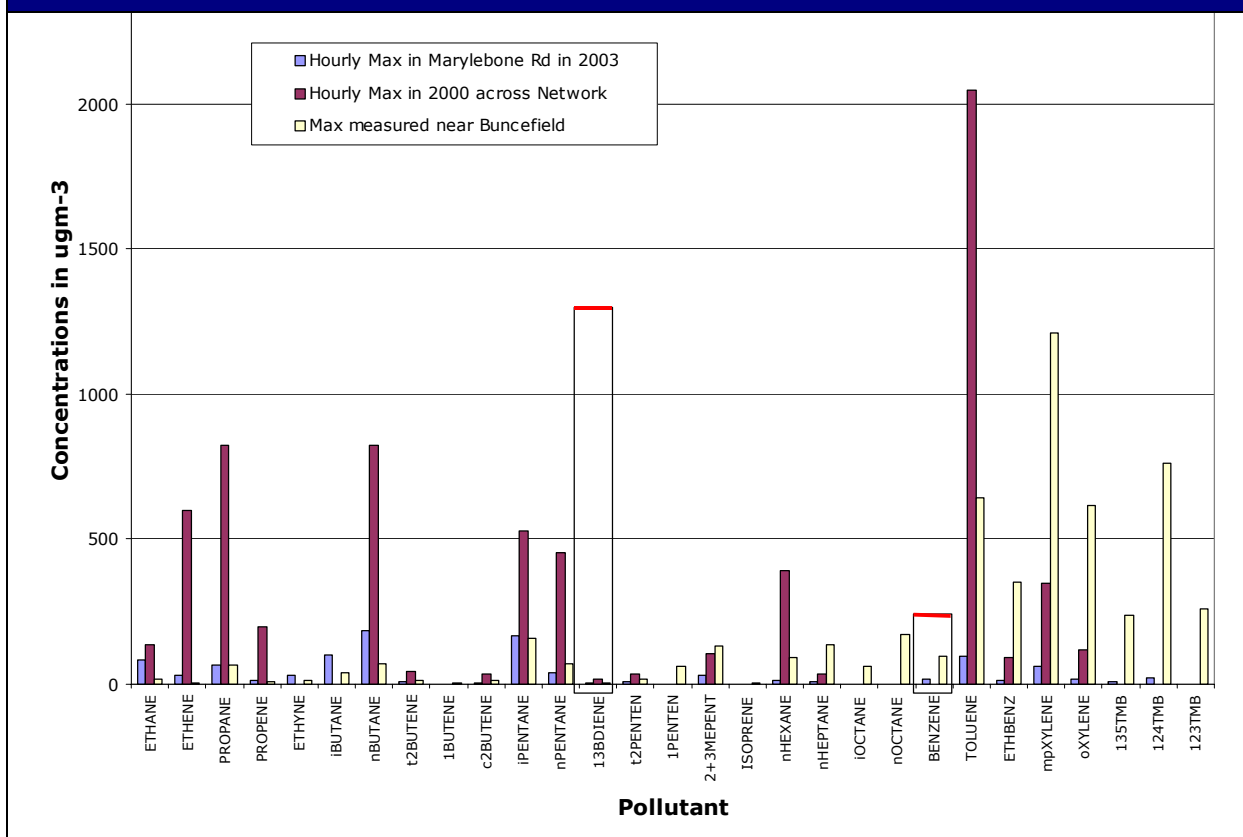


Figure 4.22 Maximum 30 second mean VOC concentrations recorded at the six VOC measurement locations between 12th and 14th December 2005 (Red line represents the short term EAL value if available)

Table 4.2 Volatile organic compound 30 seconds grab sample measurements											
Location	1	3	3	3	4	6	5	7	7	7	Short term EAL*(H1) (15min or 1hour ²)
Date	12/12/05	13/12/05	13/12/05	13/12/05	13/12/05	13/12/05	13/12/05	14/12/05	14/12/05	14/12/05	
Time	18:00 GMT	11:55 GMT	11:30 GMT	11:40 GMT	13:10 GMT	16:55 GMT	16:42 GMT	12:20 GMT	13:25 GMT	13:35 GMT	
Species (unit)	μgm^{-3}	μgm^{-3}	μgm^{-3}	μgm^{-3}	μgm^{-3}	μgm^{-3}	μgm^{-3}	μgm^{-3}	μgm^{-3}	μgm^{-3}	
mpXYLENE	6.1	440.2	392.2	548.8	655.6	23.3	19.4	599.2	479.8	1211.6	66200
124TMB	4.0	235.4	279.6	380.9	438.2	15.6	10.6	414.6	356.1	760.2	37500
TOLUENE	3.9	345.0	278.5	349.7	477.0	19.1	17.4	344.5	350.0	641.5	8000
oXYLENE	2.3	204.1	186.5	282.9	315.6	9.6	8.1	298.5	279.8	617.8	66200
nOCTANE	1.0	38.9	48.9	171.3	153.0	1.6	0.4	34.8	50.6	63.0	
ETHBENZ	2.0	124.5	106.1	145.5	189.5	7.6	5.7	175.5	260.0	353.9	55200
nHEPTANE	1.1	29.3	45.3	138.5	136.7	1.8	1.2	25.6	41.8	55.1	
123TMB	2.7	68.5	72.6	134.3	111.0	8.2	3.3	106.8	94.6	258.5	37500
135TMB	2.5	79.2	76.6	126.9	119.4	7.4	3.3	107.7	107.3	236.5	37500
BENZENE	1.7	48.8	38.9	97.4	96.0	4.7	4.4	30.1	36.8	54.9	208
2+3MEPENT	1.8	54.6	45.7	86.7	131.7	3.9	3.6	24.2	126.8	62.9	
nHEXANE	1.3	20.8	18.2	78.6	91.2	1.5	1.1	12.3	23.4	26.2	21600
iPENTANE	2.5	55.3	48.7	64.3	156.7	5.6	5.8	25.6	43.4	62.5	
nPENTANE	2.4	22.8	19.8	44.2	72.2	2.4	2.2	11.7	16.9	27.5	
iOCTANE	0.5	31.1	33.6	33.0	53.2	1.3	1.4	22.2	47.5	60.1	
nBUTANE	3.4	35.9	21.8	27.3	70.3	6.7	5.4	17.7	19.1	37.9	181000
iBUTANE	1.7	19.7	10.8	11.9	40.4	3.8	3.2	9.2	11.2	19.9	
ETHYNE	0.9	9.8	6.2	11.6	9.1	2.4	3.7	2.7	1.2	4.2	
1PENTEN	0.4	25.5	21.6	10.4	60.6	2.03	2.2	13.4	33.1	30.0	
ETHANE	3.0	16.3	14.2	10.0	18.1	14.8	11.0	10.3	7.9	15.8	
PROPENE	0.8	8.3	5.8	9.7	7.2	2.8	3.1	2.6	4.3	5.4	
PROPANE	3.6	6.3	5.2	6.4	4.9	5.6	3.7	6.4	64.3	9.0	
ETHENE		3.5	5.2	5.7	4.7	1.9	1.6	2.4	0.8		
t2PENTEN		7.0	7.1	5.2	18.2	0.5	0.3	2.4	2.3	6.3	
13BDIENE		2.3	1.7	3.0	1.7	0.6	0.7	0.6	0.3	1.1	1320
t2BUTENE	1.8	4.5	4.8	3.0	15.3	1.4	1.5	2.3	1.2	6.2	
c2BUTENE	0.8	3.4	3.2	2.3	11.0	1.1	0.4	1.5	1.4	3.8	
1BUTENE	0.3	2.7	2.4	2.1	5.9	0.9	0.8	1.1	0.7	2.4	
ISOPRENE	0.3	4.0	3.8		5.5	0.6	0.4	3.2	1.9	3.8	

* Environmental Assessment Levels for air (for the protection of human health)

² http://www.environment-agency.gov.uk/commondata/acrobat/h1v6_jul03guidance_608809.pdf

4.3.3 Targeted local monitoring by the Fire Brigade's Scientific Advisors and the Health and Safety Laboratories on behalf of HPA

Between 11th and 14th December, the Fire Brigade's Scientific Advisors (Bureau Veritas) carried out air quality monitoring at several locations around the oil depot. Concentrations of CO, CO₂, HF, SO₂, NH₃ and volatile organic compounds (VOCs) were measured. Monitoring over the period 12th, 13th, and 14th December indicated no significant increase in concentrations of CO, CO₂, HF, SO₂, NH₃ or VOCs. Please see Appendix H for further detail.

Particulate monitoring showed short-term peak concentrations between 40 µgm⁻³ and 1300 µgm⁻³ maximum on Monday and Tuesday, respectively.

4.3.4 The FAAM Aircraft

The Facility for Airborne Atmospheric Measurements (FAAM) BAe146-301 aircraft, operated jointly by the Met Office and NERC, flew on the 12th and 13th December to study the position and composition of the plume. The key flight was on 13th December (flight identifier B149), which took place between 11:59 am and 4:10 pm and included runs in the plume at a distance of around 78km from the source and directly overhead the Buncefield site (see Figure 4.23). Images of the exterior and interior of the FAAM aircraft appear as Figures 4.24 and 4.25.

The aims of the flights were:

- 1) To provide real-time information on the position of the plume to the Met Office Environment Monitoring and Response Centre (EMARC) and
- 2) To provide the only *in-situ* data on the chemical composition of the elevated smoke plume. The aerosol size distribution was measured with a Passive Cavity Aerosol Spectrometer Probe, which is capable of measuring aerosol particles between 0.1 and 3 microns diameter.

The chemical composition of particles was measured using an Aerosol Mass Spectrometer operated by Manchester University. Two sets of quartz filters were exposed to the smoke plume and analysed after the flight by Harwell Scientifics and the Health and Safety Laboratory (HSL) Buxton.

The first set of filters (Exposures 1 and 2) was analysed by Harwell Scientifics; these filters were exposed during aircraft runs 2 to 6 of the flight between 12:46 pm and 2:36 pm at a range of altitudes in and above the smoke plume, and at a distance approximately 78 km downwind from the source. The second set of filters was exposed during aircraft runs 7 to 14 between 2:47 pm and 3:56 pm and was sent to HSL, Buxton for analysis. This set consisted of two filters; one which sampled the plume at a height of 1010 m at a distance 78 km downwind from the source (Exposure 3) and one which was exposed at a range of altitudes in and above the smoke plume directly over the Buncefield site (Exposure 4).

Analysis of data gathered by the Aerosol Mass Spectrometer and other instrumentation on the aircraft showed that Poly Aromatic Hydrocarbons (PAHs) were not measured at any time during the flight and that the main constituent of the plume was black carbon (soot).

The measurement of PM₁₀ is not possible from an aircraft. Using the size distribution data gathered during the penetrations of the smoke plume directly overhead Buncefield, it is possible to estimate PM_{2.5} (i.e. the total mass of particulates of mean aerodynamic diameter of 2.5 µm). This estimation requires knowledge of the refractive indices of the particles and their density in order to convert the size information to a mass.

Using a range of values of refractive index and density from the published literature for black carbon, the PM_{2.5} mass averaged over a 7.4 km (69 second) run up the plume and directly over the source was 461 µgm⁻³, with an uncertainty ranging from 300 to 576 µgm⁻³. Directly over the source, the plume was measured at altitudes between 500 m and 700 m. The plume was not detected in a run at 930 m altitude over the source region. During the downwind runs (~78.2 km downwind), the plume was intersected at altitudes between 500 m and 1470 m. It was not detected during runs at 1750 m or 2500 m; at a distance of ~78.2 km from the source, the plume was already approximately 10 km wide.

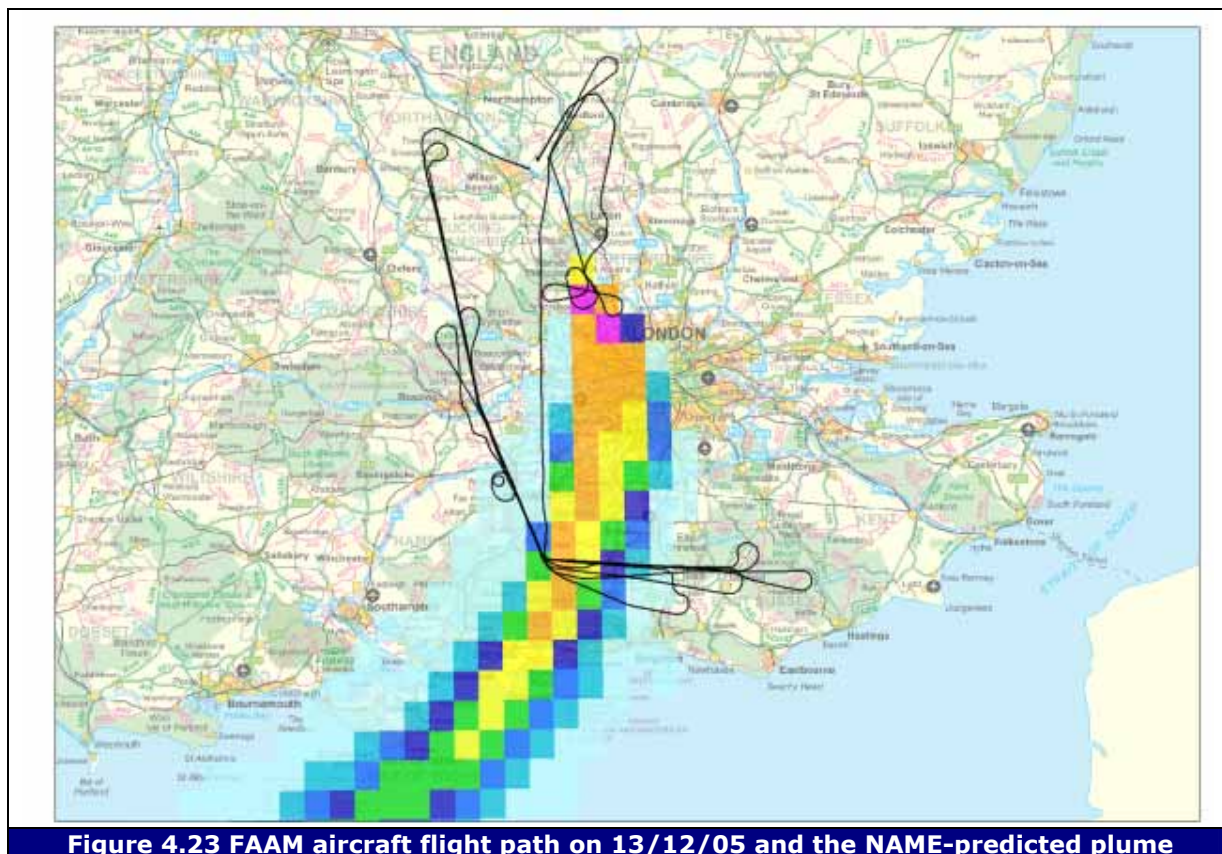


Figure 4.23 FAAM aircraft flight path on 13/12/05 and the NAME-predicted plume

4.3.4.1 Dioxins, Furans and PCBs from the FAAM aircraft monitoring

Appendix A includes a letter report from Netcen, based on analyses provided by Harwell Scientifics, on levels of dioxins, furans and PCBs from air samplers from the FAAM aircraft. These three samples consisted of a blank and samples taken during Exposures 1 and 2, which sampled air both within and outside of the plume ~78 km downwind of the source. No PCBs were detected in any of the three samples.

The letter report provides estimations of inhalation exposure that would result from the measured concentration of polychlorinated dibenzodioxins and dibenzofurans (PCDD/Fs) and PCBs. The Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment's (COT) Tolerable Daily Intake (TDI, based on the total body burden) for children was only slightly exceeded by the concentrations measured by the FAAM aircraft. The report concludes that, unless exposure at these concentrations is prolonged, there would only be a slight impact on body burdens.

Analysis of levels of dioxins, furans and PCBs in air samples from Exposures 3 and 4 was not possible due to the extraction method used by HSL, Buxton.

4.3.4.2 PAHs from the FAAM aircraft monitoring

Figure 4.26 shows the PAHs levels measured from Exposures 1 - 4. Concentrations are generally low. Focusing on B[a]p (Benzo[a]pyrene), the levels found in Exposure 1 (0.012 ngm^{-3}) and 2 (0.046 ngm^{-3}) are low for this time of year. In 2004, the level for the 4th quarter was 0.17 ngm^{-3} in London and at the rural site of Stoke Ferry $< 0.06 \text{ ngm}^{-3}$. These levels appear typical of what is seen in spring to autumn.

Results for Exposures 3 and 4 were < 0.1 and 0.4 ngm^{-3} , respectively. Exposure 4 (sampled directly over the Buncefield site) is at the lower assessment threshold of the Air Quality 4th Daughter Directive. Target values in the Directive for B[a]P are based on annual average concentrations. However, concentrations between October and March are typically higher than summer levels. This concentration is above the typical quarter 4 levels found at the London site and Stoke Ferry, a rural location. These levels are broadly typical of some of the UK's industrial monitoring sites.



Figure 4.24 The FAAM Aircraft used for plume monitoring



Figure 4.25 Inside the FAAM

Images 4.24 and 4.25 © copyright British Aerospace 2006

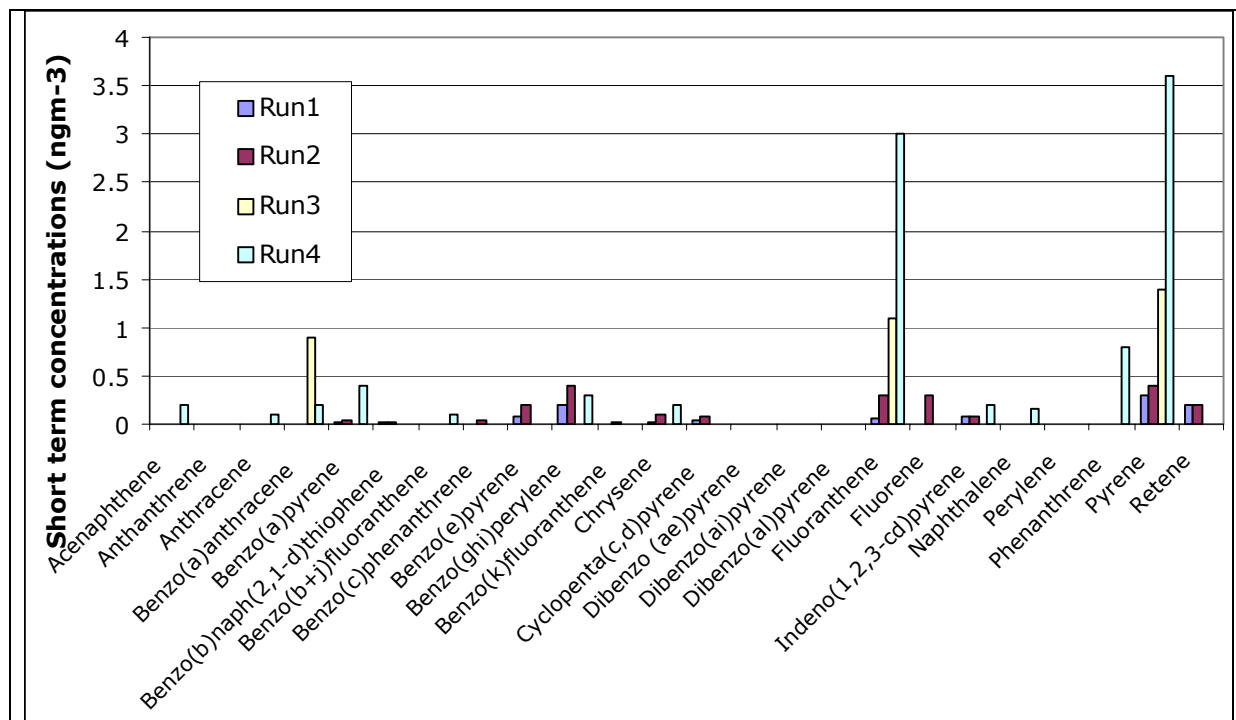


Figure 4.26 PAH measurements from the FAAM aircraft

Levels of pollutants in the plume were within normal concentrations seen at other monitoring sites. It is possible that this is the result of the high combustion temperatures associated with such a large-scale fire, or the high quality of the refined fuel being burnt.

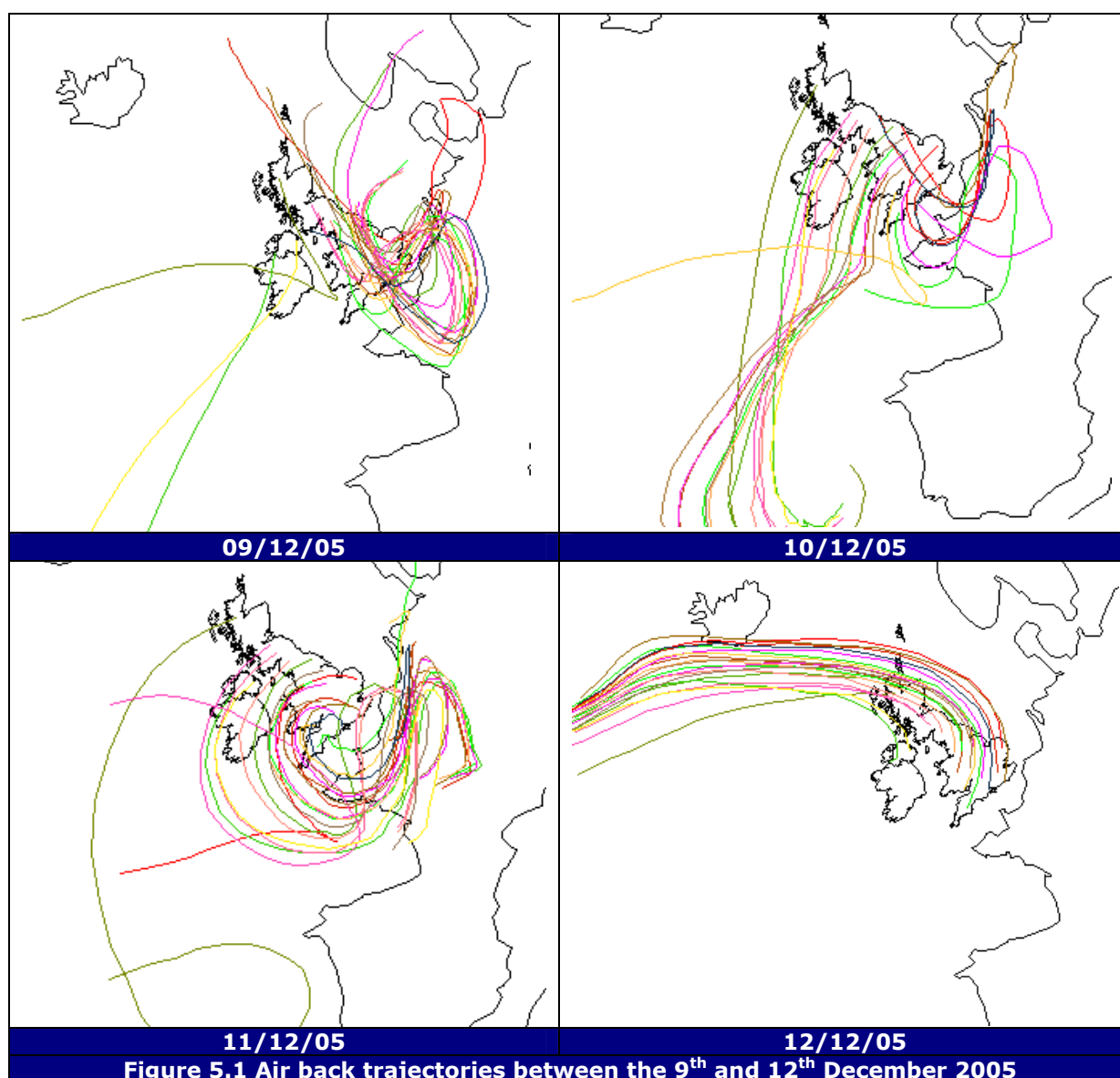
Overall, we see that a wide range of measurements, presented in this section, confirm that the Buncefield event did not appear to result in large ground-level air quality impacts over local, regional or national scales. Elevated pollution levels across a number of monitoring networks in Southern England were within normal ranges measured throughout the year.

The possibility of high concentrations of ground level pollution from the Buncefield explosion and fire cannot be totally ruled out; however, any such peaks were likely to have been localised and of a transient nature. Some of the observations highlighted in previous sections – specifically those for Horsham, Lewes Roadside and Marylebone Road – indicate the possible duration and extent of such events. However, it should be noted that none of these isolated instances can be definitively attributed to Buncefield.

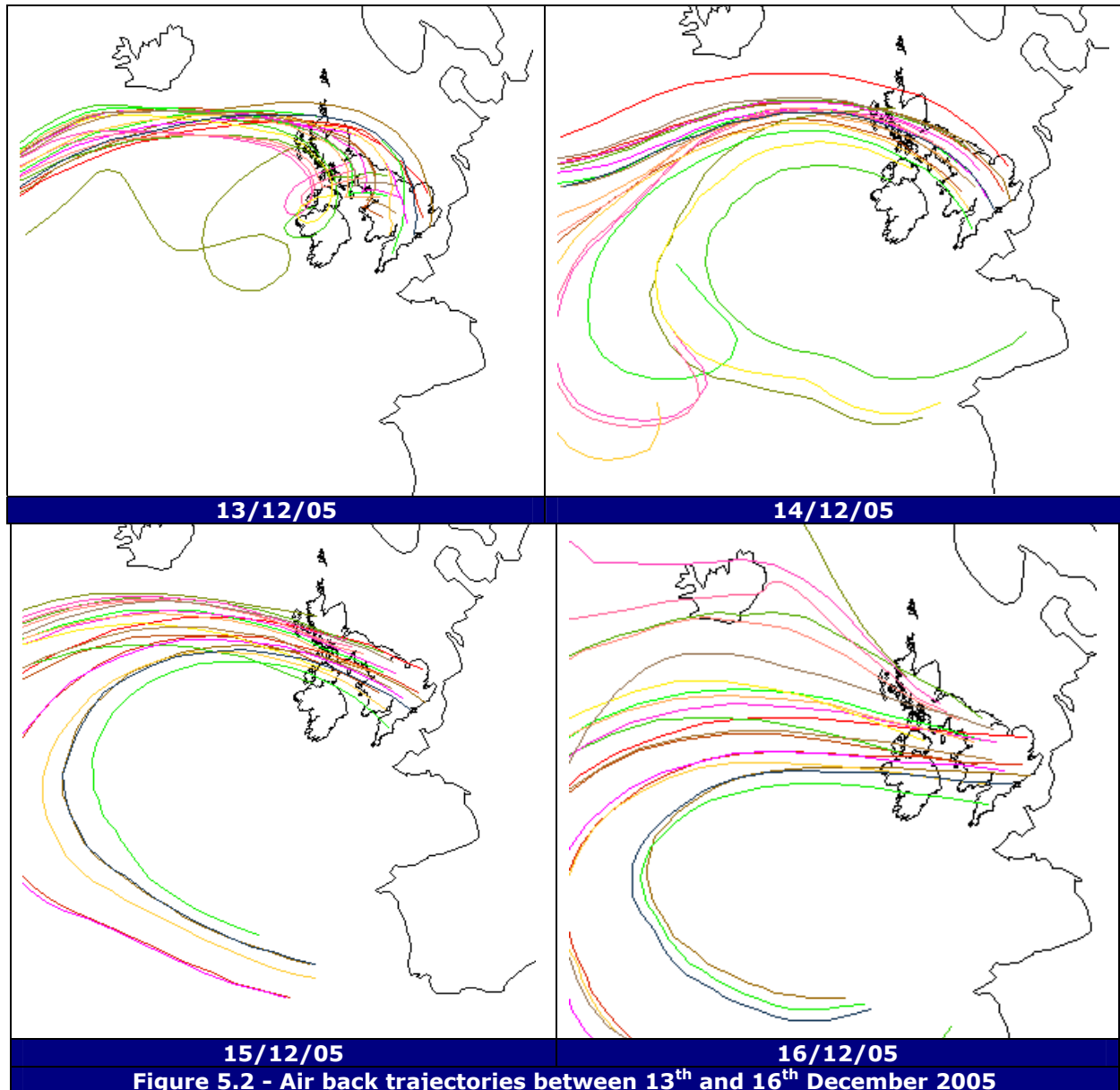
5 Analysis of Air Trajectories

Airmass Trajectories are simple linear representations of large-scale air movements in the atmosphere. Although they are relatively easy to understand and to visualise, they do not take into account the effects of turbulent mixing and therefore do not show the full range of air movements possible. Back-trajectories show how air masses may have been transported prior to reaching their destination, whereas forward-trajectories show the movement of air after leaving its origin.

To assist daily air quality forecasting in the UK, *1000 mB 96-hour Forecast Air Back-Trajectories* are produced and used on a daily basis for Netcen's Trajectory Ozone Model. This model uses output from the Met Office's numerical weather prediction models as its input, and predicts how air masses have been transported to the UK over the preceding 96 hours. The global version of the Met Office's numerical weather prediction model (the Unified Model) is used with a horizontal resolution of 40 km at mid-latitudes. The forecast back-trajectories provided were used during the Buncefield event to gain a fuller understanding of the possible plume movements, as well as understanding the amount of re-circulation over the UK. Airmass back trajectories at midday from the 9th to 16th of December are presented below in Figures 5.1 and 5.2.



The 96-hour back-trajectories show that the weather pattern changed on Monday 12th December. Up until Monday 12th, the pattern was characterised by re-circulation of air over southern England and northern France. This was due to the dominance of a high pressure system. Following the passage of a front during the morning of Monday 12th, back trajectory analysis suggests that air masses affecting the UK were originating over the Atlantic. Winds were from a northerly to north-easterly direction over the Hemel Hempstead area.



6 Met Office Plume Modelling

Using its well-established NAME dispersion model, the Met Office undertook systematic modelling of the large-scale plume from the Buncefield fires. This was carried out both during and after the event. The Met Office's atmospheric dispersion model NAME (Numerical Atmospheric dispersion Modelling Environment) has a wide range of applications including air quality forecasting, predicting the transport of airborne substances and identifying source locations. It is a Lagrangian model driven by either three-dimensional meteorology or single-site meteorological data (e.g. from observations), with turbulent dispersion simulated using random walk techniques¹.

In modelling the plume from the Buncefield oil depot fire, three-dimensional meteorological data from the mesoscale version of the Met Office's numerical weather prediction model (the Unified Model) were used with a horizontal resolution of approximately 12 km. There was (and still is) a large degree of uncertainty in the source release details and, consequently, a number of assumptions based on the available observations were adopted. These assumptions have been revised and refined following the event, taking into account all available estimates and observations. The modelling results presented in this report are based on our best estimates at this time of the worst-case scenario (100% of 105 million litres burnt) and are broadly similar to those issued during the event.

Due to the intense heat of the fire, the plume was highly buoyant and rose rapidly and vertically within the atmosphere. The large amount of vertical wind shear present on 11/12/05 enabled the height attained by the plume to be estimated by comparing NAME output with satellite imagery. This suggested that the plume reached a height of 3000 m above ground level on 11/12/05. Visual observations and modelling of the plume with NAME suggest that most of the plume remained trapped above the boundary layer (the lowest part of the atmosphere which is directly influenced by the ground) on Sunday 11th December.

Material entering the boundary layer will, in general, be mixed fairly rapidly within NAME. Hence the predicted boundary layer concentrations can be taken to be representative of predicted ground level concentrations. Boundary layer concentrations of PM₁₀ predicted over southeast England and into northern France on Sunday 11th December were low. On Monday 12th December, higher PM₁₀ boundary layer concentrations were predicted over the UK (to the south-west of the oil depot) and over the Channel and northern France. However, the monitoring networks across France did not record elevated levels during the incident.

Figure 6.1 presents hourly averaged fields of PM₁₀ concentrations over a height range between 0 and 4000 m above ground, at 12:00 pm on 11/12/05 and at 1:00 pm on 12/12/05. The results in Figure 6.1 are in good agreement with satellite imagery shown in Figure 2.2 and Figure 2.3. Predicted boundary layer PM₁₀ concentrations, which can be taken to be representative of predicted ground level concentrations, are presented in Appendix E.

A more detailed technical account of the Met Office modelling and research into the Buncefield oil depot event is presented in Appendix E, together with the results and analysis of NAME outputs. Please see Appendix H, also.

Taken together, the back trajectories presented in Section 5, together with the modelling results in this section (and Appendix E) shed considerable light on the monitoring results reviewed in Section 4.

Despite the very large quantities of pollutants emitted, particularly particulate matter (see Section 3), a wide range of air pollution monitoring undertaken before, during and after the event showed that UK ground-level concentrations of a wide range of pollutants remained low to moderate over local, regional and national scales. Although there was limited evidence of sporadic and episodic plume grounding on occasions, it appears that the high plume buoyancy and favourable meteorological conditions resulted in the overwhelming bulk of the pollution being trapped aloft, with minimal mixing to the ground. As a result, we have seen little evidence of widespread or significant air quality impacts at ground level due to the pollutants emitted from the Buncefield fires.

¹ Jones A.R., Thomson D.J., Hort M. and Devenish B., 'The U.K. Met Office's next-generation atmospheric dispersion model, NAME III', in *Air Pollution Modelling and its Application XVII*, Kluwer Academic Publishers, 2006.

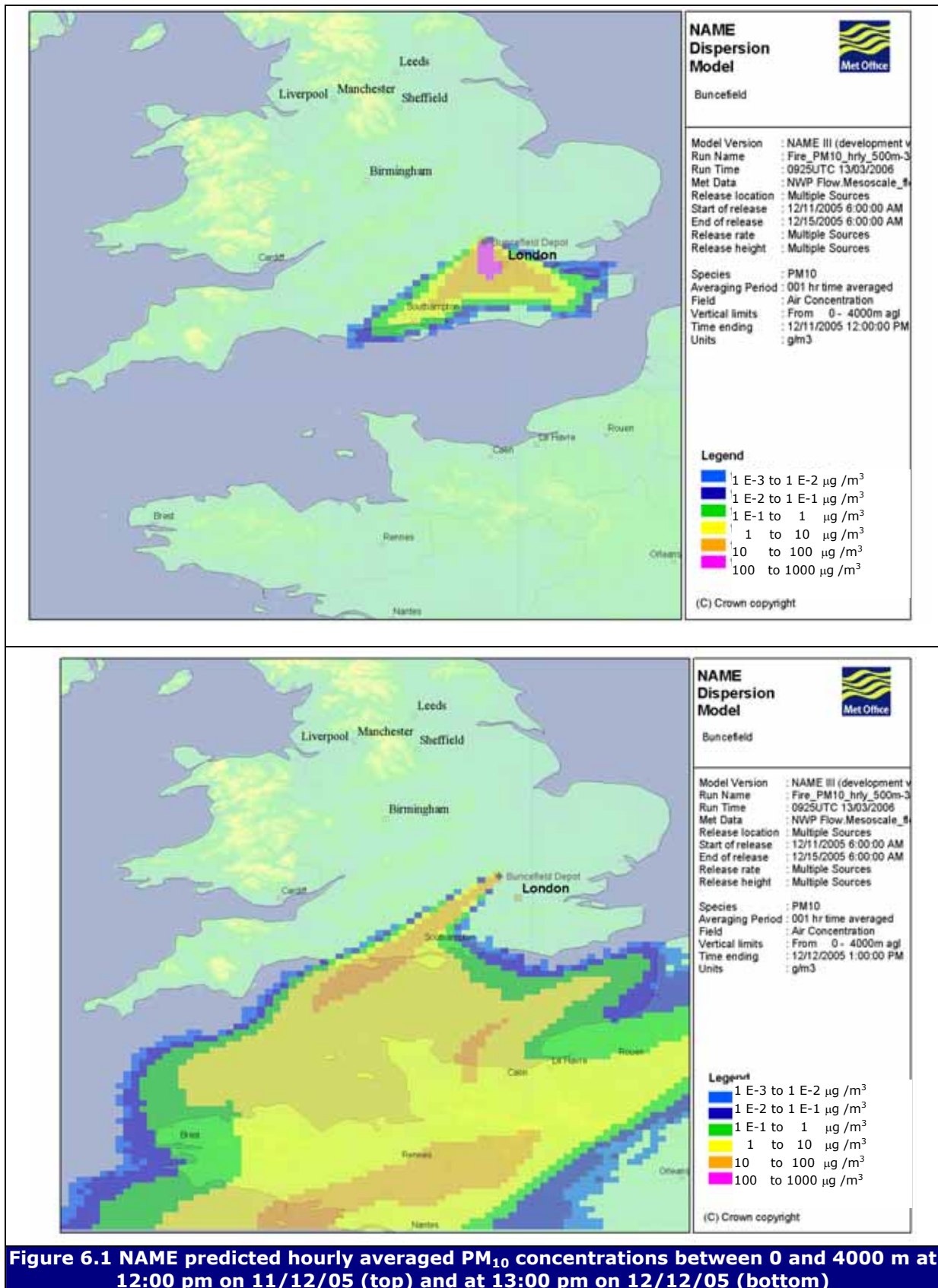


Figure 6.1 NAME predicted hourly averaged PM₁₀ concentrations between 0 and 4000 m at 12:00 pm on 11/12/05 (top) and at 13:00 pm on 12/12/05 (bottom)

7 Conclusions

On Sunday 11th December 2005, there was a major explosion at the Buncefield oil depot near Hemel Hempstead, north of London. Following the explosion, large stocks of petrol, aviation turbine fuel, diesel and gas oil at the depot remained on fire until Wednesday 14th December. Calculations based on the National Atmospheric Emissions Inventory indicate that large quantities of particles and other pollutants may have been emitted during this period.

Air quality monitoring undertaken on-site and involving several measurement networks across southern England showed no widespread increase in ground-level air pollution concentrations during this period. In particular, provisional levels of air pollution measured within the national Automatic Urban and Rural Network (AURN) did not – with a few noted exceptions which were demonstrably not related to the Buncefield event – exceed the 'Low' air pollution category as defined for ambient air quality reporting in the UK.

In general, local monitoring networks across the southeast of England also measured low levels of air pollution throughout the event. Two stations in the Sussex Air Network - Horsham Roadside and Lewes Roadside – showed excursions into the 'Moderate' air quality index band (consistent with mild health effects in sensitive individuals). In the case of Horsham roadside site, it appears that the elevated levels might not be wholly traffic pollution-related; subsequent modelling suggests that the elevated levels here may have been partly due to plume grounding. Even so, measured concentrations remained well within normal ranges.

Not surprisingly, the highest pollutant concentrations related to the event were recorded during targeted local monitoring in and around the depot itself. However, even these levels were not significant when compared to typical PM₁₀ and VOC concentrations that might be expected during UK-wide pollution episodes or due to localised events such as bonfires, idling vehicles or construction work.

Some elevated hydrocarbon levels were measured inside the depot; these were probably due to evaporative emissions from unburnt fuel rather than from direct plume impacts. Hydrocarbon concentrations at Marylebone Road were not unusually high. There were, however, some unusual observations – specifically, elevated ratios of some species with respect to benzene – at this roadside location; these cannot be simply or readily explained.

The Met Office undertook modelling of the large-scale plume from the fires. This showed that most of the plume remained trapped above the boundary layer (the part of the atmosphere interacting directly with the ground) on Sunday 11th December. Predicted boundary layer concentrations of PM₁₀ over southeast England and into northern France, which can be taken to be representative of ground level concentrations, on this day were low. On Monday 12th December, higher PM₁₀ boundary layer concentrations were predicted over the UK (to the south-west of the oil depot) and over the Channel and northern France. However, the monitoring networks across France did not record elevated levels during this day or the incident as a whole.

A fully instrumented aircraft made extensive measurements of the position and chemical composition of the smoke plume on the 13th December. These observations were broadly consistent with model predictions and showed that the plume consisted mainly of black carbon - soot.

A wide range of measurements confirm that the Buncefield fires did not appear to result in large ground-level air quality impacts over local, regional or national scales. Elevated pollution levels across the monitoring networks were within normal ranges measured on other occasions. Whilst it cannot be ruled out that the plume may have grounded in areas not currently covered by the monitoring networks, any resulting peaks were likely to have been localised and of a transient nature.

Why did such a major explosion and fires not result in greater air pollution impacts? Both the monitoring and modelling suggest that the high buoyancy of the plume resulted in the bulk of the emissions being trapped aloft, above cold, stable layers of the lower atmosphere. Because of this, the emitted pollutants came only sporadically into contact with the ground.

It is likely that corresponding ground level air pollution impacts would, however, have been far higher had this event occurred in the summer months, when the lower atmosphere is more turbulent and well-mixed.

8 Acknowledgements

This report represents the work of many scientists in different organisations. Advice and contributions - both during the Buncefield incident and in preparing this report - from the Atmospheric Dispersion Group, the Observations Based Research group and EMARC, Met Office are gratefully acknowledged.

We similarly acknowledge the comments and advice provided by Health Protection Agency following the incident.

Special thanks are owed to Hertfordshire Fire and Rescue Service, the Hertfordshire Constabulary and Chiltern Air Support Unit for the frontispiece image, Figures 3.1 and 3.2.

Appendix A - Buncefield Dioxin, Furan and PCB Results (letter report to Defra)

*Letter report from Peter Coleman (Netcen) to Martin
Meadows (Defra)*

Analysis of Buncefield Dioxin, Furan and PCB Results

You kindly provided us with two filters taken by the FAAM BAE146-301 aircraft from the Buncefield plume and a blank filter. These have now been analysed for polychlorinated-*p*-dioxins, polychlorinated dibenzofurans (dioxins) and polychlorinated biphenyls (PCBs). I gather that colleagues have already reported the results of the PAH analysis.

Our understanding is that one filter; 'B149 Exposure 1' had sampled 5.381 m³ of air; another 'B149 Exposure 2' had sampled 3.233 m³, while the third sample was a blank kindly provided to us. Visual inspection of the filters on receipt showed very little colouration at all. It is not clear how much of the air sampled through the filters was from within the Buncefield smoke plume.

50% of each filter was made available for dioxin and PCB analysis given the time pressures on the work. It would have added at least a further 24 hours to the time to report data from analysis of the whole filter.

Following the filter division a known quantity of a selection of ¹³C labelled dioxins, furans and PCBs were added to each filter. They were then extracted with toluene for 14 hours. The extract was then reduced to a smaller volume and treated to separate the dioxins, furans and PCBs from the other species present in the extract. The dioxin and furan samples are then passed through a gas chromatograph to separate the isomers of interest from each other than quantified by isotope dilution using a high-resolution mass spectrometer. The PCB samples were analysed in a similar manner except detection was by a quadrupole mass spectrometry. Both analysis approaches are UKAS accredited.

The PCB analysis results show that no PCBs were detected in any of the three samples. The analytical results are given in Table 1 and the results calculated as concentrations in Table 2.

The dioxin and furan results show positive responses for two congeners. 1,2,3,4,7,8, hexachlorodibenzo-*p*-dioxin is found in the Exposure 2 sample. The amount measured is some 27% greater than the detection limit. No detectable amount of this congener is found in either the blank or the other air sample. 1,2,3,6,7,8, hexachlorodibenzo-*p*-dioxin is found in the blank sample. The amount measured is some 53% greater than the detection limit. No detectable amount of this congener is found in either of the samples that had sampled air. The results are shown in Table 3 as reported and Table 4 as concentrations without the blank values subtracted.

The sum of the dioxin and furans as World Health Organisation Toxic equivalents is given in Table 5. Two values are reported; one which excluded the congeners which were not detected – this is the minimum that was present. The second includes the non-detected congeners as if they were present at the detection limit. This is the upper bound of what could have been present. The blank values have not been subtracted in calculating the concentrations.

The congener group totals - the sum of all the dioxins with the same number of chlorine atoms - are at measurable quantities in all three samples. When the blank results are subtracted from those of the two smoke sampling filters all of the congener group totals from Exposure 1 are negative and two of those from Exposure 2.

Given that these filters presumably received no treatment before sampling and that the volumes of smoke sampled were not high, it is possible that these results reflect the variability in the blank levels in the filters and are not representative of concentrations in the smoke which must therefore be low.

Results for the urban sites in London, Manchester and Middlesbrough for the past few years for the October to December period are shown in Tables 6 to 8 below. The levels measured over the much higher air volumes used in the network are all detected and are much lower than the detection limits shown in the present samples.

That 1,2,3,4,7,8, hexachlorodibenzo-*p*-dioxin is not generally found at particularly high concentrations at these urban sites; this suggests that its presence in Exposure 2 is an analytical artefact.

I have tried to calculate the inhalation exposure that would result from this concentration of PCDD/Fs and PCBs. To do this I have needed to use a number of assumptions:

- That the concentration on the filters is representative of the concentration in the plume
- That the dioxins, furans and PCBs were present at concentrations marginally below the detection limit
- 100% of the inhaled quantity is adsorbed.
- That 100% of the TDI is available for inhalation whereas in practice a significant fraction is used in the dioxin and PCB content of foods.
- Other assumptions as shown in Table A.9 concerning inhalation rate, and bodyweight for a number of population groups.

These assumptions have been used to calculate the fraction of the Committee on Toxicity of Chemicals in Food, Consumer Products and the Environment (COT) recommended Tolerable Daily Intake (TDI) that this upper bound concentration estimate would represent. The results are shown in Table 9. Despite the very conservative assumptions about the concentrations, there are only slight exceedences of the TDI for children. This is moderately reassuring, given that the TDI is based on the total body burden. Unless exposure at these concentrations was prolonged, it would have only a slight impact on body burdens.

Table 1 PCB Analytical Results

Sample Number	HE1576	HE1577	HE1578	QC	LOD
Sample Ref.	B149 Exposure 1	B149 Exposure 2	B149 Blank		
Compound	Total ng	Total ng	Total ng	Total ng	Total ng
PCB 18*	< 0.6	< 0.6	< 0.6	110	0.6
PCB-31/ 28	< 0.9	< 0.9	< 0.9	210	0.9
PCB-51*	< 0.09	< 0.09	< 0.09	100	0.09
PCB-52	< 0.9	< 0.9	< 0.9	100	0.9
PCB-49*	< 0.3	< 0.3	< 0.3	110	0.3
PCB-47*	< 0.2	< 0.2	< 0.2	100	0.2
PCB-101	< 0.9	< 0.9	< 0.9	110	0.9
PCB-99*	< 0.1	< 0.1	< 0.1	110	0.1
PCB-81*	< 0.08	< 0.08	< 0.08	110	0.08
PCB-77	< 0.3	< 0.3	< 0.3	110	0.3
PCB-123*	< 0.07	< 0.07	< 0.07	110	0.07
PCB-118	< 0.3	< 0.3	< 0.3	100	0.3
PCB-114*	< 0.08	< 0.08	< 0.08	100	0.08
PCB-153	< 2.0	< 2.0	< 2.0	100	2.0
PCB-105*	< 0.2	< 0.2	< 0.2	110	0.2
PCB-138	< 0.6	< 0.6	< 0.6	100	0.6
PCB-126	< 0.1	< 0.1	< 0.1	100	0.1
PCB-128*	< 0.1	< 0.1	< 0.1	110	0.1
PCB-167*	< 0.05	< 0.05	< 0.05	110	0.05
PCB-156*	< 0.1	< 0.1	< 0.1	110	0.1
PCB-157*	< 0.01	< 0.01	< 0.01	100	0.01
PCB-180	< 0.8	< 0.8	< 0.8	100	0.8
PCB-169	< 0.03	< 0.03	< 0.03	120	0.03
PCB-170*	< 0.3	< 0.3	< 0.3	110	0.3
PCB-189*	< 0.06	< 0.06	< 0.06	110	0.06
Internal Std Recovery					
13C-PCB-28	85	58	94	95	
13C-PCB-52	81	56	88	93	
13C-PCB-101	83	58	91	93	
13C-PCB-118	89	61	96	95	
13C-PCB-153	87	61	94	94	
13C-PCB-138	89	63	95	93	
13C-PCB-180	93	62	100	97	
Mean Analytical recovery	87	60	94	94	

Table 2 PCB Concentrations in the filters (pg/m³)

PCB Number	B149 Exposure 1	B149 Exposure 2
	pg/m ³	pg/m ³
18	<110	<190
31/28	<170	<280
51	<17	<28
52	<170	<280
49	<56	<93
47	<37	<62
101	<170	<280
99	<19	<31
81	<15	<25
77	<56	<93
123	<13	<22
118	<56	<93
114	<15	<25
153	<370	<620
105	<37	<62
138	<110	<190
126	<19	<31
128	<19	<31
167	<9	<15
156	<19	<31
157	<2	<3
180	<150	<250
169	<6	<9
170	<60	<93
189	<11	<19
WHO-TEQ nd=0	0	0
WHO-TEQ nd=dl	<2.0	<3.3

Table 3 Dioxin and Furan Analytical Results

Our Reference.	HE1576	HE1577	HE1578
Your Reference	B149 Exposure 1	B149 Exposure 2	B149 Blank
Congener	ng	ng	ng
2378 TCDD	<0.003	<0.003	<0.003
12378 PeCDD	<0.003	<0.003	<0.003
123478 HxCDD	<0.006	0.0076	<0.006
123678HxCDD	<0.003	<0.003	0.0046
123789HxCDD	<0.006	<0.006	<0.006
1234678HpCDD	<0.002	<0.002	<0.002
OCDD	<0.01	<0.01	<0.01
2378 TCDF	<0.002	<0.002	<0.002
12378 PeCDF	<0.003	<0.003	<0.003
23478 PeCDF	<0.003	<0.003	<0.003
123478 HxCDF	<0.004	<0.004	<0.004
123678 HxCDF	<0.004	<0.004	<0.004
123789 HxCDF	<0.004	<0.004	<0.004
234678 HxCDF	<0.004	<0.004	<0.004
1234678 HpCDF	<0.006	<0.006	<0.006
1234789 HpCDF	<0.004	<0.004	<0.004
OCDF	<0.005	<0.005	<0.005
Homologue Group Totals			
Tetra Dioxins	0.067	0.12	0.089
Penta Dioxins	0.13	0.32	0.21
Hexa Dioxins	0.14	0.2	0.16
Hepta Dioxins	0.013	0.027	0.025
Tetra Furans	0.077	0.11	0.1
Penta Furans	0.043	0.0066	0.061
Hexa Furans	0.066	0.13	0.11
Hepta Furans	0.027	0.039	0.041
Mean Analytical Standard Recovery	83%	84%	78%

Table 4 Measured Concentrations of Polychlorinated dibenzo-*p*-dioxins and Polychlorinated dibenzofurans in the Sampled Air

Congener	Concentration in Sample B149 Exposure 1	Concentration in Sample B149 Exposure 2
	fg/m ³	fg/m ³
2378 TCDD	<560	<930
12378 PeCDD	<560	<930
123478 HxCDD	<1120	2350
123678HxCDD	<560	<930
123789HxCDD	<1120	<1860
1234678HpCDD	<370	<620
OCDD	<1860	<3090
2378 TCDF	<370	<620
12378 PeCDF	<560	<930
23478 PeCDF	<560	<930
123478 HxCDF	<740	<1240
123678 HxCDF	<740	<1240
123789 HxCDF	<740	<1240
234678 HxCDF	<740	<1240
1234678 HpCDF	<1120	<1860
1234789 HpCDF	<740	<1240
OCDF	<930	<1550
ITEQ nd=0 [†]	0	240
ITEQ nd=dl [†]	1800	3000
WHO-TEQ nd=0 [†]	0	240
WHO-TEQ nd=dl [†]	2100	3500
Homologue Group Totals		
Tetra dioxins	12500	37100
Penta dioxins	24200	99000
Hexa dioxins	26000	61900
Hepta dioxins	2400	8400
Tetra furans	14300	34000
Penta furans	8000	2000
Hexa furans	12300	40200
Hepta furans	5000	12100

† this value is the toxic equivalent of the dioxins and furans only

Table 5 Concentrations of PCBs, dioxins and furans expressed as total World Health Organisation Toxic Equivalents

	Concentration B149 Exposure 1 fg/m ³	Concentration B149 Exposure 2 fg/m ³
WHO-TEQ nd=0	0	240
WHO-TEQ nd=dl	4000	6800

Table 6 Measured Fourth Quarter Dioxin Concentrations at London (fg/m³)

End Date	Q4 1999	Q4 2000	Q4 2001	Q4 2002	Q4 2003
2378 TCDD	2	2	1	2	2
12378 PeCDD	9	9	7	5	5
123478 HxCDD	22	9	8	6	5
123678 HxCDD	30	25	19	14	12
123789 HxCDD	20	0	0	0	0
1234678 HpCDD	270	210	180	160	120
OCDD	800	500	530	580	330
2378 TCDF	11	10	29	13	10
12378 PeCDF	28	19	5	10	7
23478 PeCDF	14	12	8	11	10
123478 HxCDF	33	22	16	34	11
123678 HxCDF	19	16	14	12	11
123789 HxCDF	2	2	16	4	10
234678 HxCDF	22	18	5	1	1
1234678 HpCDF	79	56	53	61	38
1234789 HpCDF	12	11	7	7	5
OCDF	77	59	46	59	30
total ITEQ	50	36	28	36	21
total WHO-TEQ	54	40	31	38	23

Table 7 Measured Fourth Quarter Dioxin Concentrations at Manchester (fg/m³)

Sampling Period		Q4 1999	Q4 2000	Q4 2001	Q4 2002	Q4 2003
2378 TCDD		2	4	1	5	2
12378 PeCDD		10	24	11	19	13
123478 HxCDD		12	25	10	22	13
123678 HxCDD		31	56	24	45	26
123789 HxCDD		26	42	0	0	0
1234678 HpCDD		280	420	180	340	200
OCDD		840	1200	480	750	540
2378 TCDF		20	37	74	98	41
12378 PeCDF		33	85	20	120	31
23478 PeCDF		23	56	25	100	39
123478 HxCDF		40	100	44	190	55
123678 HxCDF		24	80	41	160	52
123789 HxCDF		3	26	50	40	58
234678 HxCDF		37	96	5	12	4
1234678 HpCDF		120	270	150	550	180
1234789 HpCDF		16	44	19	73	22
OCDF		75	200	120	330	110
total ITEQ		61	145	63	218	78
total WHO-TEQ		66	156	68	226	84

Table 8 Measured Fourth Quarter Dioxin Concentrations at Middlesbrough (fg/m³)

Sampling Period	Q4 1999	Q4 2000	Q4 2001	Q4 2002	Q4 2003
2378 TCDD	1	3	1	6	2
12378 PeCDD	9	17	9	15	11
123478 HxCDD	11	16	9	15	8
123678 HxCDD	25	43	17	39	20
123789 HxCDD	23	30	0	0	
1234678 HpCDD	210	340	180	310	150
OCDD	550	950	500	820	390
2378 TCDF	9	23	42	25	30
12378 PeCDF	34	49	11	34	20
23478 PeCDF	16	30	12	43	22
123478 HxCDF	33	51	23	64	35
123678 HxCDF	20	35	17	42	26
123789 HxCDF	0	10	20	10	34
234678 HxCDF	28	41	5	3	2
1234678 HpCDF	110	130	58	190	100
1234789 HpCDF	15	22	11	26	15
OCDF	93	110	49	130	72
total ITEQ	52	80	34	86	50
total WHO TEQ	56	87	38	93	55

Table 9 Comparison of Concentrations with COT Tolerable Daily Intake of 2 pg per kg bodyweight per day

Parameter	Units	Infant	Child 1-6	Child 6-11	Child 11-16	Adult	Farmer
Bodyweight	kg	8.5	15	32.5	52.5	70.1	70.1
Inhalation Rate (IR) indoor	m3/hr	0.23	0.4	0.4	0.64	0.62	0.62
Inhalation Rate (IR) outdoor	m3/hr	0.26	0.45	0.45	0.74	0.7	0.7
Exposure Time (ET) indoor	hr/day	23	20	20	20	21	14
Exposure Time (ET) outdoor	hr/day	1	4	4	4	3	10
ABS _{INH}		1	1	1	1	1	1
Inhalation volume indoor	m3/day	5.29	8	8	12.8	13.02	8.68
Inhalation volume outdoor	m3/day	0.26	1.8	1.8	2.96	2.1	7
Total inhalation volume	m3/day	5.55	9.8	9.8	15.76	15.12	15.68
Specific inhalation volume	m3/(kg day)	0.653	0.653	0.302	0.300	0.216	0.224
Exposure 1 exposure	pg/kg/day	2.64	2.64	1.22	1.21	0.87	0.90
Exposure 2 exposure	pg/kg/day	4.42	4.42	2.04	2.03	1.46	1.51
Fraction of COT TDI Exposure 1	%	132	132	61	61	44	45
Fraction of COT TDI Exposure 2	%	221	221	102	102	73	76

Appendix B – PM₁₀ /NO₂ ratios for Automatic Monitoring Sites

PM₁₀/NO₂ concentration ratios for selected AURN monitoring sites are graphed here. These ratios may be used to identify whether a peak is due to an unusual event or just an increase in pollution from a local source. For a roadside site, it would be expected that an increase in PM₁₀ concentrations would be proportional to corresponding increases to NO₂ concentrations. If the PM₁₀/NO₂ ratio increases substantially, it may be concluded that the PM₁₀ source is different to the NO₂ source. These ratios have been used to try to identify the origin of recorded PM₁₀ peaks.

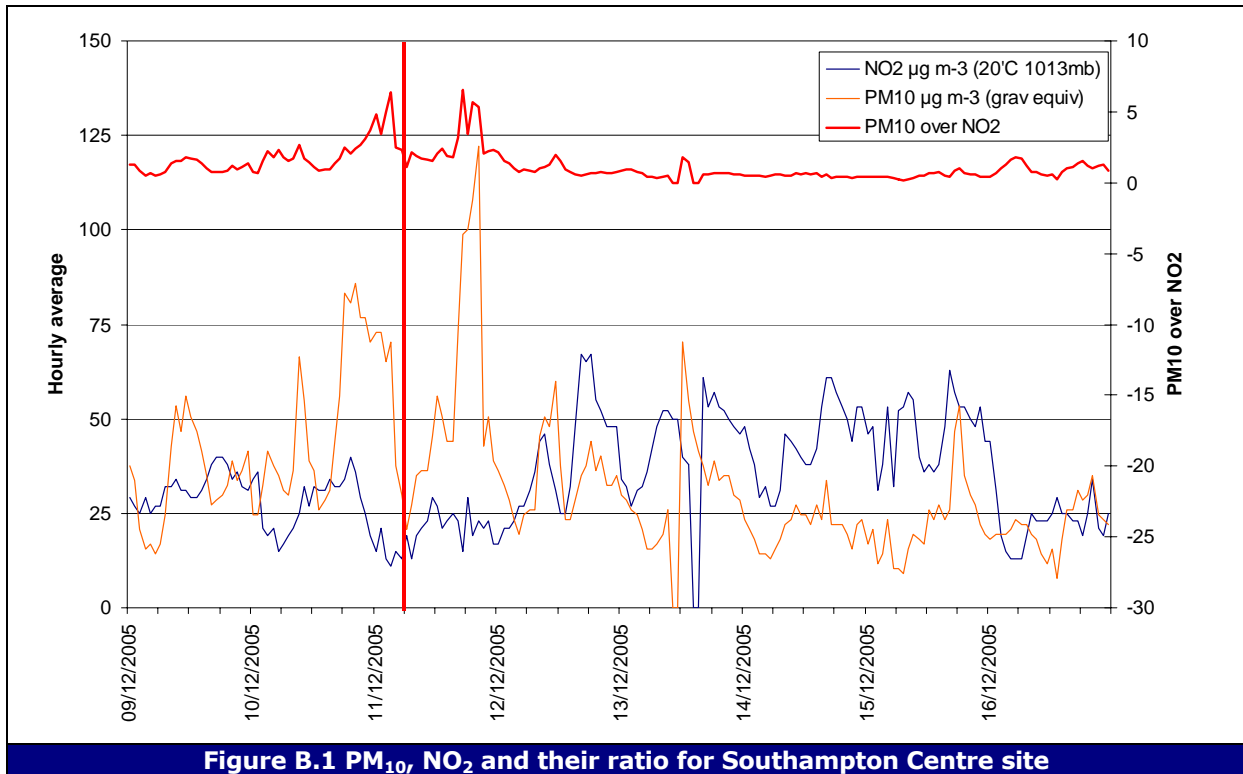


Figure B.1 PM₁₀, NO₂ and their ratio for Southampton Centre site

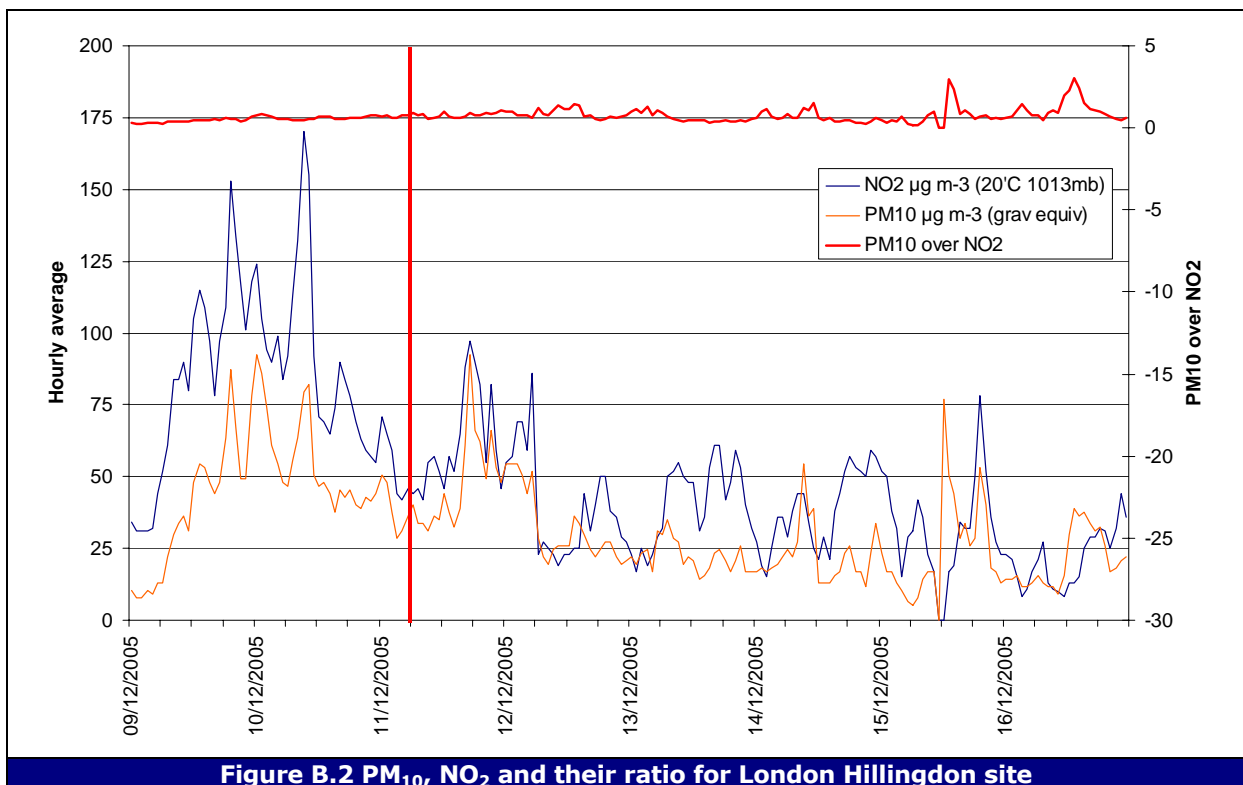


Figure B.2 PM₁₀, NO₂ and their ratio for London Hillingdon site

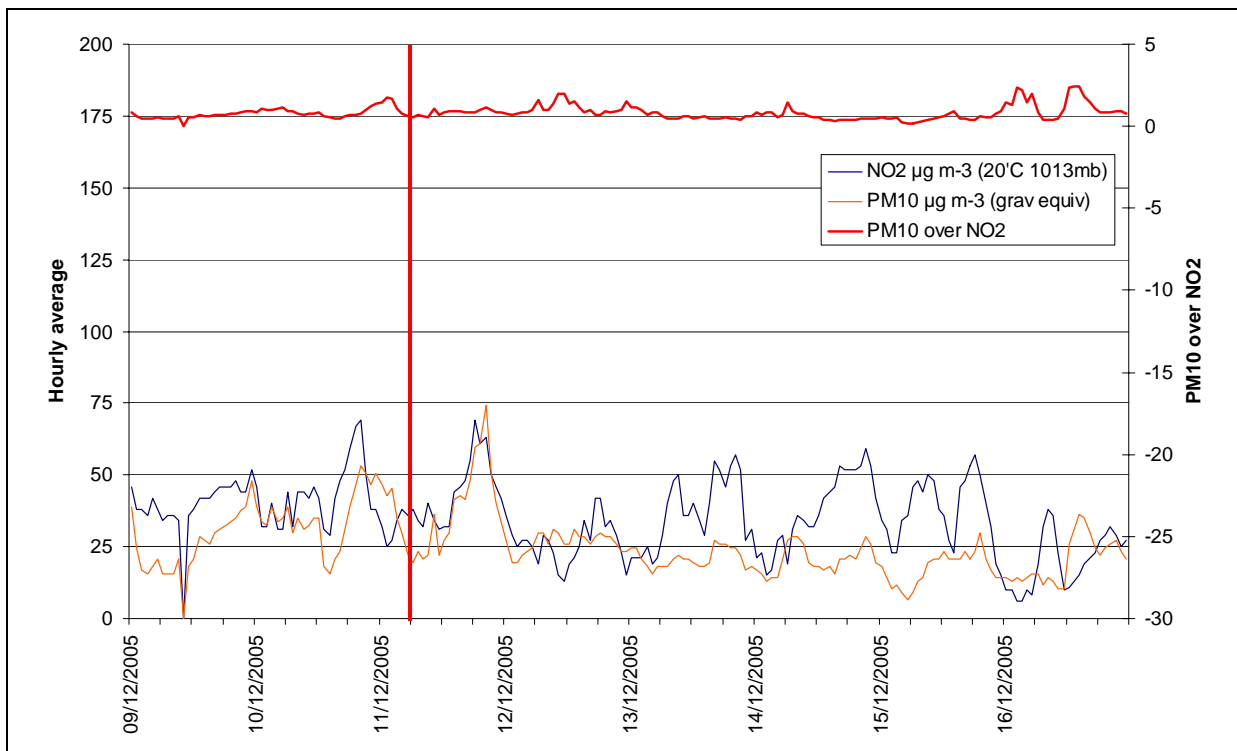


Figure B.3 PM₁₀, NO₂ and their ratio for Reading New Town site

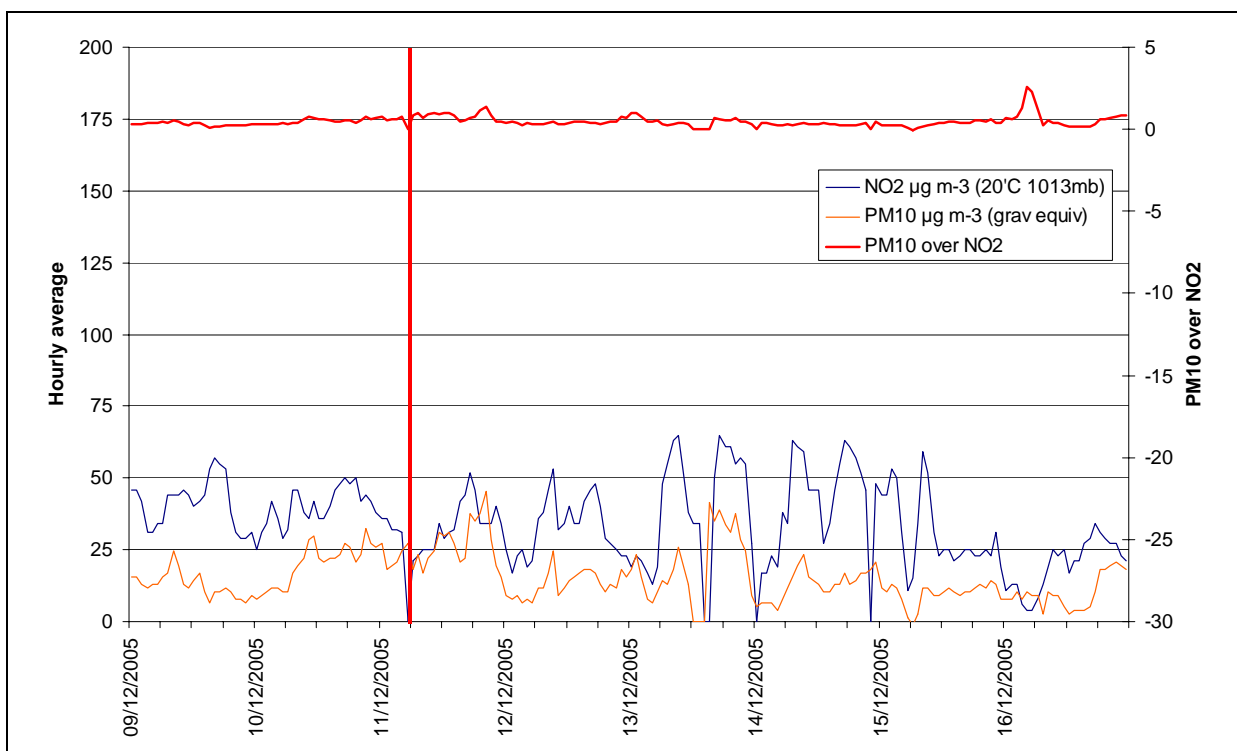
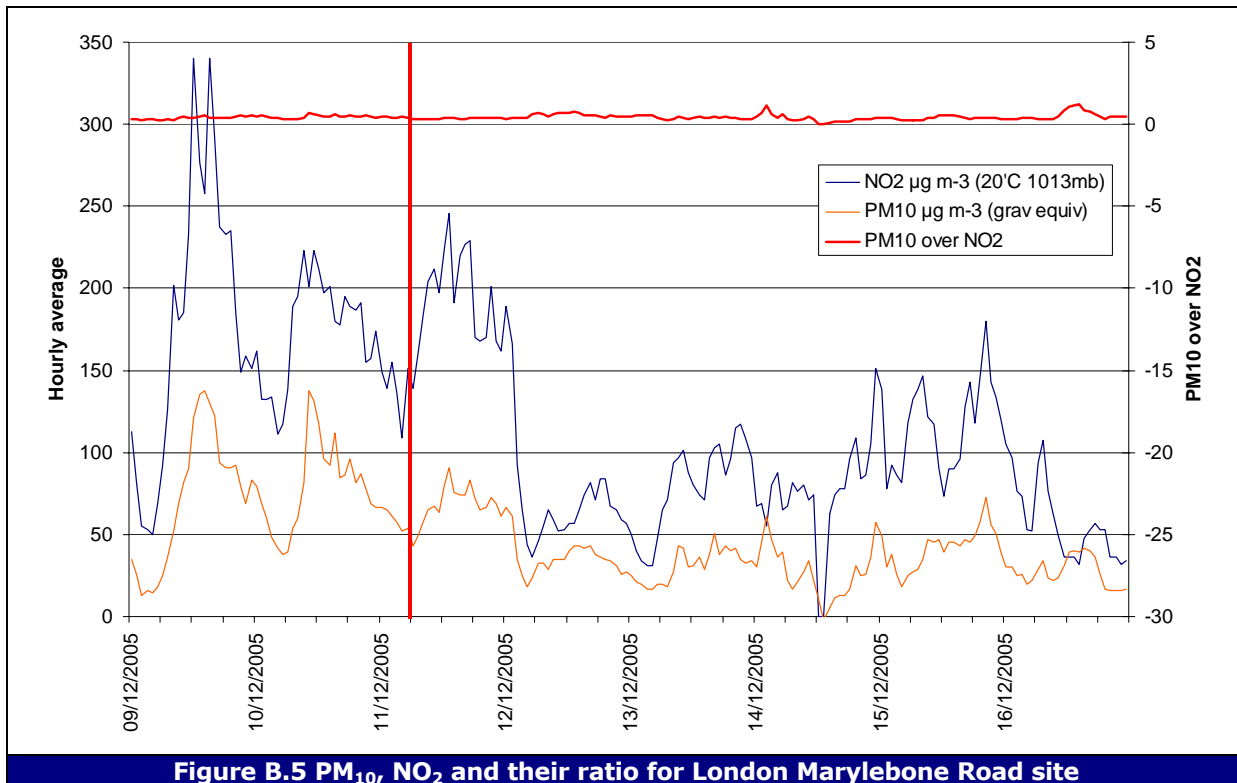


Figure B.4 PM₁₀, NO₂ and their ratio for Plymouth Centre site



Appendix C – UK Air Pollution Bandings and Index and the Impact on the Health of People who are Sensitive to Air Pollution

Old Banding	Index	Ozone 8-hourly/ Hourly Mean		Nitrogen Dioxide Hourly Mean		Sulphur Dioxide 15-Minute Mean		Carbon Monoxide 8-Hour Mean		PM ₁₀ Particles 24-Hour Mean µg m ⁻³	
		µgm ⁻³	ppb	µgm ⁻³	ppb	µgm ⁻³	ppb	mgm ⁻³	ppm	TEOM	(Grav. Equiv.)
LOW											
	1	0-32	0-16	0-95	0-49	0-88	0-32	0-3.8	0.0-3.2	0-16	0-21
	2	33-66	17-32	96-190	50-99	89-176	33-66	3.9-7.6	3.3-6.6	17-32	22-42
	3	67-99	33-49	191-286	100-149	177-265	67-99	7.7-11.5	6.7-9.9	33-49	43-64
MODERATE											
	4	100-126	50-62	287-381	150-199	266-354	100-132	11.6-13.4	10.0-11.5	50-57	65-74
	5	127-152	63-76	382-477	200-249	355-442	133-166	13.5-15.4	11.6-13.2	58-66	75-86
	6	153-179	77-89	478-572	250-299	443-531	167-199	15.5-17.3	13.3-14.9	67-74	87-96
HIGH											
	7	180-239	90-119	573-635	300-332	532-708	200-266	17.4-19.2	15.0-16.5	75-82	97-107
	8	240-299	120-149	636-700	333-366	709-886	267-332	19.3-21.2	16.6-18.2	83-91	108-118
	9	300-359	150-179	701-763	367-399	887-1063	333-399	21.3-23.1	18.3-19.9	92-99	119-129
VERY HIGH											
	10	≥ 360 µgm ⁻³	≥ 180 ppb	≥ 764 µgm ⁻³	≥ 400 ppb	≥1064 µgm ⁻³	≥ 400 ppb	≥ 23.2 mgm ⁻³	≥ 20 ppm	≥ 100	≥ 130

Old Banding	New Index	Health Descriptor
LOW		
	1	Effects are unlikely to be noticed even by individuals who know they are sensitive to air pollutants
	2	
	3	
MODERATE		
	4	Mild effects. Unlikely to require action. May be noticed amongst sensitive individuals
	5	
	6	
HIGH		
	7	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.
	8	
	9	
VERY HIGH		
	10	The effects on sensitive individuals described for "HIGH" levels of pollution may worsen.

Appendix D – Particulate Matter (PM₁₀) data across air quality monitoring networks in Northern France

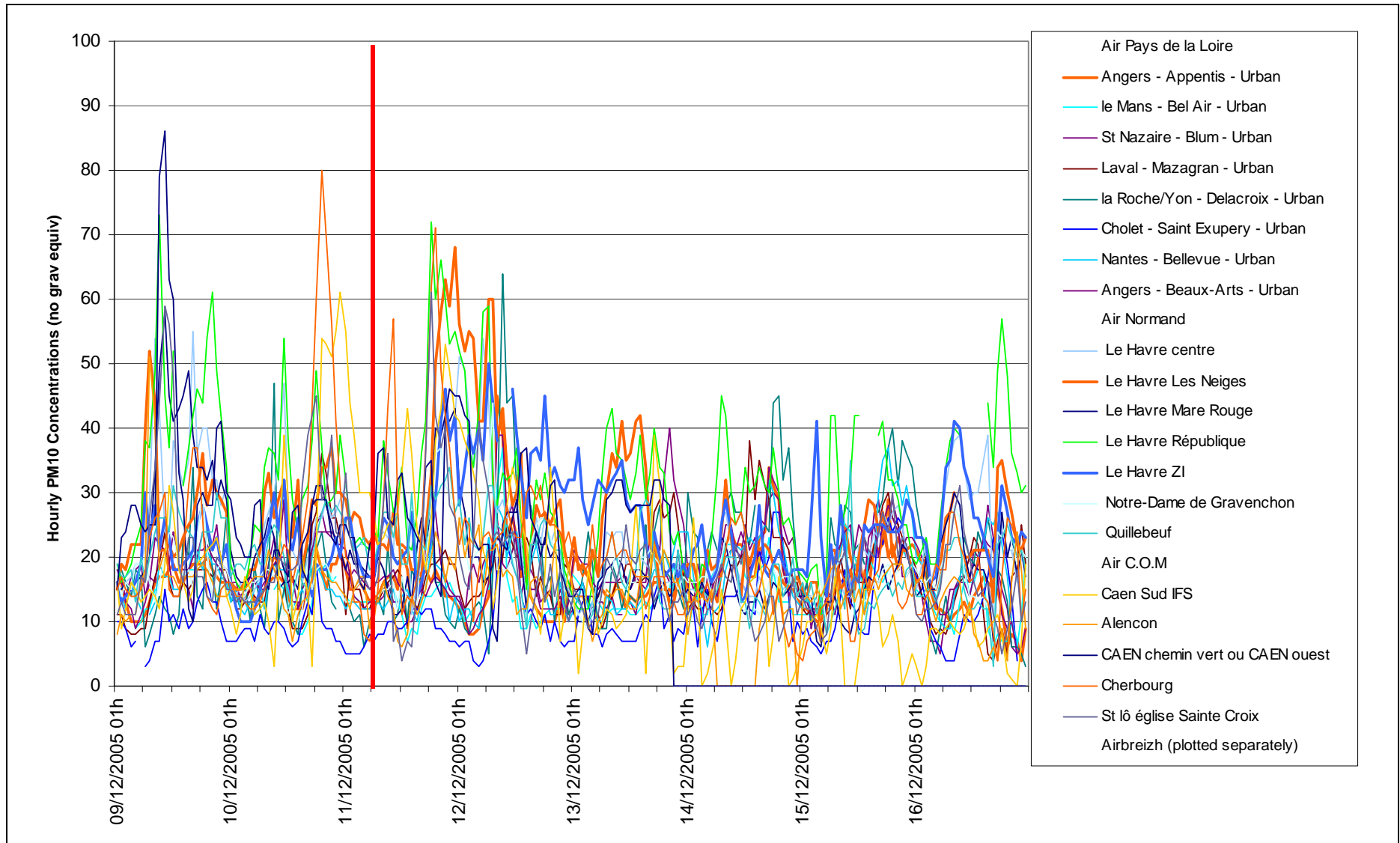
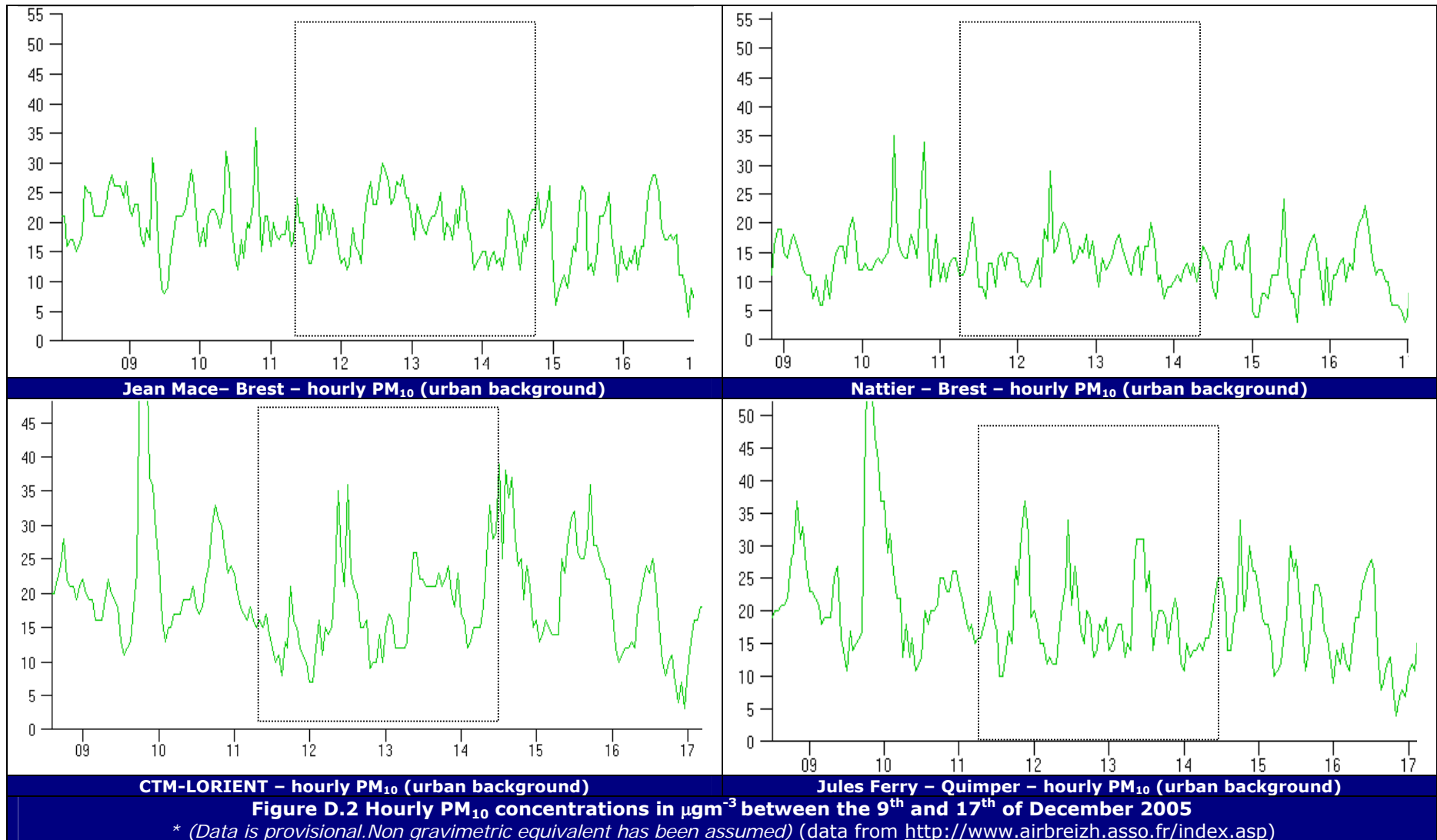


Figure D.1 Hourly PM₁₀ concentrations in μgm^{-3} across selected networks in northern France
(Data is provisional. Non gravimetric equivalent has been assumed)



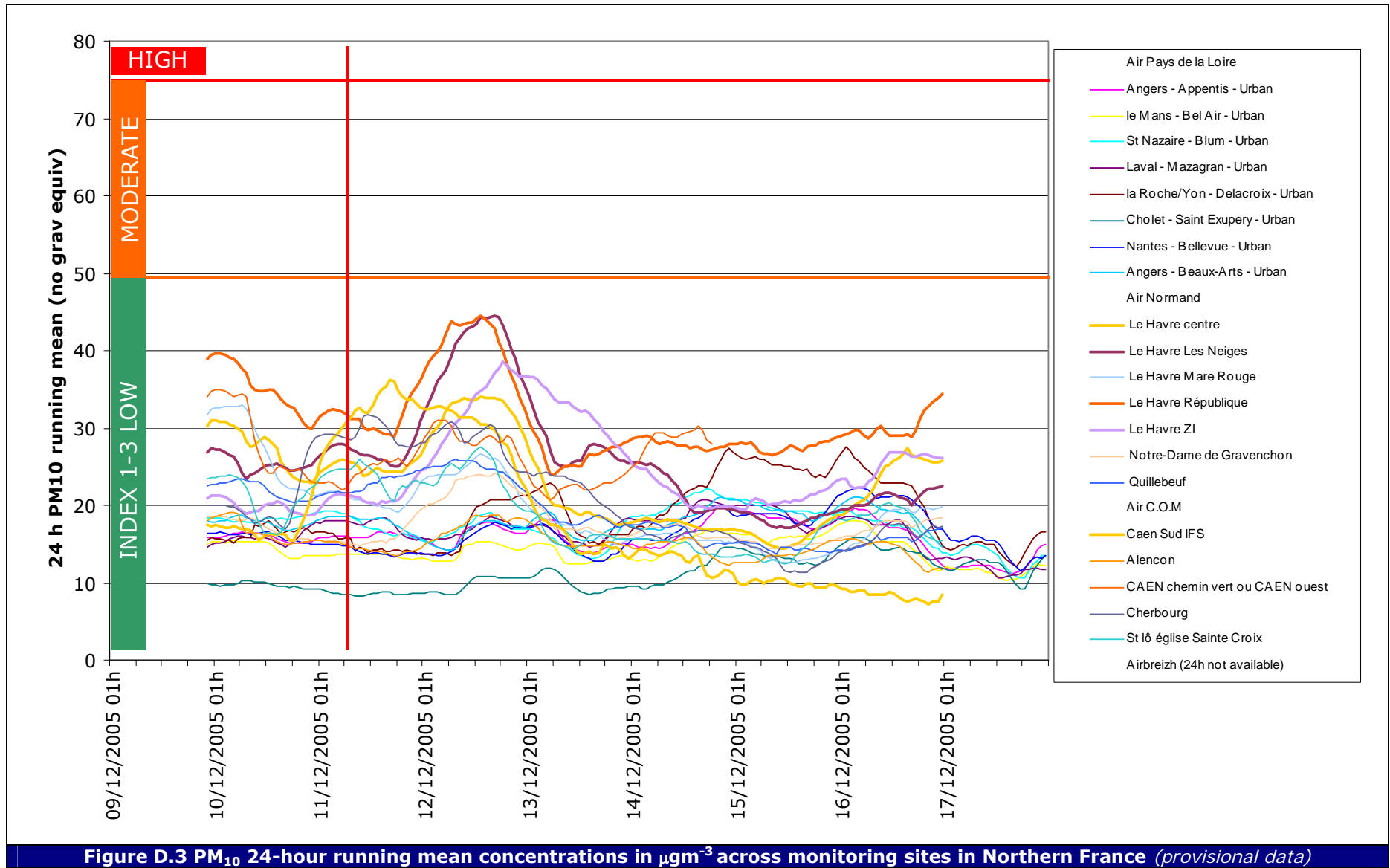


Figure D.3 PM₁₀ 24-hour running mean concentrations in $\mu\text{g m}^{-3}$ across monitoring sites in Northern France (provisional data)

Appendix E – Met Office Plume Modelling

E1 INTRODUCTION

Throughout the incident, the Met Office provided advice on the predicted spread and transport of the plume. Information on “areas at risk”, together with a text forecast reporting on the meteorological situation, the rise of the plume and the variability of the plume at various vertical levels was issued at regular intervals. In addition, more extensive modelling of the plume was undertaken using the Met Office’s atmospheric dispersion model, NAME (Jones et al., to appear)¹.

E2 The CHEMET “AREA AT RISK” MAPS

The CHEMET “area at risk” map is generated using a specific version of the ADMS modelling package (Carruthers et al., 1994)² for emergency response purposes. It is a simple tool showing the predicted area at risk at short range and is based on observations or estimates of the near surface wind speed, wind direction and atmospheric stability. Figures E.1 and E.2 show the CHEMET “area at risk” maps issued at 11:44 GMT on 11/12/05 and 12:50 GMT on 12/12/05, respectively.

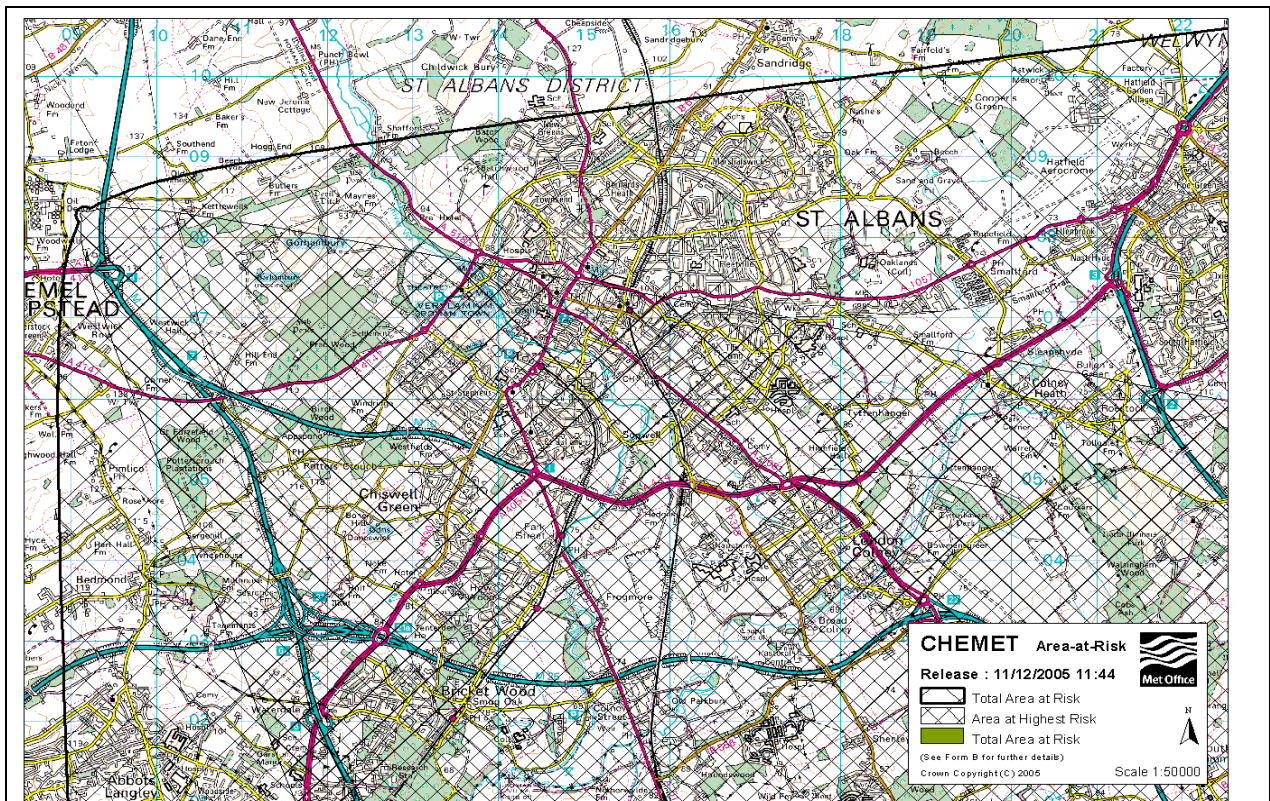


Figure E.1 The CHEMET predicted “area at risk” issued at 11:44 GMT on 11/12/05

¹ Jones A.R., Thomson D.J., Hort M. and Devenish B., 'The U.K. Met Office's next-generation atmospheric dispersion model, NAME III', in *Air Pollution Modeling and its Application XVII*, Kluwer Academic Publishers, 2006.

² Carruthers D.J., Holroyd R.J., Hunt J.C.R., Weng W.S., Robins A.G., Apsley D.D., Thomson D.J. and Smith F.B., 1994, 'UK-ADMS - a new approach to modelling dispersion in the Earth's atmospheric boundary layer', *J. Wind Eng. Ind. Aerodyn.*, **52**, 139-153.

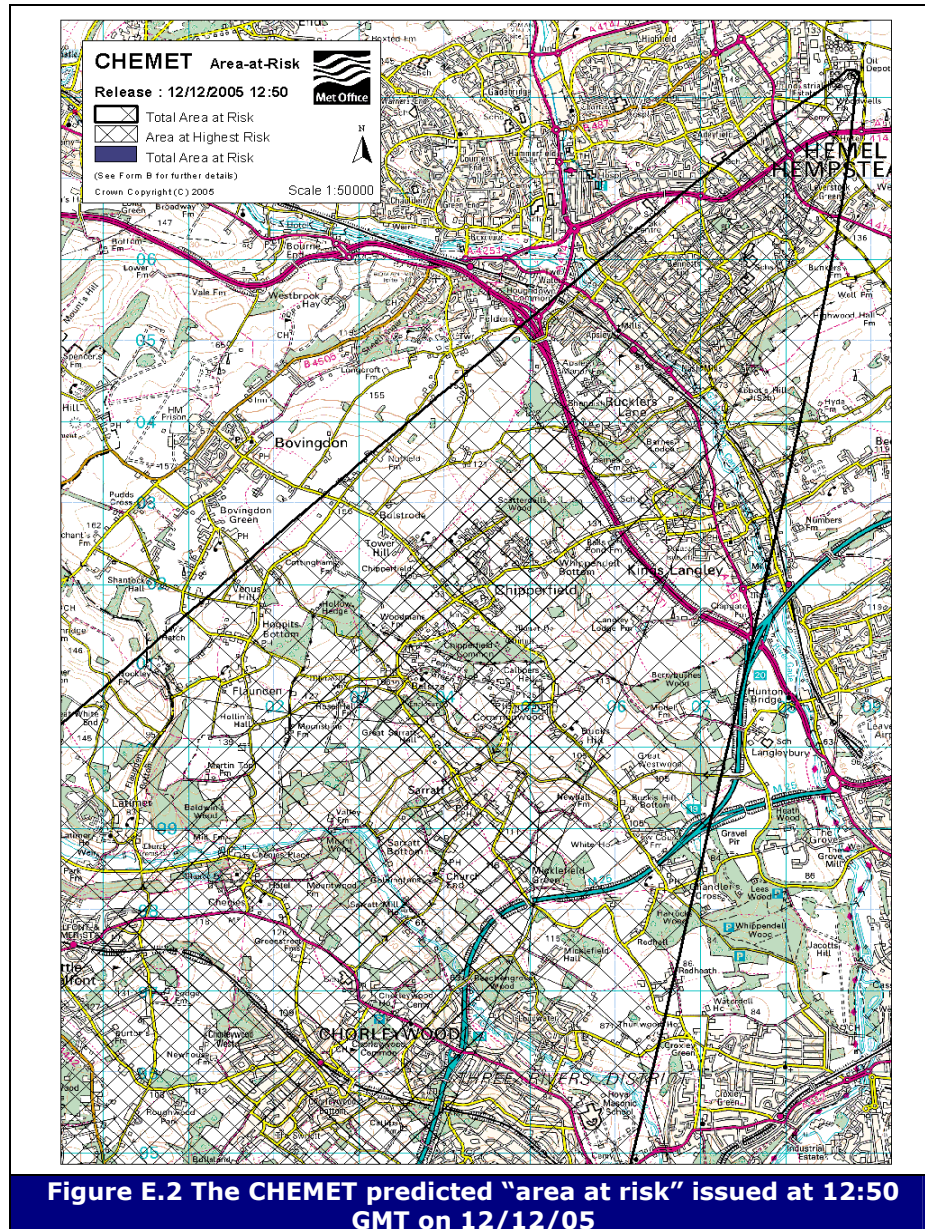


Figure E.2 The CHEMET predicted "area at risk" issued at 12:50 GMT on 12/12/05

Figure E.1 shows that the CHEMET predicted "area at risk" on 11/12/05 was to the south and east of the oil depot. The transport of the plume towards the south-west at higher levels within the atmosphere, which was observed on satellite imagery (see Figure 2.2), was not captured. This was due to the significant amount of vertical wind shear present on this day which was not taken into account by CHEMET: this is because the predicted "area at risk" is based on near-surface level winds alone. There was much better agreement between the CHEMET "area at risk" map (see Figure E.2) and satellite imagery (see Figure 2.3) on 12/12/05, when winds were from a north-easterly direction at all levels. In addition, the CHEMET "area at risk" map does not provide guidance on the height of the plume within the atmosphere.

E3 NAME MODELLING

The Met Office's atmospheric dispersion model NAME (Numerical Atmospheric dispersion Modelling Environment) has a wide range of applications including air quality forecasting, predicting the transport of hazardous airborne substances and identifying source locations. It is a Lagrangian model driven by either three dimensional meteorology or single-site meteorological data (e.g. from observations) with turbulent dispersion simulated using random walk techniques.

In modelling the plume from the Buncefield oil depot fire, three dimensional meteorological data from the mesoscale version of the Met Office's numerical weather prediction model (the Unified Model) was used with a horizontal resolution of approximately 12 km. There was a large degree of uncertainty initially in the source

release details and, consequently, a number of assumptions - or estimates - based on the available observations were adopted.

Due to the intense heat of the fire, the plume was highly buoyant and rose vertically within the atmosphere. The large amount of vertical wind shear present on 11/12/05 enabled the height attained by the plume to be estimated by comparing NAME output with satellite imagery. This suggested that the plume reached a height of 3000 m above ground level on 11/12/05; this prediction was supported by a single pilot report from a commercial airline.

On 12/12/05, winds were from a north-easterly direction at all levels and, therefore, this method could not be repeated on subsequent days. However, it was assumed that the plume reached a lower height of 2000 m on 12/12/05, taking into account the effects of fire fighting activities.

In view of uncertainties in the quantity and content of material being released, initial modelling exercises assumed a unit release rate of a tracer. These model runs were useful in predicting the transport and geographical spread of the plume, but were not expected to give accurate estimates of concentrations within the plume. They are, however, useful to identify those areas within the plume with the highest predicted concentrations, if a continuous constant release rate is an appropriate assumption. In addition, results could be easily scaled if a more realistic constant release rate became available subsequently.

Subsequent estimates of emission rates for various species were obtained from estimates of total emissions from the fire (as given in Table 3.3) together with the following suggested release rate scaling factors; 1.0 for the period 06:00 GMT on 11/12/05 to 06:00 GMT on 12/12/05, 0.9 for 06:00 GMT on 12/12/05 to 06:00 GMT on 13/12/05, 0.4 for 06:00 GMT on 13/12/05 to 06:00 GMT on 14/12/05 and 0.2 for 06:00 GMT on 14/12/05 to 06:00 GMT on 15/12/05 (Noel Nelson, DEFRA, private communication). Assuming a 96 hour release scaled to the above values and adopting the figures for scenario 4 (worst case scenario assuming 100% of 105 million litres burnt) gave a release rate for PM₁₀ of 56.1 kg/s, 50.5 kg/s, 22.4 kg/s and 11.2 kg/s for each subsequent 24 hour period. These emission rate figures are larger than those estimated using measurements from the FAAM aircraft on 13/12/05, namely a range of 4.0 kg/s to 7.9 kg/s for PM_{2.5}, even after taking into account the different particle sizes (PM₁₀ for the emission release rate estimate and PM_{2.5} for the FAAM aircraft measurements). Recall, however, that the emission rate estimates used were taken from the worst case scenario (100% of 105 million litres of fuel burnt).

The rise of the plume due to buoyancy is taken into account in the release height. A release between 500 and 3000 m was modelled during the period 06:00 GMT on 11/12/05 and 06:00 GMT on 12/12/05. This was then reduced to a height of 500 and 2000 m from 06:00 GMT on 12/12/05 onwards. The choice of 500 m as the lower height limit is somewhat arbitrary but is based on observations that the plume remained elevated (suggesting that it was above the boundary layer) together with information from the FAAM aircraft which flew through the plume at an altitude of 500m in the vicinity of the fire on 13/12/05.

Figure E.3 shows hourly averaged fields of PM₁₀ concentrations over a height range between 0 and 4000 m above ground, at 12:00 GMT on 11/12/05 and at 13:00 GMT on 12/12/05. There is good agreement between the geographical spread of the NAME predicted plume and satellite observations (see Figures 2.2 and 2.3). Modelled hourly averaged boundary layer concentrations of PM₁₀ from NAME between 12:00 GMT on 11/12/05 and 06:00 GMT on 14/12/05 are shown in Figures E.4a and E.4b at six-hourly intervals. In the main, predicted boundary layer concentrations can be taken to be representative of predicted ground level concentrations.

The NAME simulations suggest that, during Sunday 11th December, the plume was present mainly above the boundary layer. Some material from the plume could, however, have been present at lower levels over the south-east of the UK although boundary layer concentrations were predicted to be low. On Monday 12th December, NAME predicted potential grounding of the plume both in the UK to the southwest of the oil depot, over the Channel and into northern France. The maximum predicted hourly averaged PM₁₀ boundary layer concentration was 151 µg m⁻³, occurring at 04:00 GMT on 14/12/05 near to the source.

The predicted boundary layer concentrations from NAME are clearly highly sensitive to the lower boundary of the plume (taken here to be at a height of 500m). Work is continuing to improve our understanding of the plume's behaviour and incorporate this into the modelling of the plume. In addition, further work is planned to enable the initial rise of the buoyant plume to be modelled provided that appropriate estimates of the plume's properties (e.g. temperature and heat flux) can be made.

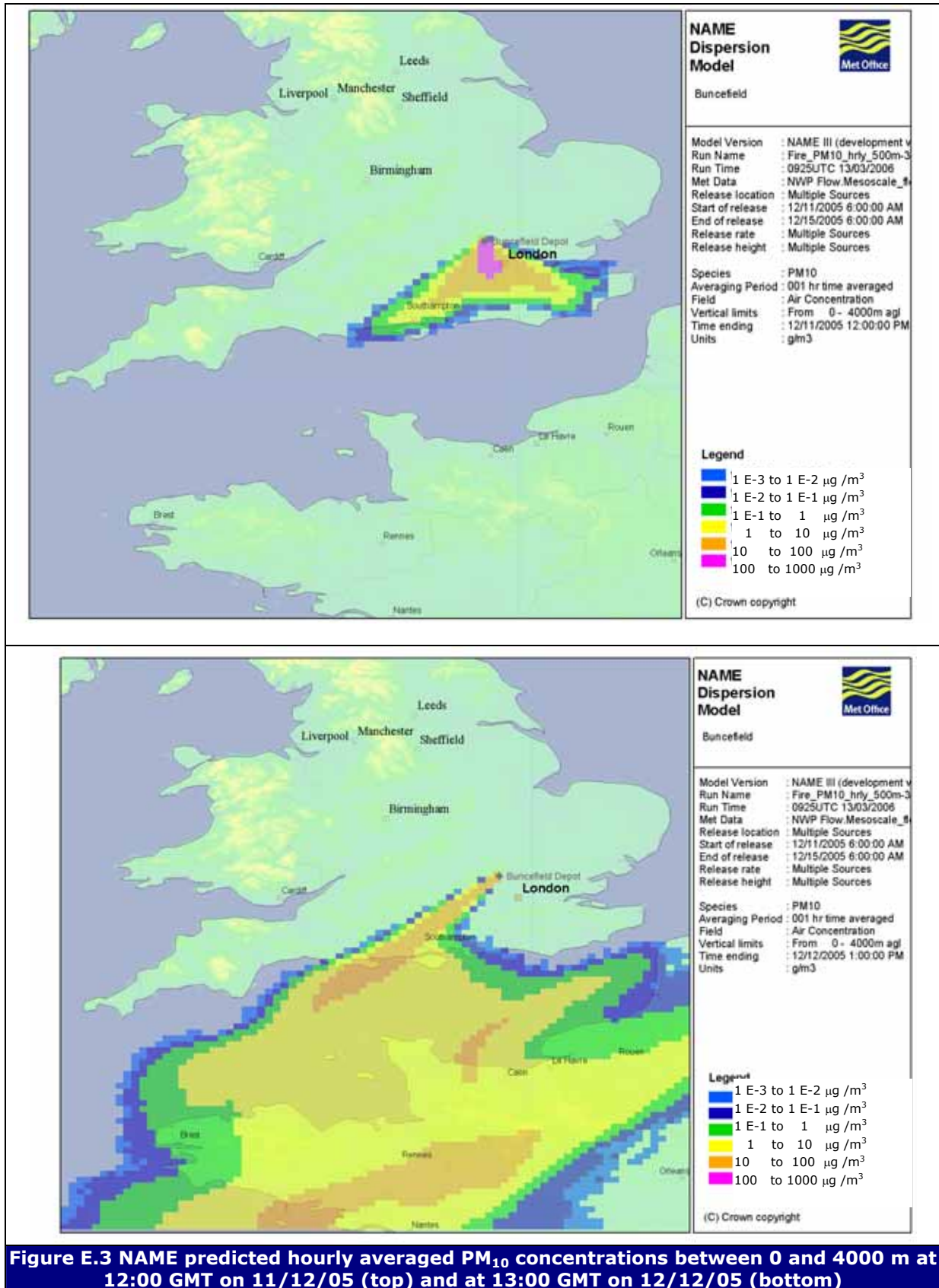


Figure E.3 NAME predicted hourly averaged PM₁₀ concentrations between 0 and 4000 m at 12:00 GMT on 11/12/05 (top) and at 13:00 GMT on 12/12/05 (bottom)

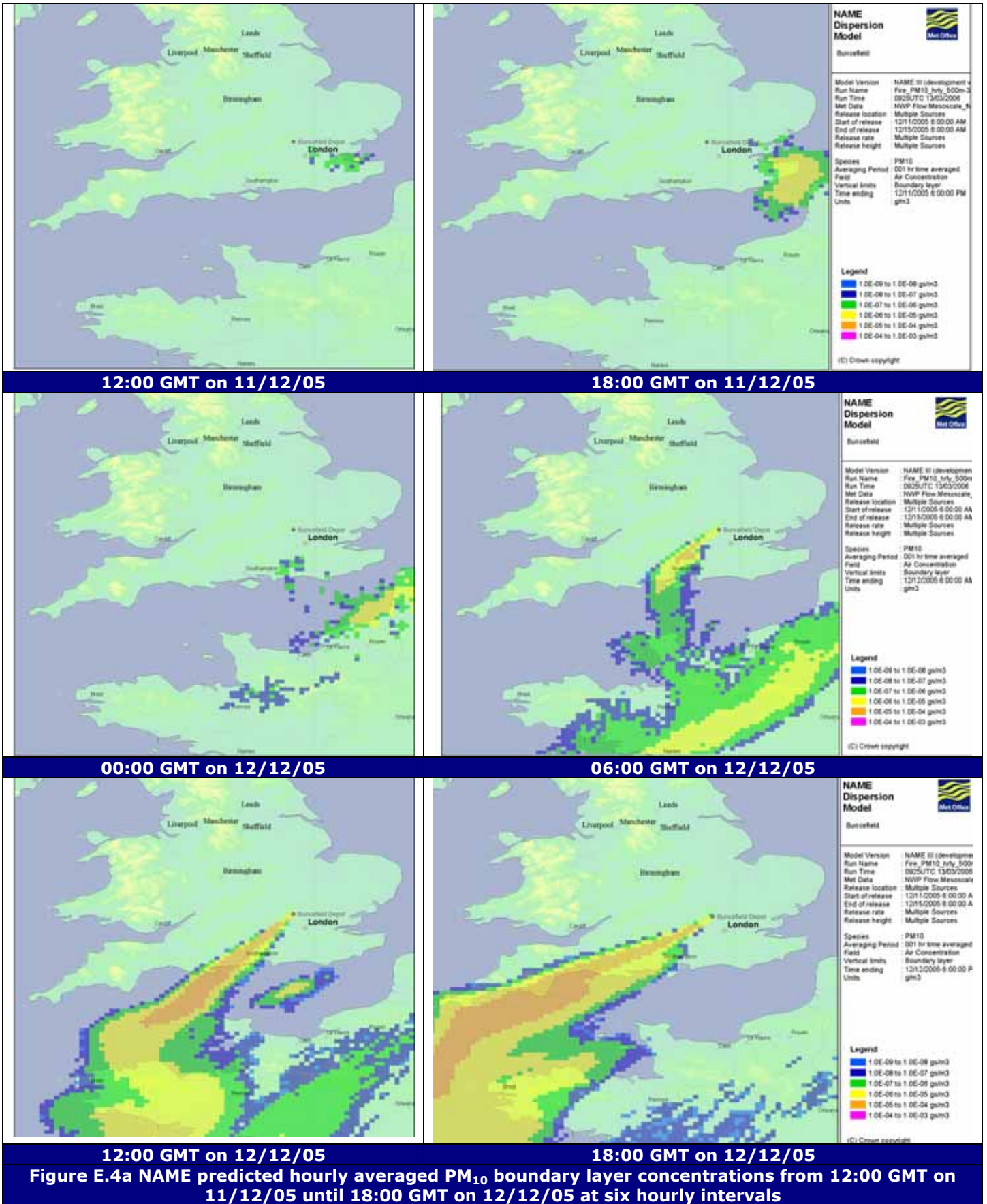
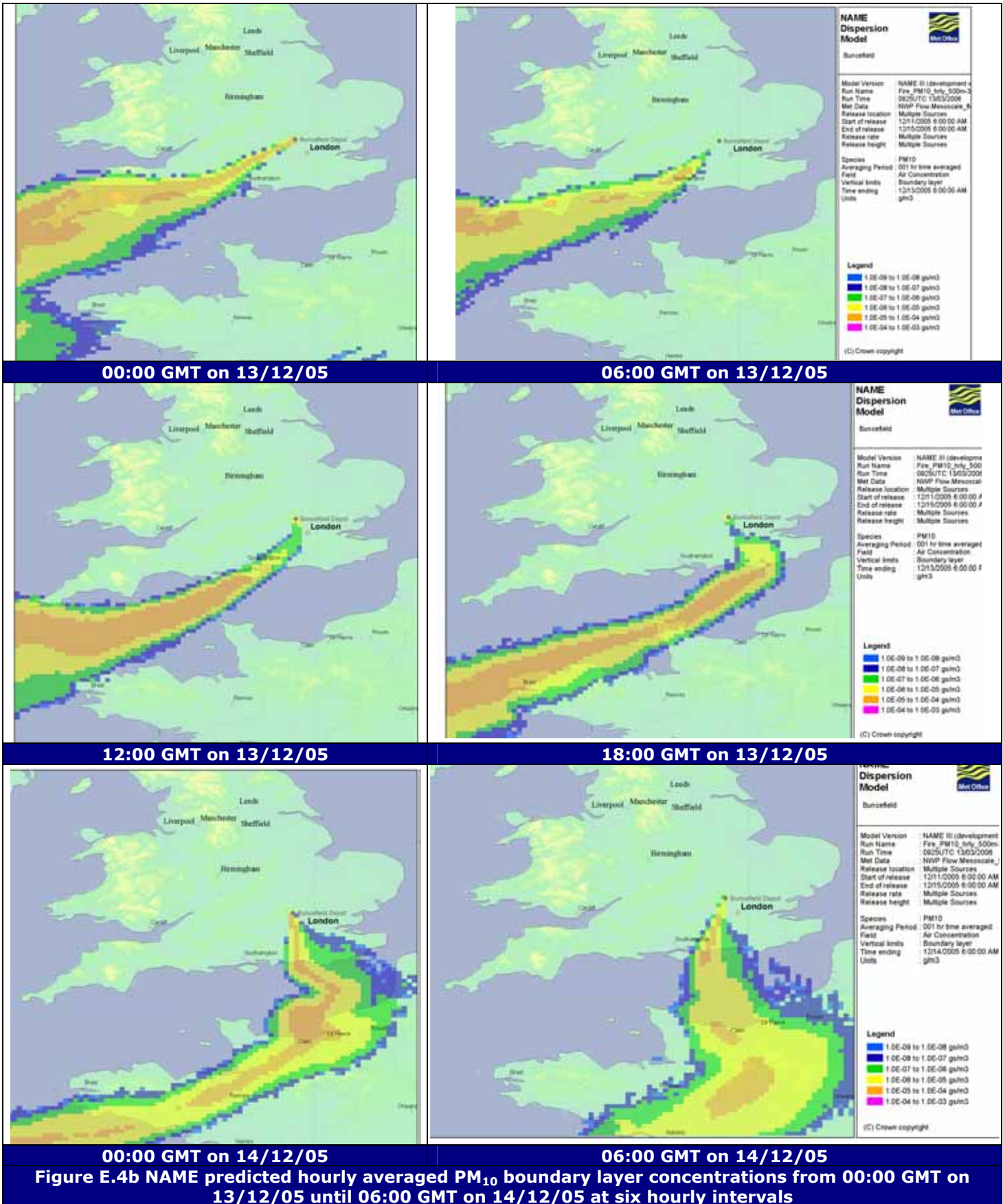


Figure E.4a NAME predicted hourly averaged PM₁₀ boundary layer concentrations from 12:00 GMT on 11/12/05 until 18:00 GMT on 12/12/05 at six hourly intervals



E4 NAME BACK MAPS MODELLING

E4.1 Southampton Centre between 20.00 and 20:15 GMT on 11/12/05

The origin of the air contributing to this 15-minute mean peak in PM₁₀ concentrations at Southampton between 20:00 and 20:15 GMT on 11/12/05 can be determined. Figure E.5 shows back maps from NAME, showing where the near surface air arriving at Southampton during the period 20:00 to 20:15 GMT on 11/12/05 has come from since the time of the explosion at 06:00 GMT on 11/12/05.

Three plots are shown here; one for air that has originated between 0 and 500 m above ground level, one for air that has originated between 500 and 1000 m above ground and one for air with an origin of between 1000 and 1500 m above ground. Within the domain shown, no air has originated above 1500 m above ground and there is only a very small contribution from air which originated between 1000 and 1500 m above ground. Most near surface air between 20:00 and 20:15 GMT on 11/12/05 at Southampton originated from the west and from a height between 0 to 500 m above ground. At no vertical level did air originate from the Buncefield oil depot and hence we can conclude that the 15-minute peak in PM₁₀ concentrations measured at Southampton was not due to the fire.

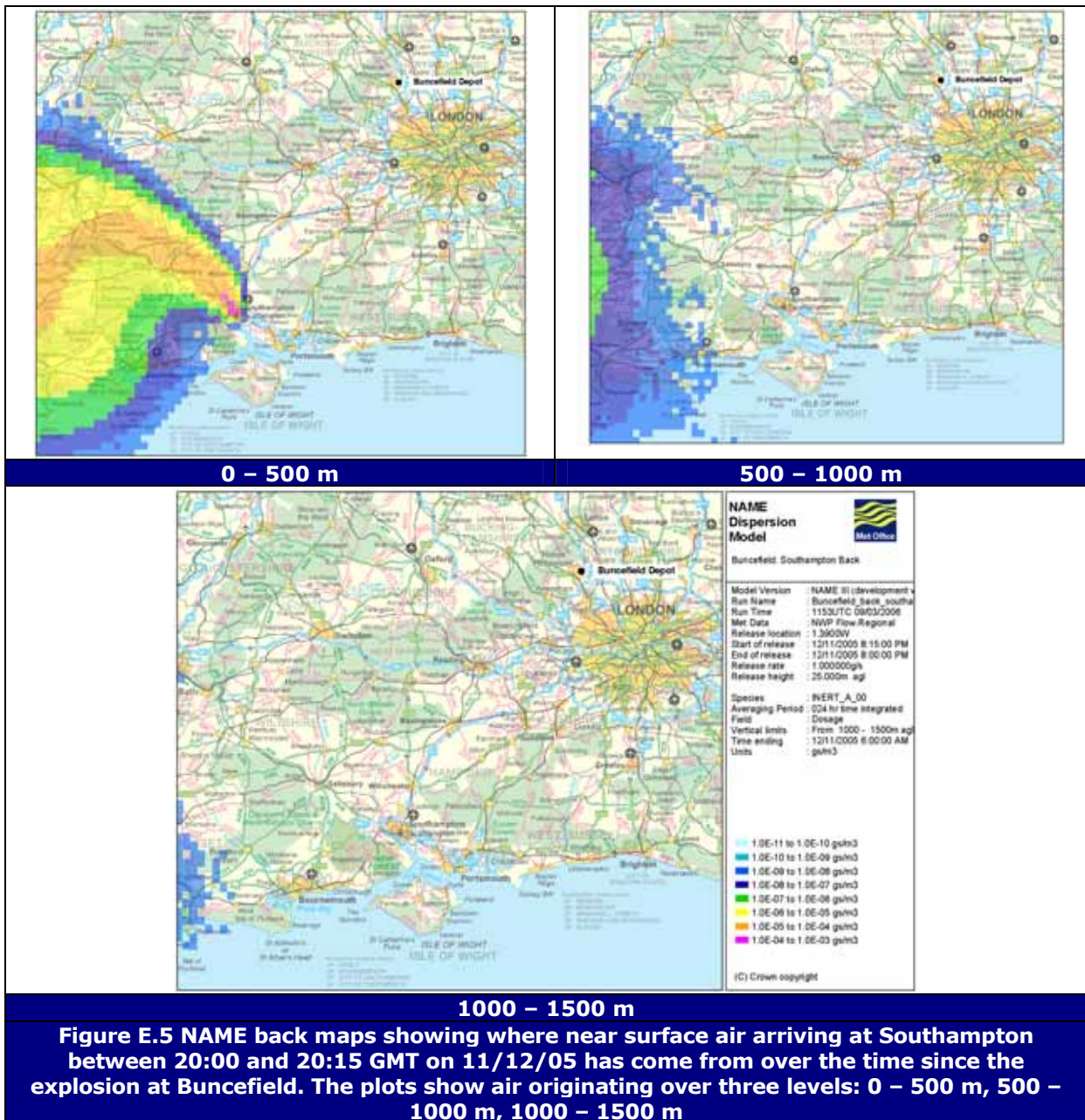


Figure E.5 NAME back maps showing where near surface air arriving at Southampton between 20:00 and 20:15 GMT on 11/12/05 has come from over the time since the explosion at Buncefield. The plots show air originating over three levels: 0 – 500 m, 500 – 1000 m, 1000 – 1500 m

Appendix F – Samples from London PAH network sites during the Buncefield fire

*Letter report from Peter Coleman (Netcen) to Martin
Meadows (Defra)*

Analytical results from samples collected in the London PAH network sites during the Buncefield fire

We have now received the analytical results from the analysis of samples from the three London PAH network sites before, during and nominally after the Buncefield fire. The samples from the PAH network are from the three sites at Brent (Kingsbury High School), London (Victoria Street), and Bromley (Crystal Palace Parade). The dates and volumes of the samples are given in Table 1. The network samples have been analysed for polychlorinated-*p*-dioxins, polychlorinated dibenzofurans (dioxins), polychlorinated biphenyls (PCBs) and polycyclic hydrocarbons (PAHs).

We have also been supplied with three extracts from the Health and Safety Laboratory at Buxton, which were from two filters taken by the Met Office aircraft from the Buncefield plume and a blank filter. As a result of the treatment the extract had already received they could only be meaningfully analysed for PAHs.

London PAH Network Site Samples

Analysis

Each of the network canisters was extracted in dichloromethane and then toluene. 50% of each extract was made available for dioxin and PCB analysis. The other half was used for PAH analysis. The extract was then reduced to a smaller volume and passed through an open column clean-up treatment to separate the dioxins, furans and PCBs from the other species present in the extract. The dioxin and furan samples were then passed through a gas chromatograph to separate the isomers of interest from each other and then quantified using a high resolution mass spectrometer. The PCB samples were analysed in a similar manner except detection was by a quadrupole mass spectrometry. Both analysis approaches are UKAS accredited. The PAHs were also analysed by gas chromatography quadrupole mass spectrometry following a UKAS accredited approach.

Results - Dioxins

The concentrations of the 2,3,7,8 chlorine-substituted dioxins measured in the nine samples were generally above the levels found in the blank. No 2,3,7,8 chlorine-substituted congeners were detected in the blank. Most congeners, 129 out of 153, were detected in the network samples. The detection limits make little difference to the total toxic equivalent.

The concentrations of the congeners included in the toxic equivalent are shown in Table 2. Table 3 shows the concentration of the sum of the isomers with a particular level of chlorination and the toxic equivalence of the results, expressed as the mass of the most toxic congener, 2378 TCDD, which would have the same effect as the mixture present in the sample according to both the International and World Health Organisation approaches. These are slightly different. The latter requests that the dioxin-like PCBs also be included. The value given in Table 3 is only for the dioxins.

Table 6 compares the total WHO TEQ from the dioxins, PCBs and in total. The results are expressed using two alternative treatments of a congener, which was not detected. In one case 'nd=0' the congener is taken as not being present; this provides a lower bound estimate of the toxic equivalent and hence the exposure. In the other case 'nd=dl' the non-detected congener is assumed to have been present at a concentration only slightly below the detection limit and so the detection limit is used as the concentration for that isomer; this provides an upper bound estimate of toxic equivalent and so of exposures.

It can be seen that the concentrations of dioxins measured in the samples from the middle sampling period, during the Buncefield fire, are greater in toxic equivalent terms than the samples before or after. While the increase in toxic equivalent is consistent between the three sites, the change in profiles within the three groups of samples is not consistent. Hence there is no evidence that a particular congener or group of congeners were preferentially elevated in air during the fire and the increase in the toxic equivalent is caused by increases in congeners which vary between the three sites. It can be seen that, while no dioxin-like PCBs were detected, the relatively high detection limits of the PCBs dominate the total toxic equivalents in the 'nd=dl' case.

I have tried to calculate the inhalation exposure that would result from this concentration of PCDD/Fs and PCBs. To do this I, have used a number of assumptions;

- That the concentration on the filters is representative of the concentration in the plume
- 100% of the inhaled quantity is adsorbed.
- That 100% of the TDI is available for inhalation whereas in practice a significant fraction is used in the dioxin and PCB content of foods.
- A number of other assumptions as shown in Table 7 concerning inhalation rate, and bodyweight for a number of population groups.

These assumptions have been used to calculate the fraction of the UK COT recommended Tolerable Daily Intake (2 pg WHO-TEQ/kg bodyweight/day) that this would represent. The results are shown in Tables 8 and 9, using concentrations using zero or the detection limit for congeners that were not detected. Despite the very conservative assumptions used to calculate the results shown in Table 9, there are no exceedences of the TDI. This is reassuring, given that the effects of dioxins and PCBs are based on the total body burden of the subject so that - unless exposure at concentrations higher than these was prolonged - it would have only a slight impact on total body burdens.

Results - PCBs

Significant difficulties were experienced with the PCB analysis. The open column clean-up was repeated on several samples. Despite this, meaningful results were not obtained for one sample (Bromley 128). The analytical results are given in Table 4 and the results calculated as concentrations in Table 5. The contribution of the dioxin-like PCBs to the toxic equivalence of the samples is discussed above. The PCB analysis results show that no significant quantity of PCBs, except for PCB 18, was detected in any of the nine samples. The other detected congeners are not at quantities greatly above the detection limit. PCB 18 increased across the three samples from Brent and decreased in the three from London.

Results - PAHs

The PAH analytical results and concentrations are given in Table 10 and Table 11. Only two PAHs were detected in the field blank: fluorine and coronene. The fluorene result is less than 1% of the amounts found in the other samples and the coronene result is less than 10% of 6 of the 9 samples. The field blank results have are not subtracted.

The results show that the concentrations of most PAHs at the measurement sites were greater during the Buncefield fire than before or after. The ratio of the measured concentrations during the middle period to the average before and after concentration varies between individual PAHs. This ratio is greater than 1 for all PAHs sampled at Brent averaging 1.98 and ranging between 1.18 and 2.8. At Bromley, the average is 1.6, ranging between 0.84 and 5.4, whilst in London the average is 1.32, ranging between 0.47 and 3.3. At Bromley and Brent, the PAHs which are decreasing are those which are most volatile and particularly at both sites those which are methyl substituted: fluorene, phenanthrene, fluoranthene and retene. Hence the increase is generally associated with the particle-phase PAHs.

The benzo[a]pyrene concentration increased by a factor of 2.3 at Brent and around 1.5 at Bromley and London. The UK National Air Quality Objective would have been exceeded during all sampling periods at Brent and Bromley if the concentrations measured had prevailed for an entire year, but not in Victoria Street. It is known that benzo[a]pyrene concentrations are higher in winter than summer. The dibenzo[a]pyrene increased by a factor of 2.4 at Brent, 1.5 at Bromley and 1.3 at London.

Analysis of the Met Office Flight samples

The extract received from the Health and Safety Laboratory represented an ultrasonic extraction of the three filters, two from the flight and a blank. Our understanding is that one of the filter extracts 'B149 Exposure 3' had sampled 2.625 m³ of air; another 'B149 Exposure 4' had sampled 7.926 m³, while the third sample was a blank. It is not clear how much of the air reported to have been sampled through the filters was from within the Buncefield smoke plume. It has been assumed that the volumes provided are corrected to normal conditions of temperature and pressure.

The extract was then blown down HSL to 1 ml and a standard of d₁₂ chrysene added. A portion of the extract was used for analysis by HSL but only 4 µl out of 1000 was used. The extract was then stored in a fridge for 6 weeks.

When we received the samples, there was considerably less than 1ml present due - we hope - to evaporation of the solvent rather than the compounds of interest. This is an unfortunate problem with storing extracts. We effectively received the entire sample 99.6%. The solution was made up to 5ml in a volumetric flask with cyclohexane. This was then spiked with the normal Harwell Scientifics cocktail of deuterated internal quantitation and recovery standards used for the network samples, blown down to approximately 50µl and analysed. The results from the analysis of the extracts received are shown in Table 12.

Given that these filters presumably received no treatment before sampling and that the volumes of smoke sampled were not high, it is possible that these results reflect the variability in the blank levels in the filters and are not representative of concentrations in the smoke, which therefore appear to have been low. The results are compared below with the original HSL results from December and with the PAH results from the first batch of filters from the same flight we were sent in December.

The comparison does not suggest that PAH concentrations were high in the smoke plume when it was sampled. Many of the measured concentrations e.g. benzo[a]pyrene are significantly below the concentrations measured in the London PAH network samples. The poor agreement between samples is, perhaps, as a result of the storage conditions of the samples, differences in analytical approaches or perhaps the reduced pressure during sampling that may have lead to volatilisation of PAHs and other POPs from the filter during sampling.

Discussion

The London PAH network samples indicate that, during the week in which the Buncefield oil depot was burning, the concentrations of dioxins and PAHs increased at the three Greater London sites at Brent, London Victoria Street and Bromley. However, the increase in concentrations during the fire does not follow expected geographical variations resulting from the proximity of the individual sites to the fire; levels at Brent increase most, however levels at Bromley increase more than those at Victoria Street. Moreover, the rise in concentrations of individual compounds is not consistent between sites.

It is possible that the higher results observed in the third period (which coincides with the ending of the fire) compared to the first period reflect the emissions of persistent organic pollutants (POPs) during the smouldering phase of the fire fighting and the time taken for the smoke plume to travel to the sites. Hence the third period also may include a contribution from the fire.

However, given i) the lack of consistency in the rise in concentrations of individual compounds between the sites and ii) the lack of evidence from the automated networks of any significant increase in PM₁₀ concentration indicating plume grounding at both Brent and Bromley, the results presented here do not demonstrate that the increase in concentrations is other than that which may occur as a result of normal temporal variability. This variability is not normally observed with the PAH network samples, as a result of the quarterly analysis frequency used.

The issue as to whether the increase in PAH and dioxin concentration measured is a result of plume grounding in London or the result of temporal variability in concentration independent of the fire could be addressed through both the Met Office's dispersion modelling and analysis of further samples from the PAH network.

Table 1 Sampling Data from the PAH Network Sites

Sample	Spike Used [‡]	Date On	Time On	Date Off	Time Off	Volume Sampled (m ³)
Bromley 128 [†]	Normal	23/11/2005	13:53	08/12/2005	12:15	1394.71
Bromley 129 [†]	Normal	08/12/2005	12:30	14/12/2005	16:30	626.34
Bromley 130 [†]	Cocktail	14/12/2005	16:45	22/12/2005	12:50	780.01
Bromley 131	Cocktail	22/12/2005	13:00	04/01/2006	12:00	1294.82
Brent 95 [†]	Normal	22/11/2005	14:50	06/12/2005	16:50	1664.12
Brent 96 [†]	Normal	06/12/2005	17:00	14/12/2005	14:22	789.53
Brent 97 [†]	Cocktail	14/12/2005	14:30	22/12/2005	10:04	966.4
Brent 98	Cocktail	22/12/2005	11:00	05/12/2005	15:00	1740.1
London B 220 [†]	Normal	01/12/2005	n/a	08/12/2005	n/a	407.97
London B 221 [†]	Normal	08/12/2005	n/a	14/12/2005	n/a	381.92
London B 222 [†]	Cocktail	14/12/2005	n/a	22/12/2005	n/a	500.82
London B 223	Cocktail	22/12/2005	n/a	04/01/2006	n/a	821.16

The Buncefield fire is reported to have started in the early morning of Sunday 11th December and to have been mainly extinguished by midday on 14th December.

[†]Samples for which the results are reported here.

[‡] The 'Normal' spike is that used within the PAH network which contains only PAHs. The 'Cocktail' spike includes PAHs, PCDD/Fs and PCBs.

Table 2 Measured Concentrations of Polychlorinated dibenzo-*p*-dioxins and Polychlorinated dibenzofurans in the Samples

Sample	Brent 95	Brent 96	Brent 97	Bromley 128	Bromley 129	Bromley 130	London B220	London B221	London B222
	fg/m ³	fg/m ³	fg/m ³	fg/m ³	fg/m ³	fg/m ³	fg/m ³	fg/m ³	fg/m ³
2378 TCDD	0.7	<1.3	<1	3	1.6	<1.3	<2.5	3.4	<2
12378 PeCDD	7.2	17.7	20.7	2.6	11.3	5.8	<4.9	9.2	5.4
123478 HxCDD	12	20	12	13	10	10	<12	34	11
123678HxCDD	20	27	18	8	12	13	12	11	17
123789HxCDD	19	23	20	6	21	10	<15	<16	<12
1234678HpCDD	170	410	240	120	220	180	220	90	180
OCDD	520	1040	580	360	750	510	510	500	500
2378 TCDF	4.1	13.9	5.5	3.4	<6.4	<5.1	<9.8	<10.5	<8
12378 PeCDF	10	6	12	6	8	4	15	<5	5
23478 PeCDF	19	19	12	2	11	9	6	13	7
123478 HxCDF	25	41	33	21	19	17	23	15	10
123678 HxCDF	23	38	28	13	22	15	16	10	16
123789 HxCDF	19	29	47	16	16	24	14	23	11
234678 HxCDF	6	18	11	11	8	7	<10	<10	<8
1234678 HpCDF	100	120	120	60	80	80	40	40	50
1234789 HpCDF	20	<8	9	<4	18	8	<15	<16	<12
OCDF	66	75	69	21	21	47	42	29	22
ITEQ nd= 0	31	46	39	17	28	21	13	26	16
ITEQ nd = dl	31	47	39	17	29	22	23	30	20
WHO ⁺ TEQ nd=0	34	54	49	18	33	23	13	30	18
WHO ⁺ TEQ nd=dl	34	55	50	18	34	25	25	34	23

† this value is the toxic equivalent of the dioxins and furans only

Table 3 Homologue Group Totals

Sample	Brent 95	Brent 96	Brent 97	Bromley 128	Bromley 129	Bromley 130	London B 220	London B 221	London B 222
Homologue Group Totals	fg/m ³	fg/m ³	fg/m ³	fg/m ³	fg/m ³	fg/m ³	fg/m ³	fg/m ³	fg/m ³
ΣTCDDs	270	490	320	260	270	440	390	260	260
ΣPeCDDs	270	560	320	240	290	330	590	450	500
ΣHxCDDs	450	820	480	380	540	510	660	550	520
ΣHpCDDs	400	950	590	290	570	440	540	390	400
ΣTCDFs	490	960	710	380	540	470	540	390	260
ΣPeCDFs	440	800	500	290	450	320	290	290	200
ΣHxCDF	170	330	240	170	220	180	230	200	130
ΣHpCDFs	190	270	230	150	210	150	160	190	130

Table 4 Analytical Results for PCBs from the London sites and associated field blank

Sample	Brent 95	Brent 96	Brent 97	Bromley 128	Bromley 129	Bromley 130	London B220	London B221	London B222	Travel Blank
Isomer Number	ng	ng	ng	ng	ng	ng	ng	ng	ng	ng
18	29	20	36	n/m	<3	<1	12	5.2	9.8	<1
31+28	23	15	14	n/m	11	<2	8.7	<5	7.1	<2
51	<0.5	<0.5	0.73	n/m	<2	<0.5	<2	<2	<0.5	<0.5
52	8.2	9.3	<1	n/m	<3	<1	<3	<3	<1	<1
49	3.9	2.4	1.4	n/m	<2	<0.6	<2	<2	2.9	<0.6
47	<0.5	<0.5	3	n/m	<2	<0.5	<2	<2	<0.5	<0.5
101	7.6	3.6	<3	n/m	<6	<3.1	13	<6	<3	<3
99	<0.5	2	1.1	n/m	<3	<0.79	<3	<3	0.77	<0.5
81	<0.6	<0.6	1.4	n/m	<5	<0.6	<5	<5	<0.6	<0.6
77	<0.4	<0.4	1.4	n/m	<5	<0.4	<5	<5	<0.4	<0.4
123	<0.4	<0.4	<0.4	n/m	<5	<0.4	<5	<5	<0.4	<0.4
118	1.6	1.6	<0.8	n/m	<7	<0.8	<7	<7	<0.8	<0.8
114	<0.4	<0.4	<0.4	n/m	<4	<0.4	<4	<4	<0.4	<0.4
153	4.4	<4	<4	n/m	<7	<4	<7	<7	<4	<4
105	<0.6	<0.6	<0.6	n/m	<5	<0.6	<5	<5	<0.6	<0.6
138	4.6	5.1	2.4	n/m	<6	<7.2	<6	<6	<2	<2
126	<0.8	<0.8	<0.8	n/m	<6	<0.8	<6	<6	<0.8	<0.8
128	<0.6	<0.6	2.3	n/m	<6	<0.6	<6	<6	<0.6	<0.6
167	<0.4	<0.4	2.1	n/m	<5	<0.4	<5	<5	<0.4	<<0.4
156	<0.5	<0.5	0.5	n/m	<5	<0.5	<5	<5	<0.5	<0.5
157	<0.4	<0.4	1.1	n/m	<6	<0.4	<6	<6	<0.4	<0.4
180	<2	<2	<2	n/m	<7	<2	8.4	<7	<2	<2
169	<0.4	<0.4	0.95	n/m	<5	<0.4	<5	<5	<0.4	<0.4

Sample	Brent 95	Brent 96	Brent 97	Bromley 128	Bromley 129	Bromley 130	London B220	London B221	London B222	Travel Blank
Isomer Number	ng	ng	ng	ng	ng	ng	ng	ng	ng	ng
170	<0.7	<0.7	1.4	n/m	<6	<0.7	<6	<6.0	<0.7	<0.7
189	<0.5	<0.5	0.88	n/m	<5	<0.5	<5	<5.0	<0.5	<0.5

n/m – not measured

Table 5 PCB Concentrations from the London PAH Network sites before, during and after the Buncefield fire.

Isomer Number	Brent 95	Brent 96	Brent 97	Bromley 128	Bromley 129	Bromley 130	London B 220	London B 221	London B 222
	pg/m ³	pg/m ³	pg/m ³	pg/m ³	pg/m ³	pg/m ³	pg/m ³	pg/m ³	pg/m ³
18	17.4	25.3	37.3	n/m	<4.79	<1.28	29.4	13.6	19.6
31+28	13.8	19	14.5	n/m	17.6	<2.56	21.3	<13.1	14.2
51	<0.3	<0.63	0.76	n/m	<3.19	<0.64	<4.9	<5.24	<1
52	4.93	11.8	<1.03	n/m	<4.79	<1.28	<7.35	<7.86	<2
49	2.34	3.04	1.45	n/m	<3.19	<0.77	<4.9	<5.24	5.79
47	<0.3	<0.63	3.1	n/m	<3.19	<0.64	<4.9	<5.24	<1
101	4.57	4.56	<3.1	n/m	<9.58	3.97	31.9	<15.7	<5.99
99	<0.3	2.53	1.14	n/m	<4.79	1.01	<7.35	<7.86	1.54
81	<0.36	<0.76	1.45	n/m	<7.98	<0.77	<12.3	<13.1	<1.2
77	<0.24	<0.51	1.45	n/m	<7.98	<0.51	<12.3	<13.1	<0.8
123	<0.24	<0.51	<0.41	n/m	<7.98	<0.51	<12.3	<13.1	<0.8
118	0.96	2.03	<0.83	n/m	<11.2	<1.03	<17.2	<18.3	<1.6
114	<0.24	<0.51	<0.41	n/m	<6.39	<0.51	<9.8	<10.5	<0.8
153	2.64	<5.07	<4.14	n/m	<11.2	<5.13	<17.2	<18.3	<7.99
105	<0.36	<0.76	<0.62	n/m	<7.98	<0.77	<12.3	<13.1	<1.2
138	2.76	6.46	2.48	n/m	<9.58	9.23	<14.7	<15.7	<3.99
126	<0.48	<1.01	<0.83	n/m	<9.58	<1.03	<14.7	<15.7	<1.6
128	<0.36	<0.76	2.38	n/m	<9.58	<0.77	<14.7	<15.7	<1.2

167	<0.24	<0.51	2.17	n/m	<7.98	<0.51	<12.3	<13.1	<0.8
156	<0.3	<0.63	0.52	n/m	<7.98	<0.64	<12.3	<13.1	<1
157	<0.24	<0.51	1.14	n/m	<9.58	<0.51	<14.7	<15.7	<0.8
180	<1.2	<2.53	<2.07	n/m	<11.2	<2.56	20.6	<18.3	<3.99
169	<0.24	<0.51	0.98	n/m	<7.98	<0.51	<12.3	<13.1	<0.8
170	<0.42	<0.89	1.45	n/m	<9.58	<0.9	<14.7	<15.7	<1.4
189	<0.3	<0.63	0.91	n/m	<7.98	<0.64	<12.3	<13.1	<1

n/m – not measured

Table 6 Concentrations of PCBs, dioxins and furans expressed as World Health Organisation Toxic Equivalents

Sample	Brent 95	Brent 96	Brent 97	Bromley 128	Bromley 129	Bromley 130	London B220	London B221	London B222
Units	fg TEQ/m ³	fg TEQ/m ³	fg TEQ/m ³	fg TEQ/m ³	fg TEQ/m ³	fg TEQ/m ³	fg TEQ/m ³	fg TEQ/m ³	fg TEQ/m ³
PCDD/Fs nd=0	34	54	49	18	33	23	13	30	18
PCDD/Fs nd=dl	34	55	50	18	34	25	25	34	23
PCBs nd=0	0	0	0	n/a	0	0	0	0	0
PCBs nd=dl	51	108	95	n/a	1058	109	1625	1736	170
Total nd=0	34	54	49	18	33	23	13	30	18
Total nd=dl	85	163	145	18	1092	134	1650	1770	193

Table 7 Inhalation Exposure Assumptions.

	Units	Infant Resident	Child Resident 1-6	Schoolchild 6-11	Schoolchild 11-16	Adult Resident	Infant of farmer	Child of farmer 1-6	Farmer
Bodyweight	kg	8.5	15	32.5	52.5	70.1	8.5	15	70.1
Inhalation Rate indoors	m ³ /hr	0.23	0.4	0.4	0.64	0.62	0.23	0.4	0.62
Inhalation Rate outdoors	m ³ /hr	0.26	0.45	0.45	0.74	0.7	0.26	0.45	0.7
Exposure Time indoors	hr/day	23	20	20	20	21	23	20	14
Exposure Time outdoors	hr/day	1	4	4	4	3	1	4	10
Fraction of intake adsorbed		1	1	1	1	1	1	1	1
Inhalation volume indoor	m ³ /day	5.29	8	8	12.8	13.02	5.29	8	8.68
Inhalation volume outdoor	m ³ /day	0.26	1.8	1.8	2.96	2.1	0.26	1.8	7
Total inhalation volume	m ³ /day	5.55	9.8	9.8	15.76	15.12	5.55	9.8	15.68
Specific inhalation volume	m ³ / (kg day)	0.65	0.65	0.30	0.30	0.22	0.65	0.65	0.22

Table 8 Inhalation exposure expressed as a percentage of the UK Committee on Toxicology's Tolerable Daily Intake for dioxins and dioxin-like PCBs including zero where congeners were not detected.

Sample	Units	Infant Resident	Child Resident 1-6	Schoolchild 6-11	Schoolchild 11-16	Adult Resident	Infant of farmer	Child of farmer 1-6	Farmer
Brent 95	%	1.1	1.1	0.51	0.51	0.36	1.1	1.1	0.38
Brent 96	%	1.76	1.76	0.81	0.81	0.58	1.76	1.76	0.6
Brent 97	%	1.59	1.59	0.74	0.73	0.53	1.59	1.59	0.55
Bromley 128	%	0.59	0.59	0.27	0.27	0.19	0.59	0.59	0.2
Bromley 129	%	1.07	1.08	0.5	0.49	0.36	1.07	1.08	0.37
Bromley 130	%	0.75	0.75	0.35	0.34	0.25	0.75	0.75	0.26
London 220	%	0.42	0.42	0.19	0.19	0.14	0.42	0.42	0.14
London 221	%	0.97	0.97	0.45	0.45	0.32	0.97	0.97	0.33
London 222	%	0.58	0.58	0.27	0.27	0.19	0.58	0.58	0.2

Table 9 Inhalation exposure expressed as a percentage of the UK Committee on Toxicology's Tolerable Daily Intake for dioxins and dioxin-like PCBs including the detection limits where congeners were not detected.

Sample	Units	Infant Resident	Child Resident 1-6	Schoolchild 6-11	Schoolchild 11-16	Adult Resident	Infant of farmer	Child of farmer 1-6	Farmer
Brent 95	%	2.77	2.78	1.28	1.28	0.92	2.77	2.78	0.95
Brent 96	%	5.32	5.33	2.46	2.45	1.76	5.32	5.33	1.82
Brent 97	%	4.72	4.72	2.18	2.17	1.56	4.72	4.72	1.62
Bromley 128	%	0.59	0.59	0.27	0.27	0.19	0.59	0.59	0.2
Bromley 129	%	35.6	35.7	16.5	16.4	11.8	35.6	35.7	12.2
Bromley 130	%	4.37	4.37	2.02	2.01	1.44	4.37	4.37	1.5
London 220	%	53.9	53.9	24.9	24.8	17.8	53.9	53.9	18.5

London 221	%	57.8	57.8	26.7	26.6	19.1	57.8	57.8	19.8
London 222	%	6.29	6.3	2.91	2.89	2.08	6.29	6.3	2.16

Table 10 Analytical Results for PAHs from the London sites and associated field blank

Sample	Brent 95	Brent 96	Brent 97	Bromley 128	Bromley 129	Bromley 130	London B220	London B221	London B222	Field Blank
Compound	µg	µg	µg	µg	µg	µg	µg	µg	µg	µg
Napthalene	2.1	1.7	2.3	3.9	5.6	<0.4	<0.4	1.6	1.4	<0.4
2-Methyl Napthalene	1.9	1.6	1.7	2.7	4.4	1.5	<0.2	2.1	1.4	<0.2
1-Methyl Napthalene	1.3	0.95	0.93	1.6	2.6	0.93	0.15	1.3	0.94	<0.1
Biphenyl	1.5	1.5	1.1	2.8	2.7	1.4	0.61	1.8	1.5	<0.1
Acenaphthylene	1.8	1.5	1.4	3.7	4.7	3.3	0.9	2.2	1.7	<0.01
Acenaphthene	1.3	1.3	1.3	1.6	1.4	1	0.81	1.1	1	<0.03
Fluorene	4.5	9.4	6.3	9	9.7	9.6	3.3	1.8	2.1	0.012
Phenanthrene	24	17	16	43	19	27	9.3	3.6	4.7	<0.04
Anthracene	1.6	2	1.3	6.2	3	3.7	0.61	0.33	0.32	<0.01
2-Methyl Phenanthrene	4.2	3	2.7	9.4	3.8	6	2.2	0.69	1	<0.01
2-Methyl Anthracene	0.44	0.55	0.36	1.9	0.99	1.4	0.18	0.1	0.098	<0.01
1-Methyl Anthracene	2.5	2	1.7	5.9	2.5	3.6	1.6	0.48	0.72	<0.01
1-Methyl Phenanthrene	2.4	1.8	1.7	5.2	2.1	3.3	1.3	0.42	0.62	<0.01
9-Methyl Anthracene	0.022	0.034	0.022	0.071	0.054	0.058	0.011	<0.01	<0.01	<0.01
4,5-Methylene Phenanthrene	2	1.5	1.3	4	1.7	2.5	0.78	0.28	0.37	<0.01
Fluoranthene	2.9	2.4	2.3	5	2.2	3.4	0.83	0.37	0.55	<0.01
Pyrene	2.5	2	1.8	4.7	2.1	3.3	0.74	0.34	0.49	<0.01
Retene	0.73	0.62	0.68	0.61	0.32	0.52	0.2	0.096	0.12	<0.02
Benzo[c]phenanthrene	0.16	0.19	0.13	0.22	0.12	0.15	0.037	0.03	0.029	<0.01
Benzo[a]anthracene	0.45	0.78	0.47	0.71	0.51	0.56	0.15	0.15	0.13	<0.01
Chrysene	0.68	0.91	0.58	0.84	0.62	0.64	0.16	0.17	0.14	<0.01

Sample	Brent 95	Brent 96	Brent 97	Bromley 128	Bromley 129	Bromley 130	London B220	London B221	London B222	Field Blank
Compound	µg	µg	µg	µg	µg	µg	µg	µg	µg	µg
Cyclopenta[c,d]pyrene	0.19	0.28	0.18	0.23	0.24	0.17	0.052	0.072	0.042	<0.01
Benzo[b]naph[2,1-d]thiophene	0.022	0.029	0.021	0.028	0.017	0.016	<0.01	<0.01	<0.01	<0.01
5-Methyl Chrysene	0.038	0.065	0.045	0.057	0.04	0.043	0.012	0.013	0.01	<0.01
Benzo[b+j]fluoranthene	1.1	1.4	0.8	1.3	0.84	0.85	0.27	0.26	0.21	<0.01
Benzo[k]fluoranthene	0.11	0.071	0.069	0.077	0.064	0.054	0.017	0.029	0.015	<0.01
Cholanthrene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Benzo[e]pyrene	0.43	0.64	0.35	0.62	0.41	0.44	0.11	0.11	0.083	<0.01
Benzo[a]pyrene	0.27	0.47	0.35	0.42	0.36	0.36	0.094	0.12	0.1	<0.01
Perylene	0.042	0.067	0.051	0.055	0.053	0.059	<0.01	0.013	0.011	<0.01
Indeno[1,2,3-cd]pyrene	0.5	0.73	0.47	0.75	0.5	0.56	0.13	0.13	0.11	<0.01
Dibenzo[ah/ac]anthracene	0.054	0.088	0.059	0.071	0.054	0.049	0.014	0.02	0.014	<0.01
Benzo[ghi]perylene	0.59	0.84	0.47	0.89	0.62	0.72	0.15	0.15	0.14	<0.06
Anthanthrene	0.043	0.053	0.04	0.048	0.063	0.038	0.012	0.021	0.013	<0.01
Dibenzo[al]pyrene	0.04	0.06	0.037	0.045	0.037	0.035	<0.01	0.011	<0.01	<0.01
Dibenzo[ae]pyrene	0.059	0.095	0.053	0.079	0.064	0.065	0.018	0.02	0.013	<0.01
Dibenzo[ai]pyrene	0.022	0.038	0.024	0.015	0.021	0.019	<0.01	<0.01	<0.01	<0.01
Dibenzo[ah]pyrene	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Coronene	0.24	0.4	0.21	0.52	0.28	0.37	0.099	0.089	0.068	0.016

Table 11 PAH Concentrations from the London PAH Network sites before during and after the Buncefield fire.

Sample	Brent 95	Brent 96	Brent 97	Bromley 128	Bromley 129	Bromley 130	London B220	London B221	London B222
Compound	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³
Napthalene	1.26	2.15	2.38	2.8	10	<0.51	<0.98	4.19	2.8
2-Methyl Napthalene	1.14	2.03	1.76	1.94	7.02	1.92	<0.49	5.5	2.8
1-Methyl Napthalene	0.78	1.2	0.96	1.15	4.15	1.19	0.37	3.4	1.88
Biphenyl	0.9	1.9	1.14	2.01	4.31	1.79	1.5	4.71	3
Acenaphthylene	1.08	1.9	1.45	2.65	7.5	4.23	2.21	5.76	3.39
Acenaphthene	0.78	1.65	1.35	1.15	2.24	1.28	1.99	2.88	2
Fluorene	2.7	11.91	6.52	6.45	15.49	12.31	8.09	4.71	4.19
Phenanthrene	14.42	21.53	16.56	30.83	30.33	34.61	22.8	9.43	9.38
Anthracene	0.96	2.53	1.35	4.45	4.79	4.74	1.5	0.86	0.64
2-Methyl Phenanthrene	2.52	3.8	2.79	6.74	6.07	7.69	5.39	1.81	2
2-Methyl Anthracene	0.26	0.7	0.37	1.36	1.58	1.79	0.44	0.26	0.2
1-Methyl Anthracene	1.5	2.53	1.76	4.23	3.99	4.62	3.92	1.26	1.44
1-Methyl Phenanthrene	1.44	2.28	1.76	3.73	3.35	4.23	3.19	1.1	1.24
9-Methyl Anthracene	0.01	0.04	0.02	0.05	0.09	0.07	0.03	<0.03	<0.02
4,5-Methylene Phenanthrene	1.2	1.9	1.35	2.87	2.71	3.21	1.91	0.73	0.74
Fluoranthene	1.74	3.04	2.38	3.58	3.51	4.36	2.03	0.97	1.1
Pyrene	1.5	2.53	1.86	3.37	3.35	4.23	1.81	0.89	0.98
Retene	0.44	0.79	0.7	0.44	0.51	0.67	0.49	0.25	0.24
Benzo[c]phenanthrene	0.1	0.24	0.13	0.16	0.19	0.19	0.09	0.08	0.06
Benzo[a]anthracene	0.27	0.99	0.49	0.51	0.81	0.72	0.37	0.39	0.26
Chrysene	0.41	1.15	0.6	0.6	0.99	0.82	0.39	0.45	0.28
Cyclopenta[c,d]pyrene	0.11	0.35	0.19	0.16	0.38	0.22	0.13	0.19	0.08

Sample	Brent 95	Brent 96	Brent 97	Bromley 128	Bromley 129	Bromley 130	London B220	London B221	London B222
Compound	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³
Benzo[b]naph[2,1-d]thiophene	0.01	0.04	0.02	0.02	0.03	0.02	<0.02	<0.03	<0.02
5-Methyl Chrysene	0.02	0.08	0.05	0.04	0.06	0.06	0.03	0.03	0.02
Benzo[b+j]fluoranthene	0.66	1.77	0.83	0.93	1.34	1.09	0.66	0.68	0.42
Benzo[k]fluoranthene	0.07	0.09	0.07	0.06	0.1	0.07	0.04	0.08	0.03
Cholanthrene	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01	<0.02	<0.03	<0.02
Benzo[e]pyrene	0.26	0.81	0.36	0.44	0.65	0.56	0.27	0.29	0.17
Benzo[a]pyrene	0.16	0.6	0.36	0.3	0.57	0.46	0.23	0.31	0.2
Perylene	0.03	0.08	0.05	0.04	0.08	0.08	<0.02	0.03	0.02
Indeno[1,2,3-cd]pyrene	0.3	0.92	0.49	0.54	0.8	0.72	0.32	0.34	0.22
Dibenzo[ah/ac]anthracene	0.03	0.11	0.06	0.05	0.09	0.06	0.03	0.05	0.03
Benzo[ghi]perylene	0.35	1.06	0.49	0.64	0.99	0.92	0.37	0.39	0.28
Anthanthrene	0.03	0.07	0.04	0.03	0.1	0.05	0.03	0.05	0.03
Dibenzo[al]pyrene	0.02	0.08	0.04	0.03	0.06	0.04	<0.02	0.03	<0.02
Dibenzo[ae]pyrene	0.04	0.12	0.05	0.06	0.1	0.08	0.04	0.05	0.03
Dibenzo[ai]pyrene	0.01	0.05	0.02	0.01	0.03	0.02	<0.02	<0.03	<0.02
Dibenzo[ah]pyrene	<0.01	<0.01	<0.01	<0.01	<0.02	<0.01	<0.02	<0.03	<0.02
Coronene	0.14	0.51	0.22	0.37	0.45	0.47	0.24	0.23	0.14

Table 12 PAH Concentrations in the Met Office Flight Filters

Sample	Exposure 1 Flight	Exposure 2 Flight	Exposure 3 Flight	Exposure 3 Flight	Exposure 4 Flight	Exposure 4 Flight
Analysing Laboratory	Harwell Scientifics Ltd	Harwell Scientifics Ltd	Harwell Scientifics Ltd	Health and Safety Lab.	Harwell Scientifics Ltd	Health and Safety Lab.
Units	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³
Napthalene	<3.7	<6.2	<1.14	<0.1	<0.38	0.16
2-Methyl Napthalene	<1.9	<3.1	<0.38	n/m	<0.13	n/m
1-Methyl Napthalene	<1.7	<2.8	<0.76	n/m	<0.25	n/m
Biphenyl	<0.6	<0.9	<0.19	n/m	<0.063	n/m
Acenaphthylene	0.05	0.04	<0.04	n/m	<0.013	n/m
Acenaphthene	<2	<3	1.22	<0.1	0.58	0.2
Fluorene	<0.2	0.3	<0.11	n/m	<0.038	n/m
Phenanthrene	0.7	1.3	<0.76	<0.1	<0.25	0.8
Anthracene	0.1	0.2	<0.04	<0.1	<0.013	0.1
2-Methyl Phenanthrene	<0.2	<0.3	<0.23	n/m	<0.076	n/m
2-Methyl Anthracene	0.02	0.02	0.01	n/m	0.006	n/m
1-Methyl Anthracene	0.5	0.4	<0.19	n/m	<0.063	n/m
1-Methyl Phenanthrene	<0.1	<0.2	<0.11	n/m	<0.038	n/m
9-Methyl Anthracene	<0.002	<0.005	0.008	n/m	<0.003	n/m
4,5-Methylene Phenanthrene	0.03	0.06	0.69	n/m	<0.05	n/m
Fluoranthene	0.2	0.5	<0.11	n/m	0.23	n/m
Pyrene	0.3	0.6	0.072	1.4	0.34	3.6
Retene	0.3	0.4	<1.14	n/m	<0.38	n/m
Benzo[c]phenanthrene	0.02	0.06	<0.03	n/m	0.035	n/m
Benzo[a]anthracene	0.02	0.03	0.05	0.9	0.011	0.2

Sample	Exposure 1 Flight	Exposure 2 Flight	Exposure 3 Flight	Exposure 3 Flight	Exposure 4 Flight	Exposure 4 Flight
Analysing Laboratory	Harwell Scientifics Ltd	Harwell Scientifics Ltd	Harwell Scientifics Ltd	Health and Safety Lab.	Harwell Scientifics Ltd	Health and Safety Lab.
Units	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³	ng/m ³
Chrysene	0.02	0.2	<0.04	<0.1	0.063	0.2
Cyclopenta[c,d]pyrene	0.04	0.1	0.53	n/m	0.43	n/m
Benzo[b]naph[2,1-d]thiophene	0.02	0.01	<0.038	n/m	<0.013	n/m
5-Methyl Chrysene	0.002	0.004	<0.11	n/m	<0.038	n/m
Benzo[b+j]fluoranthene	0.3	0.3	0.25	<0.1	0.047	0.1
Benzo[k]fluoranthene	<0.004	0.03	<0.011	<0.1	0.008	<0.1
Cholanthrene	<0.004	0.006	0.016	n/m	<0.005	n/m
Benzo[e]pyrene	0.1	0.2	<0.08	n/m	0.07	n/m
Benzo[a]pyrene	0.012	0.046	0.012	<0.1	0.05	0.4
Perylene	0.02	0.06	<0.004	n/m	0.01	n/m
Indeno[1,2,3-cd]pyrene	0.1	0.2	<0.38	<0.1	<0.13	<0.2
Dibenzo[ah/ac]anthracene	<0.02	<0.03	<0.027	n/m	<0.009	n/m
Benzo[ghi]perylene	0.4	0.7	0.46	<0.1	0.16	<0.3
Anthanthrene	0.01	0.008	<0.015	n/m	<0.005	n/m
Dibenzo[al]pyrene	0.004	0.02	0.009	n/m	0.002	n/m
Dibenzo[ae]pyrene	0.03	0.04	<0.004	n/m	0.003	n/m
Dibenzo[ai]pyrene	0.03	<0.003	<0.004	n/m	<0.001	n/m
Dibenzo[ah]pyrene	0.01	<0.003	<0.004	n/m	<0.001	n/m
Coronene	<0.6	<0.9	<0.38	n/m	<0.13	n/m

n/m – not measured

Appendix G – Further Analysis of samples from London PAH network sites during the Buncefield fire

Letter report from Peter Coleman (Netcen) to Janet Dixon (Defra)

FURTHER ANALYSIS OF SAMPLES FROM LONDON PAH NETWORK SITES DURING THE BUNCEFIELD FIRE

We have now received the analytical results from the analysis of samples from the three London PAH network sites before, during and nominally after the Buncefield fire, together with additional samples that Defra requested to be analysed (additional samples before and after the Buncefield fire and analysis of the contemporary samples from the Hove site).

The samples previously analysed were from Brent (Kingsbury High School) canister numbers 95, 96, 97, London (Victoria Street) canisters 220, 221, 222, and Bromley (Crystal Palace Parade) canisters 128, 129, 130. These samples were analysed for polychlorinated-*p*-dioxins, polychlorinated dibenzofurans (dioxins), polychlorinated biphenyls (PCBs) and polycyclic hydrocarbons (PAHs).

Since the reporting of the results of these air sampling canisters, Netcen has also, at the request of Defra, analysed the following air sampling canisters for PAH and - in some cases - polychlorinated-*p*-dioxins and polychlorinated dibenzofurans (dioxins), details are provided below:

CANISTERS:	PAH	DIOXINS
Brent 94	✓	
Brent 98	✓	✓
Bromley 127	✓	
Bromley 131	✓	✓
London 219	✓	
London 223	✓	✓
Hove 91	✓	
Hove 92	✓	
Hove 93	✓	

This letter report will only discuss results for the analysis of PAH and Dioxins in the samples from the South East of England, as well as the concentrations found at the sites before, during and after the Buncefield fire. The fire is reported to have started in the early morning of the 11th December and to be been mainly extinguished by midday on the 14th December 2005.

South East of England PAH Network Site Samples

ANALYSIS

Each of the network canisters was extracted in dichloromethane and then in the case of samples from the three London sites extracted after the incident toluene. The extracts were then combined, reduced to a smaller volume and passed through an open column clean-up treatment to separate the dioxins, furans, PAH and PCBs from the other species present in the extract. The dioxin and furan samples were then passed through a gas chromatograph to separate the isomers of interest from each other and then quantified using a high-resolution mass spectrometer. The PAHs were analysed by gas chromatography quadrupole mass spectrometry following a UKAS accredited approach.

RESULTS

Dioxins

Blank Analysis

The analysis of the blank canister revealed no detectable levels of 2,3,7,8 chlorine substituted dioxin or furan congeners.

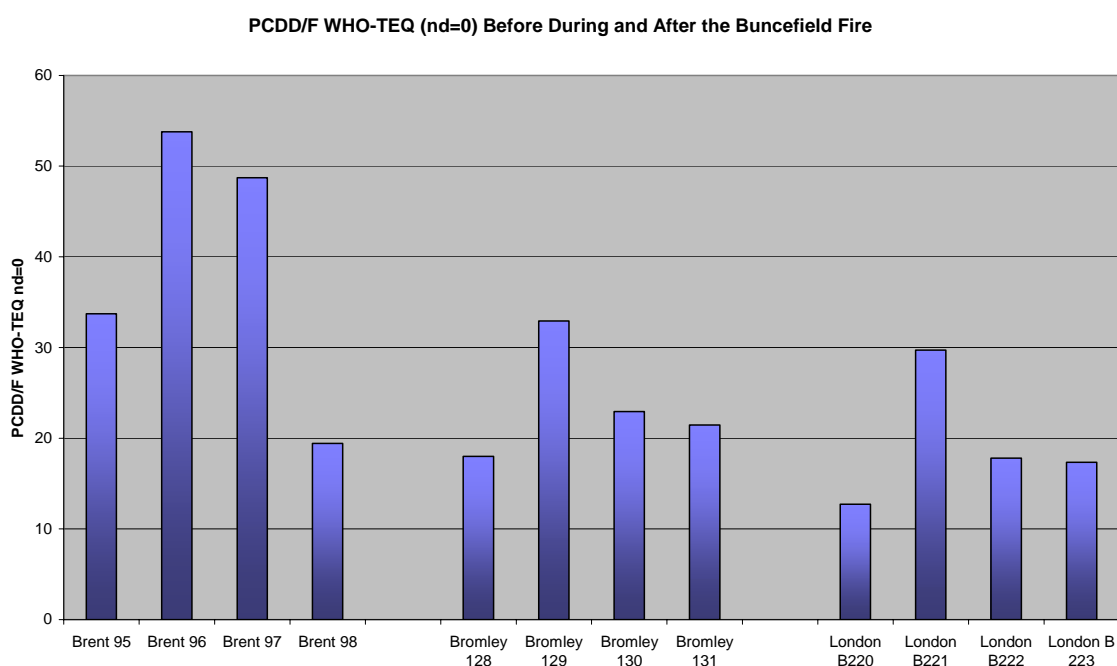
Air Samples

The concentrations of the 2,3,7,8 chlorine substituted dioxins measured in the nine samples were generally above the levels found in the blank. Blank results have not been subtracted from samples.

The concentrations of the congeners including the toxic equivalence are shown in Table 2, together with the toxic equivalence expressed as the mass of the most toxic congener, 2378 TCDD; this would have the same health effect as the mixture present in the sample according to both the International and World Health Organisation (WHO) approaches. The International Toxic Equivalence Factors (TEFs) are slightly different. The WHO approach usually includes the dioxin-like PCBs. However, in this report, these have not been included, as not all samples have been analysed for PCBs. Hence the values given in Table 2 are only for the dioxins.

As reported previously, it can be seen that the concentrations of dioxins measured in the samples from the periods that encompass the Buncefield fire are greater in toxic equivalent terms (both ITEQ and WHO TEQ_(dioxins only)) than the sample before or the two samples following the fire being extinguished. While the increase in toxic equivalent is consistent between the three sites, the change in profiles within the three groups of samples is not consistent. Hence there is no evidence that any particular congener or group of congeners was elevated at all sites as a direct result of the Buncefield fire. The increase in the toxic equivalence appears to be caused by increases in congener concentrations, which vary between the three sites. This suggests that the source of the increase was not consistent at the three sites and was therefore unlikely to have been the Buncefield incident.

The Figure below show the observed concentrations expressed as WHO TEQ_(dioxins only) for the three sites before during and after the Buncefield fire.



It can be seen from this figure that the magnitude of the increases in WHO TEQ do not correspond with the geographical relationship between Buncefield and the sampling sites. If a close relationship were found, it would be expected that the levels would be elevated more at Brent than London and more at London than Bromley. The additional analysis of the fourth sample in the graph is the period of the Christmas and New Year holidays.

Results - PAHs

PAH concentration results are shown in the two tables below. As reported previously, only two PAHs were detected in the field blank: fluorene and coronene. The fluorene result is less than 1% of the amounts found in the other samples and the coronene result is less than 10% of 6 of the 9 samples. The field blank results have not been subtracted.

The results show that the concentrations of most PAHs measured at the four sites were greater during the Buncefield fire period than during the periods immediately before or after. The ratio of the concentration that encompassed the Buncefield fire to the average of all of the surrounding monitoring periods analysed have been calculated for each of the PAH and an average, a maximum and a minimum obtained. These ratios are shown below, together with the number of PAH ratios greater and less than 1:

	Brent	Bromley	London 2a	Hove
Average Ratio	1.94	1.63	1.12	1.24
Maximum	3.21	4.83	2.87	2.03
Minimum	0.57	0.58	0.48	0.50
Number >1	38	35	13	34
Number <1	1	4	26	5

The average ratios of the Buncefield fire period to the surrounding periods are all above one. However the ratios of the individual PAH concentrations vary greatly between PAHs. For Brent Bromley and Hove, there appear to be many more ratios which are greater than 1. For the London sites, by contrast, it is apparent that there are a larger number of ratios that are less than 1.

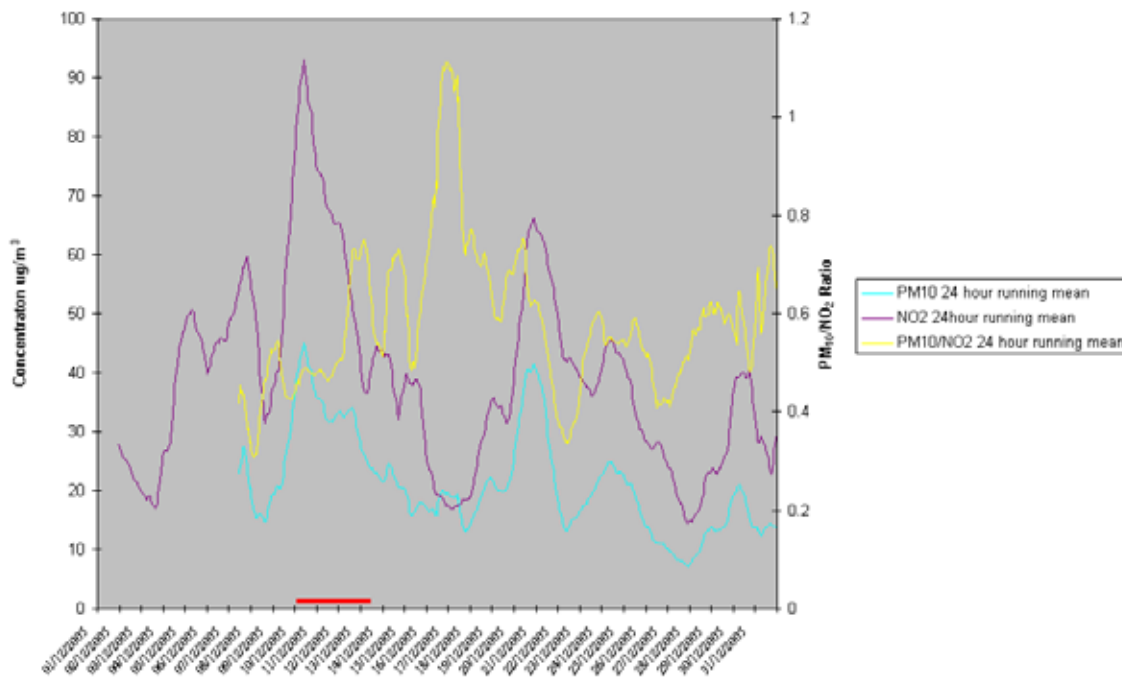
There does not appear to be any particular trend in the ratios of during the fire to the surrounding periods for particular PAH at the four sites.

The corresponding ratios for benzo [a] pyrene, B[a]P are shown below:

	Brent	Bromley	London 2a	Hove
B[a]P Ratio	1.66	1.16	0.83	1.29

The above data show that the all of the sites except London show an increase in concentrations of B[a]P.

The only site of these four with contemporaneous PM₁₀ and nitrogen dioxide measurements was London Brent. However, there is no evidence from investigating these PM₁₀ to NO₂ ratios that any significant change in pollution climate occurred during the Buncefield incident. The figure below shows the change in these three parameters during December 2005.



DISCUSSION

The London and Hove PAH network samples provide some evidence that, during the week in which the Buncefield oil depot was burning, measured concentrations of dioxins and PAHs increased at the four PAH network sites in South East England—London Brent, London Victoria Street, London Bromley and Hove. As reported previously, however, the increase in concentrations during the fire does not appear to follow that would be expected from the proximity of the individual sites to the fire.

The lack of consistency in the concentration profiles of individual compounds at the sites indicates that the increased concentrations observed during the period cannot be confidently attributed to emissions from the Buncefield fire. The lack of consistency in the profiles of the PAHs and dioxins, together with the lack of evidence of increased PM₁₀ concentrations at the Brent sites during or just after the Buncefield fire, suggests that the observed increases may simply be due to normal temporal variations.

Appendix H – Role and Activities of Health Protection Agency (HPA) in relation to air quality issues associated with the Buncefield Incident

Role and Activities of Health Protection Agency in relation to the Buncefield Incident

H1 Introduction

On Sunday, 11th December at 06.00, a series of explosions started what was reputed to have been the largest fire in Europe for the past five decades. The fire continued over four days, causing a black plume of smoke that covered tens of kilometres, even visible on satellite images, heading south over London and ultimately towards mainland Europe.

This annex summarises the atmospheric modelling and monitoring that was carried out during and after the incident and how this was used by the Chemical Hazards and Poisons Division (CHaPD) of the Health Protection Agency (HPA) for exposure assessment and toxicological risk assessment. It explains how this data was used to provide HPA advice to the Strategic Co-ordinating Group (SCG) at Hertfordshire Police Headquarters during the first four days of the incident. In addition, it details how the HPA has taken forward further actions since the acute response stage of the incident.

H1.1 The Health Protection Agency

The HPA's role is to provide an integrated approach to protecting UK public health through the provision of support and advice to the National Health Service (NHS), local authorities, emergency services, other Arms Length Bodies, the Department of Health and the Devolved Administrations. The Agency was established as a Special Health Authority (SpHA) in 2003. On 1 April 2005, the HPA was established as a non-departmental public body, replacing the HPA SpHA and the National Radiological Protection Board (NRPB) and with radiation protection as part of health protection incorporated in its remit.

The HPA Act 2004 sets out the functions of the HPA as "to protect the community (or any part of the community) against infectious diseases and other dangers to health".

In addition to the HPA's role in reducing the dangers to health from infections, chemical and radiation hazards, it also provides support to, and works in partnership with others who have health protection responsibilities and advises, through the Department of Health, all government departments and Devolved Administrations throughout the UK. In England, the HPA provides the local health protection services which in the rest of the UK are delivered by the three other lead health protection bodies; the National Public Health Service Wales; Health Protection Scotland; the Department of Health and the Social Services and Public Safety, Northern Ireland. The HPA works closely with all these organisations.

At the UK level, the HPA is responsible for providing information and services to support a co-ordinated and consistent UK public health response to national level emergencies (Health Protection Agency, 2006d) within its role as a Category One Responder under the Civil Contingencies Act (UK Resilience, 2006).

H1.2 Chemical Hazards and Poisons Division

The Chemical Hazards and Poisons Division (ChaPD), part of the Centre for Radiation, Chemical and Environmental Hazards (CRCE), provides comprehensive expert advice and support for chemical incidents across England and Wales (Health Protection Agency, 2006a).

The Division provides advice to UK Government Departments and Agencies on human health effects from chemicals in water, soil and waste as well as information and support to the NHS and health professionals on toxicology.

The Division's Strategic Goal is to anticipate and prevent the adverse effects of acute and chronic exposure to hazardous chemicals and other poisons.

Exposure to hazardous substances can also occur during accidents at home and work, and as a result of deliberate, malicious releases. The long-term consequences of low level, chronic exposure to chemicals and poisons are currently not well understood and there is increasing public concern over their possible impact, especially in relation to reproductive health, asthma and cancers. The Division is undertaking intensive research to improve our understanding of these issues.

The HPA provides authoritative scientific and medical advice to the NHS and other bodies about the known health effects of chemicals, poisons and other environmental hazards. This advice covers clinical issues such as:

- Personal protective equipment
- Decontamination and evacuation
- Toxicological and epidemiological advice on impact on public health
- Clinical advice on antidotes and medical treatment
- The public health impact of industrial sites
- Health effects from chemicals in the environment (including water, soil, waste)

Guidance is available round-the-clock from medical toxicologists, clinical pharmacologists, environmental scientists, epidemiologists and other specialists. The Division also advises doctors and nurses on the best way to manage patients who have been poisoned, through a contract with the National Poisons Information Service (NPIS).

The CHaPD head office is located in Chilton, Oxfordshire, there are four specialist centres in Birmingham, Cardiff, London and Newcastle.

The CHaPD works closely with and in support of the Local and Regional Services (LaRS) of the HPA (Health Protection Agency, 2006c).

H2 CHaPD role in the Buncefield incident

On Day 1 (11.12.05) at 06.00 hours the first of a series of explosions began, that resulted in a huge fire producing a massive visible smoke plume covering London and the South East of England. A major incident was declared at 06.08 hours and command and control set up near the site (operational) within minutes, with strategic command in place at the Hertfordshire Police Headquarters by 09.00 hours. A decision was made at 09.00 hours to evacuate those with damaged homes and workplaces, and to tell everyone under the plume to shelter, 'go in, stay in, tune in'. Strategic command continued until 18.30 hours on Day 4 (14.12.05). There was extensive media news coverage locally, nationally and internationally.

The co-ordination and management framework at any incident identifies three layers or tiers of inter-linked leadership and co-ordination:

- Operational - **Bronze**
- Tactical - **Silver**
- Strategic - **Gold**

Representation of all agencies deployed to resolve the Buncefield incident, was established through a meeting process known as the Strategic Co-ordinating Group (SCG) also known as Gold Command (UK resilience, 2006). This Group had its first multi-agency meeting at 09.00 hours on Sunday 11th December at Hertfordshire Police Head Quarters which was chaired by the Police SCG Commander. The SCG remained in place until Wednesday 14th December. SCG relied on a process of advice and discussion to reach decisions that ensured that the implementation of strategic aims was delivered by the Tactical and Operational tiers. Health advice was provided to the Strategic Co-ordinating Group (SCG) by the Health Advice Team (HAT), which had representation from both the NHS and HPA (Department of Health, 2006).

The SCG provided opportunity for continuous collaboration and co-ordination with all present including police, fire, ambulance, NHS, Environment Agency, Local Authorities, Government Office for East of England and other agencies such as the Food Standards Agency. It also allowed for occupational health services for relevant organisations to

become involved. LaRS and CHaPD provided continuous support throughout the duration of the SCG.

The provision of accurate, timely public information is vital in an emergency and on this basis the Communications Division of the Health Protection Agency was able to inform and reinforce the health advice provided by strategic gold. The Communications Division ensured that the residents of Hemel Hempstead and the public in general had access to health advice via the Agency's website and through regular media statements. The Division adopted a networked approach to managing the huge volume of media enquiries and requests for information. The regional communications manager for the HPA East of England provided support to strategic health gold and was responsible for briefing and supporting local Agency spokespeople particularly the consultants in communicable disease control. The CHaPD communications team fielded the specialists in air pollution who were able to explain what was being investigated in terms of air quality monitoring.

Additional support was provided by the communications managers based at the Health Protection Agency's London headquarters who briefed and supported the Agency's Chief Executive who acted as spokesperson for the Agency. Once the fire was extinguished the regional communications manager worked in collaboration with the local primary care trust communications manager on media activities to explain the continued health monitoring and surveillance of residents and frontline workers involved in putting out the fire.

Section H2.1 outlines a timeline of CHaPD's involvement with the Buncefield incident, especially with regard to air quality monitoring and modelling. This expands the timeline given in Section 2. The activities undertaken by HPA in other areas related to the incident are not included in this timeline, or only very briefly mentioned. These areas are:

- (i) Advice provided since 11 December on health impact assessment including health surveillance and epidemiological follow up
- (ii) Aspects in relating to early assessment of psychological impacts and psychologically-mediated health impacts.
- (iii) Possible water contamination aspects and related human exposure/toxicology issues

H2.1 CHaPD Buncefield incident timeline targeting air quality monitoring and modelling activities

Date	Time	Action
11/12/2005	06.00	Explosions at Buncefield oil depot.
	06.50	CHaPD informed of an explosion at an oil storage depot.
	08.15	CHaPD contacted the Met Office. A Chemical Meteorological (CHEMET) forecast had been run but; it had not been requested. The Numerical Atmospheric-dispersion Modelling Environment (NAME) model was also being run. CHaPD requested that the results be forwarded to them.
	08.50	CHaPD arrived at SCG.
	08.50	CHaPD contacted Met Office to get models sent via email and fax.
	09.00	CHaPD, via SCG, advised members of the public to 'go in, stay in; tune in' and for those with houses damaged by the explosion to follow police advice to evacuate. CHaPD shown COMAH site plan and Material Safety Data Sheets for the products involved.
	09.45	CHaPD started collaborating with Local and Regional Services (LaRS) and the NHS on health impact assessment.
	10.30	CHaPD started organising locally targeted environmental sampling with help of Health and Safety Laboratory (HSL) and the Fire Brigade's Scientific Advisers.
	10.30	CHaPD started collaborating with Local and Regional Services (LaRS).and the NHS started organising surveillance activities.
	11.00	CHaPD started to receive satellite photographs, NAME models predicting plume dispersion over Southern England and across the Channel at different heights in the atmosphere.
	12.00	CHaPD involved with discussions about occupational health for responders.
	12.00	CHaPD started to provide advice about health surveillance activities via HAT at SCG.
	13.50	CHaPD consulted the UK's national Automatic Urban and Rural Network (AURN) to obtain real time data from UK fixed monitoring sites to advise Gold Command.
	16.00	HSL and Fire Brigade's Scientific Advisers arrived at SCG to agree sampling brief with CHaPD for locally targeted sampling.
	17.00	CHaPD contacted the Met Office. NAME model to be run for a 72-hour period.
	18.00	Results from HSL and Fire Brigade's Scientific Advisers start to arrive at SCG.
20.00	Further results from HSL and Fire Brigade's Scientific Advisers arrive at SCG.	
21.30	Further meeting on locally targeted environmental sampling held at SCG.	
12/12/2005	09.00	First discussions on possibility of further environmental sampling.
	09.35	CHaPD received NAME model outputs for different scenarios from the Met Office.
	10.45	CHaPD contacted Environmental Research Group (ERG) at Kings College for information regarding air quality in London and the south east.
	12.30	CHaPD informed about sampling being undertaken by the FAAM plane.
	12.55	Received further NAME models and satellite information from the Met Office.
	14.10	CHaPD meet with Fire Brigade's Scientific Advisers and HSL on site close to Tactical (Silver) Command regarding air quality monitoring.
	17.45	CHaPD informed by Fire Brigade's Scientific Advisers and HSL of the results of their air quality sampling. They had not detected significant concentrations of any of the chemicals monitored.

Date	Time	Action
13/12/2005	07.00	CHaPD received atmospheric dispersion modelling using Atmospheric Dispersion Modelling System (ADMS) and AERMOD from the Environment Agency predicting the location of the plume if it were to ground.
	07.15	CHaPD request asbestos sampling from the HSL.
	09.05	CHaPD contact Defra's air quality division. Netcen have been sent to the site to monitor particulate matter less than 10 µm (PM ₁₀) and volatile organic compounds (VOCs).
	09.55	HSL informed CHaPD that they did not detect any asbestos in the plume.
	11.10	CHaPD received preliminary information on air quality from Netcen.
	12.00	Decision made at CHaPD to sample soils and grasses using the results of the Environment Agency dispersion modelling and reports of the plume grounding.
	13.00	CHaPD contacted Netcen and requested hourly bulletins with air quality information.
	14.40	CHaPD received results of FAAM plane sampling.
	15.40	ERG set up an hourly email service to send detailed air quality information and summaries to CHaPD.
	19.00	CHaPD discussed VOC and particulate matter (PM) sampling with Netcen.
	19.25	Netcen results for the 12/11/05 sent to CHaPD. These did not indicate elevated concentrations of VOCs or PM.
14/12/2005	08.40	Fire Brigade's Scientific Advisers informed CHaPD that the results of the air quality sampling were typical of ambient levels of these chemicals for urban areas.
	09.00	Sampling teams mobilised by CHaPD to undertake sampling of soils and grasses.
	09.30	HSL inform CHaPD of the results of their polycyclic aromatic hydrocarbon (PAH) monitoring.
	12.10	CHaPD set up link with Surrey Health Protection Unit (HPU) requesting that if they receive any air quality information from their local authorities that they send it to CHaPD.
	18.30	SCG stood down.
	18.45	CHaPD informed by Fire Brigade's Scientific Advisers that levels of atmospheric chemicals detected at three schools were within ambient levels.
	19.30	Discussion for the need for an inter-agency liaison group started.
15/12/2005	09.00	Sampling strategy for further soil and vegetation sampling sent to RPD by CHaPD. Sample teams mobilised to the location of the peak ground level concentrations.
	11.45	Telephone conference to set up the Inter-Agency Liaison Group agreed.
16/12/2005	12.00	First meeting of Inter-Agency Liaison Group held at Drinking Water Inspectorate offices.
20/12/2005	16.05	CHaPD suggested that occupational health monitoring data for those on site during clean up could be used as surrogates for members of the public's exposure.

CHaPD has continued close contact with all agencies in assessing any ongoing air monitoring data to inform LaRS of any potential health impact. This work and other work are specified further in H9.

H.3 Modelling of the plume

H3.1 Chemical Meteorological (CHEMET) model

CHEMET is a service provided by the Emergency Response and Monitoring Centre (EMARC) within the UK Met Office as part of their responsibility for the provision of meteorological advice to the emergency services in the event of an accidental release of potentially hazardous substances into the atmosphere (Welch, 2006). The model quickly predicts an 'area at risk' which accounts for the likely path of the plume, as well as allowing for plume meander and drift (see Figure E1). The model is routinely forwarded to CHaPD and other agencies for use in response to chemical incidents.

The first CHEMET model was requested by the fire brigade at 08.14 on 11th December and sent to CHaPD offices, via email and fax and also to the HAT at SCG. The CHEMET model was run continuously on a three hourly basis during the incident. This model is designed to be very simple and quick to run to aid decisions, for incident response. However, important factors such as the nature of the chemical release are not considered. As a result the more complex Numerical Atmospheric-dispersion Modelling Environment (NAME) was used to assist with exposure assessments.

H3.2 NAME (Numerical Atmospheric-dispersion Modelling Environment)

The NAME model described in appendix E3 and Section 6 was run at regular intervals by the Met Office during the Buncefield incident and sent to CHaPD offices and the Health Advisory Team (HAT) at SCG command. The NAME model is not routinely used for small-scale chemical incidents and would only normally be used for larger scale incidents, involving the long-range transport of atmospheric pollutants.

The first NAME model outputs were received at approximately 10.00 on 11th December. The modelling predicted the spread of the plume over the time period of the incident, allowing HAT to determine where the areas of potential exposure were. The NAME model not only predicted the two dimensional spread of the plume, but also the plume spread at different heights (0 - 500 m, 500 - 1500 m, 1500 - 3000 m, 3000 - 6000 m, 6000 - 9000m and 9000 - 12000 m) in the atmosphere as seen in Figures H1 and H2. Note that this modelling was done using an arbitrary release rate as is commonly done in emergencies when there is no accurate information about the source term, therefore, the predicted concentrations are not absolute concentrations, rather they show the distribution of the chemicals in the atmosphere.

The model was regularly re-run with updated meteorological data and to incorporate additional release information, when it became available. This information, together with advice from the Met Office, informed CHaPD on the areas of potential exposure and allowed advice to SCG to be developed. The rapid delivery of these models to SCG aided quick decision-making and allowed the potential for plume deposition to be considered. The modelling also predicted deposition of the plume, which helped identify if, and where plume deposition would occur.

Figure H1 Output from the NAME model at different heights in the atmosphere at 09.00 on 11th December.

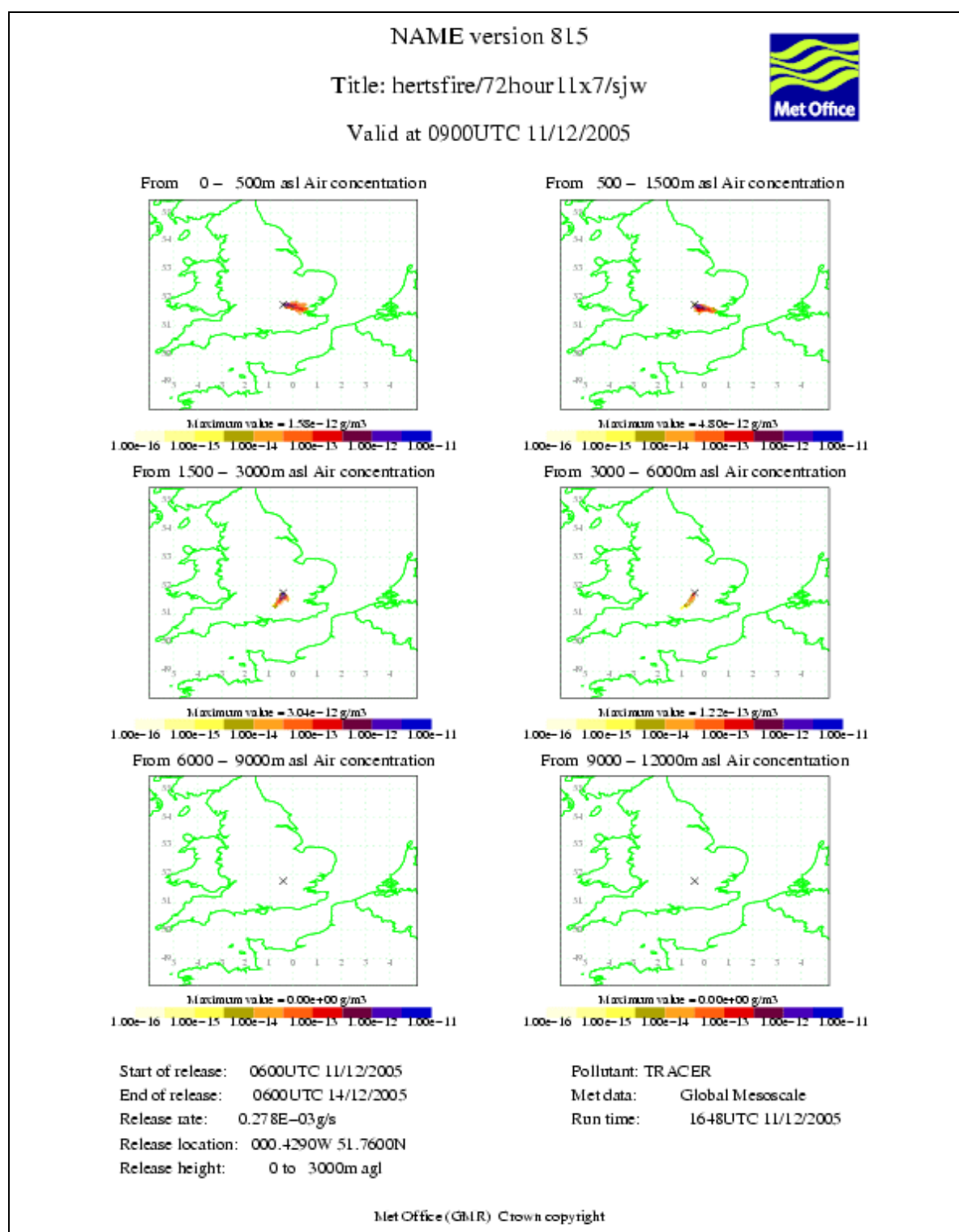
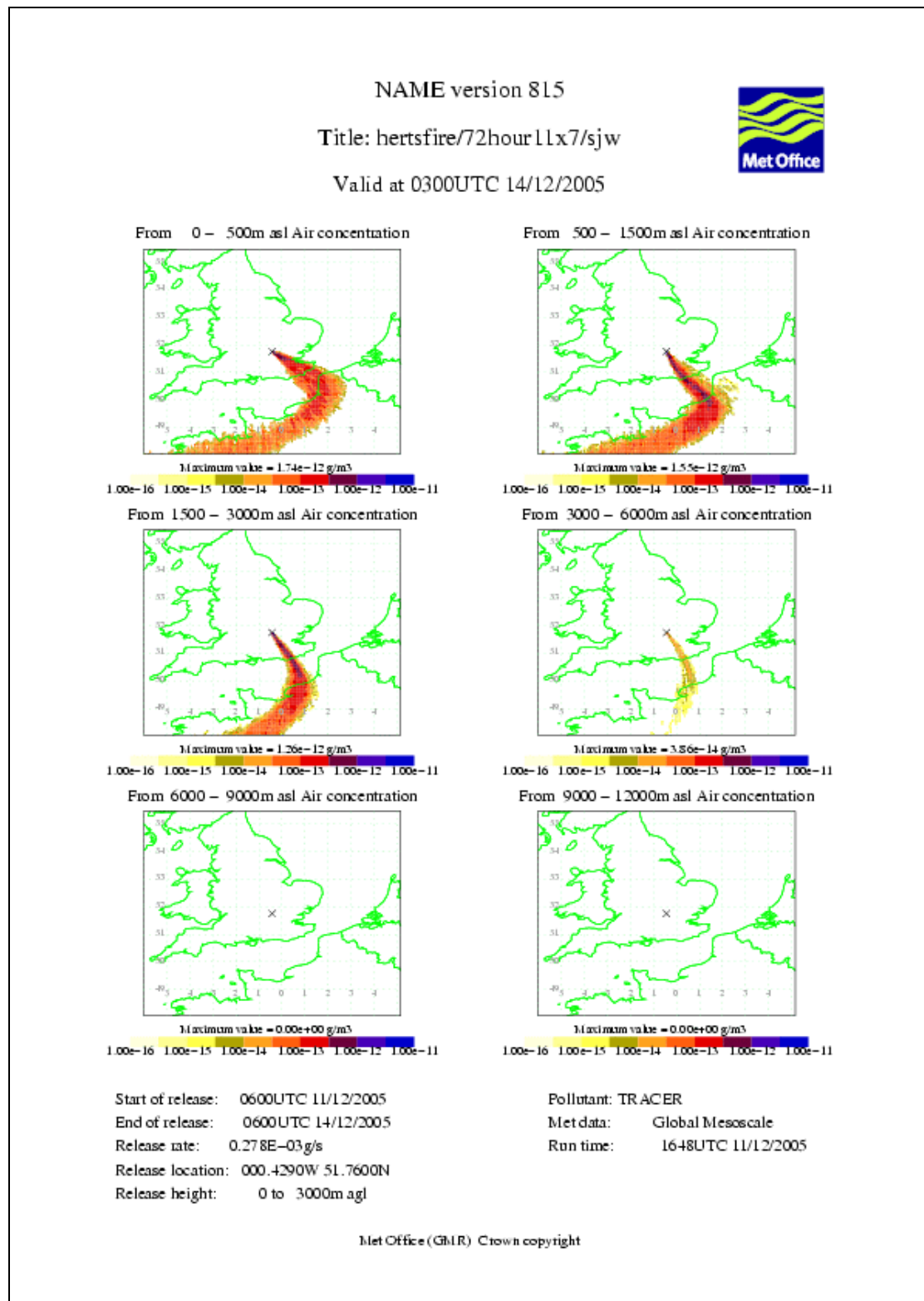


Figure H2 Output from the NAME model at different heights in the atmosphere at 03.00 on 14th December



H3.3 Satellite Imagery

Throughout the incident CHaPD received satellite images of the plume from the Met Office (see Figures 2.2 – 2.4 in Section 2). These images gave an indication of the geographical spread of the plume during the incident and supported the modelling data that were received in the forms of CHEMETs, NAME and visual observations on the ground, thereby assisting CHaPD to confirm which fixed local air quality monitoring stations were most likely to identify whether the plume was grounding.

H3.4 Environment Agency atmospheric dispersion modelling

The Environment Agency also conducted short-range atmospheric dispersion modelling using the models ADMS and AERMOD and the forecast meteorological data for the period 19.00 on 11th December to 24.00 on 14th December. ADMS and AERMOD are Gaussian plume models widely used in the UK to predict atmospheric dispersion of chemicals (Carruthers *et al.* 1994, Colvile, Briggs, & Nieuwenhuijsen 2003, Chemical Hazards and Poisons Division, 2006).

In order to predict the short range spread of the plume and the location of the maximum ground level concentration of pollution if the plume were to ground modeling was undertaken that included different plume rises (ranging from 100 to 500 m). CHaPD received the results for plume rises between 100m and 200m on the mornings of the 13th and 14th of December for the time periods 09.00 on 13th December and 12.00 on 14th December. The modelling output was overlaid on a map which together with outputs from the NAME models, CHEMETs and visual observations assisted CHaPD in determining the areas where grass and soil sampling should be conducted.

H4 Air quality monitoring

CHaPD considered that several strands of monitoring were required to provide advice for public health protection. These included:

- Locally targeted air monitoring
- Collection of samples from the plume
- Use of air quality monitoring networks
- Soil and grass samples from areas potentially at risk from plume deposition

H4.1 Locally targeted monitoring

Two expert groups were identified to provide locally targeted monitoring. These were the Fire Brigade's Scientific Advisers and the Health and Safety Laboratory (HSL) (see Sections 4.3 and 4.3.3). Both groups worked in order to address issues identified at the SCG. Sampling sites were agreed by the HAT and both groups conducted sampling at the same locations as far as possible.

H 4.1.1 Fire Brigade's Scientific Advisers

Hertfordshire Fire and Rescue Service requested the attendance of a team from the Fire Brigade's Scientific Advisers (Bureau Veritas) to monitor atmospheric chemicals which were possibly released from the fire (Bureau Veritas, 2006). For over thirty years, the scientific advisers have assisted the fire service by providing advice on chemical hazards and when necessary, attending incidents to help with detection, identification and monitoring of hazardous materials.

The Fire Brigade's Scientific Advisers sampled for the following chemicals: carbon dioxide, carbon monoxide, sulphur dioxide, hydrocarbons, particulates, volatile organic compounds (VOCs), hydrogen sulphide, ammonia and hydrogen fluoride at various locations close to the fire on a number of occasions during the incident. The air quality monitoring around the Buncefield site was performed using Dräger tubes, a Hapsite Smart (Inficon), running in 15min loop mode after an initial survey using the survey mode to locate the highest concentration of VOCs, a Dräger Miniwarn gas handheld gas detector and two particulate monitoring devices (Casella Microdust and AMS 950). No samples were taken by the Fire Brigade's Scientific Advisers for further analysis. Some of the equipment deployed is

designed to give immediate readings providing a snapshot of the local conditions although the Miniwarn and dust monitors were set up to give continuous real time readings.

As each stage of the monitoring was completed, the team's reports were communicated to SCG. The results of the sampling displayed in Tables H1 – H4 indicate that the air sampling did not suggest that the Buncefield incident caused a deterioration of air quality.

Table H1 Air quality monitoring results from Fire Brigade's Scientific Advisers 11/12/05

Location	Time	Chemical	Concentration (ppm) unless stated otherwise
St Albans Police Station Yard	17.55	Carbon monoxide	Not detected
	17.55	Carbon dioxide	No increase detected above normal background readings
	17.55	Hydrogen sulphide	Not detected
	17.55	Sulphur dioxide	Not detected
	17.55	Organic Compounds	No significant quantities detected
Approximately 50 m downwind of the fire	19.42	Carbon monoxide	Not detected
	19.42	Carbon dioxide	No increase detected above normal background readings
	19.42	Hydrogen sulphide	Not detected
	19.42	Sulphur dioxide	Not detected
	19.42	Organic Compounds	No significant quantities detected

**Table H2 Air quality monitoring results from Fire Brigade's Scientific Advisers
12/12/05**

Location	Time	Chemical	Concentration (ppm) unless stated otherwise
Junction of Maxted Road and Maxted Close	12:45	Organic Compounds	No significant quantities detected
	12:45	Particulates	0.223mg/m ³ (maximum level)
	12:45	Carbon dioxide	No increase detected above normal background readings
	12:45	Hydrogen sulphide	Not detected
	12:45	Hydrogen fluoride	Not detected
	12:45	Sulphur dioxide	Not detected
	12:45	Ammonia	Not detected
	12:45	Carbon monoxide	Not detected
Junction of Wood Lane End and Maylands Avenue	13.15	Organic Compounds	No significant quantities detected
	13.15	Particulates	0.361mg/m ³ (maximum level)
	13.15	Carbon dioxide	No increase detected above normal background readings
	13.15	Hydrogen sulphide	Not detected
	13.15	Hydrogen fluoride	Not detected
	13.15	Sulphur dioxide	Not detected
	13.15	Ammonia	Not detected
	13.15	Carbon monoxide	Not detected
Adeyfield School	14.00	Organic Compounds	No significant quantities detected
	14.00	Particulates	0.245mg/m ³ (maximum level)
	14.00	Carbon dioxide	No increase detected above normal background readings
	14.00	Hydrogen sulphide	Not detected
	14.00	Hydrogen fluoride	Not detected
	14.00	Sulphur dioxide	Not detected
	14.00	Ammonia	Not detected
	14.00	Carbon monoxide	Not detected
RC Church car park, Ritcroft Street	15:45	Organic Compounds	No significant quantities detected
	15:45	Particulates	1.300mg/m ³ (maximum level)
	15:45	Carbon dioxide	No increase detected above normal background readings
	15:45	Hydrogen sulphide	Not detected
	15:45	Hydrogen fluoride	Not detected
	15:45	Sulphur dioxide	Not detected
	15:45	Ammonia	Not detected
	15:45	Carbon monoxide	Not detected

**Table H3 Air quality monitoring results from Fire Brigade's Scientific Advisers
13/12/05**

Location	Time	Chemical	Concentration (ppm) unless stated otherwise
Tiny Toes nursery	10.10	Carbon monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Sulphur dioxide	Not detected
		Ammonia	Not detected
		Hydrogen Fluoride	Not detected
		Organic Compounds	No significant quantities detected
		Particulates (Casella Microdust Pro)	0.124mg/m ³ (Max) 0.095mg/m ³ (Mean)
Leapfrog Day Nursery	12.47	Carbon monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Sulphur dioxide	Not detected
		Ammonia	Not detected
		Sulphur dioxide	Not detected
		Organic Compounds	No significant quantities detected
		Particulates (AMS 950)	0.06mg/m ³ (Max) 0.02mg/m ³ (Mean)
Three Cherry Trees Caravan Site	15.02	Carbon monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Sulphur dioxide	Not detected
		Ammonia	Not detected
		Hydrogen Fluoride	Not detected
		Organic Compounds	No significant quantities detected
		Particulates (AMS 950)	0.1mg/m ³ (Max) 0.02mg/m ³ (Mean)
Particulate (Casella Microdust Pro)	0.124mg/m ³ (Max) 0.094mg/m ³ (Mean)		

**Table H4 Air quality monitoring results from Fire Brigade's Scientific Advisers
13/12/05**

Location	Time	Chemical	Concentration (ppm) unless stated otherwise
Two Waters School, High Ridge Road, Aps	12.45	Ammonia	Not detected
		Carbon monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Hydrogen fluoride	Not detected
		Sulphur dioxide	Not detected
		Particulates (Casella Microdust Pro)	0.149 mg/m ³ (Max) 0.036 mg/m ³ (Mean)
Woodfield School, Malmes Croft, Leverstock Green	14.00	Ammonia	Not detected
		Carbon monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Hydrogen fluoride	Not detected
		Sulphur dioxide	Not detected
		Particulates (Casella Microdust Pro)	0.105 mg/m ³ (Max) 0.059 mg/m ³ (Mean)
Abbots Langley School, Farsonage Close, Abbots Langley	14.45	Ammonia	Not detected
		Carbon Monoxide	Not detected
		Carbon dioxide	No increase detected above normal background readings
		Hydrogen sulphide	Not detected
		Hydrogen fluoride	Not detected
		Sulphur dioxide	Not detected
		Particulates (Casella Microdust Pro)	0.148 mg/m ³ (Max) 0.097 mg/m ³ (Mean)

H4.1.2 Air Sampling Strategy Used by HSL During the Buncefield Fire

At the request of CHaPD, the Health and Safety Laboratory (HSL) also conducted targeted local sampling to determine the impact of the fire upon air quality. Operating as an agency of the Health and Safety Executive (HSE), the HSL support the HSE's mission to protect people's health and safety by ensuring risks in the changing workplace are properly controlled (Health and Safety Laboratory, 2006a).

Methods summary

Sunday 11th December: Air sampling was undertaken at St Albans Police station and at the Buncefield Depot adjacent to the fire.

Samples were collected so that they could be subsequently analysed for total particulate, volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAH). Samples for total particulates were collected in accordance with Health & Safety Executive publication 'Method for determination of Hazardous Substances (MDHS) 14/3 'General Methods for sampling & gravimetric analysis of respirable & inhalable dust'. In brief, this method involves drawing air at a rate of 2 litres/minute through a pre- weighed GFA filter held in an IOM sampling head (Health and Safety Executive, 2006). The filters are subsequently reweighed and the weight gain expressed as micrograms per metre cubed of air (mg/m³).

The GFA filters and XAD2 sorbent tubes were submitted for analysis for PAHs. Samples for VOCs were taken actively (pumped at 50ml/minute) onto Tenax and Chromosorb 106 sorbent media in accordance with MDHS 70 'General methods for sampling airborne gases & vapours'.

Monday 12th December: Air samples were taken at the same locations as the Fire Brigades' scientific advisors. Sampling was undertaken as described previously, however, VOCs were sampled using passive rather than active sampling techniques so that the sampling period could be extended. This is in accordance with MDHS 80 volatile organic compounds diffusive/thermal desorption. Carbon dioxide (CO₂) levels were screened using long-term diffusive sampling Dräger tubes. As normal background levels were detected, no other sampling for CO₂ was undertaken. Sampling and analysis for asbestos fibres in air was monitored in accordance with MDHS 39/4 'asbestos fibres light microscopy' (Health and Safety Laboratory, 2006b).

Tuesday 13th December: Air samples were again taken at the same locations as the Fire Brigades' scientific advisors. Samples were collected for subsequent analysis for PAH and VOC following the same approach as that taken on 11th December.

Results Summary

The results of this sampling were verbally communicated to CHaPD staff as soon as they were available and the formal results were sent to CHaPD at a later date. The sampling results in tables H5-H10 indicated that none of the concentrations of pollutants monitored close to the site were above background concentrations.

Table H5 Results of air quality monitoring undertaken by HSL on 11th December

Location	NA	ACL	AC	FL	PH	AN	FA	PY	BAAN	CHR	BBKFA	BAP	IP	DBAHA	BGHIP
	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3
St Albans Police Yard 12410/05	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	0.002	0.002	0.003	0.003	0.005	0.003	<0.001	<0.001	0.002
Seat of fire Hemel Hempstead 12411/05	<0.001	<0.001	<0.001	<0.001	0.003	<0.001	0.020	0.020	0.010	0.010	0.020	0.010	0.010	<0.001	0.010
Blank 12412/05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Blank 12413/05	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Abbreviations used in tables:- NA = Naphthalene; ACL = Acenaphthylene; AC = Acenaphthene; FL = Fluorine; PH = Phenanthrene; AN = Anthracene; FA = Fluoranthene; Py = Pyrene; BAAN = Benzo(a)anthracene; CHR = Chrysene; BBKFA = Benzo(b)fluoranthene and Benzo(k)fluoranthene mixture; BAP = Benzo(a)pyrene; IP = Indeno(1,2,3-c,d)pyrene; DBAHA = Dibenzo(a,h)anthracene; BGHIP = Benzo(g,h,i)peryl

Table H6 Results of air quality monitoring undertaken by HSL on 11th December

Location	Benzene	Toluene	Ethyl-benzene	o/m/p-Xylene	Ethyltoluenes & Trimethyl-benzenes	nC5,nC6,nC7	nC8 to nC16 inclusive	TOTAL VOC	Sample Volume
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	(Litres)
St Albans Police Yard 12414/05	1.3	5.0	0.5	2.0	1.6	1.1	0.7	9	18.37
Seat of fire Heme1 Hempstead 2415/05	2.3	10.6	0.7	4.3	3.6	7.9	5.6	65	10.76
Blank 12416/05	0.2	0.5	0.1	0.4	< 0.1	0.6	< 0.1	5	15
Blank 12417/05	not reported								

Table H7 Results of air quality monitoring undertaken by HSL on 12th December

Location	NA	ACL	AC	FL	PH	AN	FA	PY	BAAN	CHR	BBKFA	BAP	IP	DBAHA	BGHIP
	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3
Wood Lane End 12422/05	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Our Lady RC Church 12423/05	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Blank 12424/05	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
Blank 12425/05	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002

Abbreviations used in tables:- NA = Naphthalene; ACL = Acenaphthylene; AC = Acenaphthene; FL = Fluorine; PH = Phenanthrene; AN = Anthracene; FA = Fluoranthene; Py = Pyrene; BAAN = Benzo(a)anthracene; CHR = Chrysene; BBKFA = Benzo(b)fluoranthene and Benzo(k)fluoranthene mixture; BAP = Benzo(a)pyrene; IP = Indeno(1,2,3-c,d)pyrene; DBAHA = Dibenzo(a,h)anthracene; BGHIP = Benzo(g,h,i)perylene

Table H8 Results of air quality monitoring undertaken by HSL on 12th December

Location	Benzene	Toluene	Ethylbenzene	o/m/p-Xylene	Ethyltoluenes & Trimethylbenzenes	nC7	nC9	TOTAL VOC	Sample Time
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	(mins)
Wood Lane End 12426/05	interference	6	< 5	5	< 5	58	14	3000	189
Adeyfield School 12427/05	24	7	< 5	6	< 5	51	< 5	1300	195
Our Lady RC Church 12428/05	35	54	< 5	15	< 5	113	15	3000	85
Blank 12429/05	46	5	< 5	9	< 5	58	< 5	1300	150
Blank 12430/05	51	12	< 5	9	< 5	61	< 5	2000	150

Table H9 Results of air quality monitoring undertaken by HSL on 13th December

Location	NA	ACL	AC	FL	PH	AN	FA	PY	BAAN	CHR	BBKFA	BAP	IP	DBAHA	BGHIP
	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3	μ/m^3
Leverstock Green school, Hemel Hempstead 12438/05	0.37	0.01	<0.01	<0.01	0.01	<0.01	<0.01	<0.001	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Leverstock Green school, Hemel Hempstead 12439/05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Leapfrog Nursery, Wood End Lane Hemel Hemp 12440/05	0.16	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Leapfrog Nursery, Wood End Lane Hemel Hemp 12441/05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Blank 12442/05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Blank 12443/05	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

Abbreviations used in tables:- NA = Naphthalene; ACL = Acenaphthylene; AC = Acenaphthene; FL = Fluorine; PH = Phenanthrene; AN = Anthracene; FA = Fluoranthene; Py = Pyrene; BAAN = Benzo(a)anthracene; CHR = Chrysene; BBKFA = Benzo(b)fluoranthene and Benzo(k)fluoranthene mixture; BAP = Benzo(a)pyrene; IP = Indeno(1,2,3-c,d)pyrene; DBAHA = Dibenzo(a,h)anthracene; BGHIP = Benzo(g,h,i)perylene

Table H10 Results of air quality monitoring undertaken by HSL on the 13.12.05

Location	Benzene	Toluene	Ethyl- benzene	o/m/p- Xylene	Ethyltoluenes & Trimethyl- benzenes	nC7	nC9	Sorbent Type	Sample Time
	ppb	ppb	ppb	ppb	ppb	ppb	ppb	ppb	(mins)
Leverstock Green School, Hemel 12444/05	11	9	~	< 5	~	37	< 5	TA	280
Leverstock Green School, Hemel 12445/05	31	10	~	< 5	~	29	< 5	C106	280
Leapfrog Nursery, Wood End Lane, Hemel 12446/05	17	5	~	< 5	~	32	< 5	TA	240
Leapfrog Nursery, Wood End Lane, Hemel 12447/05	67	13	~	12	~	28	< 5	C106	240
12448/05 (Blank)	11	< 5	~	< 5	~	29	< 5	TA	250
12449/05 (Blank)	11	< 5	~	< 5	~	34	< 5	TA	250
12450/05 (Blank)	75	10	~	< 5	~	26	< 5	C106	250
12451/05 12452/05 12453/05	Not Analysed - Additional Blanks								

Abbreviations used in tables:- NA = Naphthalene; ACL = Acenaphthylene; AC = Acenaphthene; FL = Fluorine; PH = Phenanthrene; AN = Anthracene; FA = Fluoranthene; Py = Pyrene; BAAN = Benzo(a)anthracene; CHR = Chrysene; BBKFA = Benzo(b)fluoranthene and Benzo(k)fluoranthene mixture; BAP = Benzo(a)pyrene; IP = Indeno(1,2,3-c,d)pyrene; DBAHA = Dibenzo(a,h)anthracene; BGHIP = Benzo(g,h,i)perylene

H.4.1.3 Locally targeted monitoring carried out by Netcen

As outlined in Section 4.2, Netcen also conducted targeted air quality sampling during the incident, monitoring particulate matter (PM₁₀) and volatile organic compounds (VOCs) at different locations around the site. The results of some of this sampling (see Section 4.3.2) were made available to CHaPD by the evening of 13th of December.

H4.2 Facility for Airborne Atmospheric Measurements (FAAM) aircraft samples

The FAAM research aircraft, which the Met Office jointly operates with Natural Environment Research Council (NERC), was deployed on 12th and 13th of December to take *in situ* measurements of the plume (Met Office, 2006). As outlined in Section 4.3.4 of this report, this had two purposes: firstly, to determine the location of the plume and secondly to determine the chemical composition of the plume. The results of the sampling were available at approximately 15.00 hours on 13th December. These indicated that the plume was at a high level in the atmosphere between approximately 600 and 1500 m, suggesting that exposures of members of the public should be low. The information on the concentrations of particulate matter in the plume and the chemical composition of the particulates that was available at this stage of the incident indicated that the main constituent was black carbon (soot) and that the concentrations of polycyclic aromatic hydrocarbons (PAHs) in the plume were low. A full description of the results of the aircraft sampling is in Section 4.3.4.

H4.3 Defra automated network

During the response to the incident, CHaPD used information from the UK's national Automatic Urban and Rural Network (AURN) which continuously monitors the following chemicals: particulate matter (both PM₁₀ and PM_{2.5}), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), carbon monoxide (CO) and ozone (O₃) in near real-time by using the AURN website (NETCEN, 2006). This sampling is described in detail in Section 4.1.1 of this report.

H 4.4 Automated monitoring network managed by Environmental Research Group (ERG) King's College London

H 4.4.1 Background

Air pollution in London and the Home Counties is measured by four regional air quality monitoring networks comprising over 140 monitoring sites (see chapter 4). These networks are managed by King's College London (KCL) on behalf of local authorities and Defra. The spatial resolution of the continuous monitoring sites in London is far greater than the AURN and is far greater than anywhere else in the UK. These combined networks therefore represent a unique resource for the quantification of exposure during local and regional PM₁₀ events. Details of these networks can be found online (London Air Quality Network, 2006, Herts & Beds Air Pollution Monitoring Network, 2006, Sussex Air Quality Steering Group, 2006, Kent & Medway Air Quality Monitoring Network, 2006)

Measurements are collected from monitoring sites either hourly or twice daily and disseminated on network web pages. On the morning of Sunday 11th, in response to the Buncefield fire, the KCL Duty Team increased the frequency of data collection from PM₁₀ monitoring sites to maximise the number of measurements available in near real-time to the public via the network web pages.

H4.4.2 Detecting the Buncefield Plume

PM₁₀ concentrations can be assumed to consist of a regional background of particulate from secondary and natural sources and a local primary component that is linked to oxides of nitrogen (NO_x) (Fuller *et al.*, 2002). However PM₁₀ from fires and other local sources with high PM₁₀:NO_x ratios are not accounted for by this model (Fuller and Green 2004). Deviations from the concentrations expected by this approach were, therefore, used to identify possible incidents of grounding of the Buncefield plume. Experience from the grounding of industrial plumes across London provides evidence that plume grounding incidents from sources several kilometres away are rarely measured at a single site only.

ERG has reported that there were several occasions when the plume appears to have had an impact on air quality (Kings College London, 2006). However, the only occasions when the plume was thought to have made a moderate impact upon air quality at ground level was on the evening of Sunday 11th and early in the morning of Monday 12th. The smoke from the fire was detected at

monitoring sites in parts of east Surrey and Sussex causing PM₁₀ particulate concentrations to reach 'moderate' levels in Horsham and Lewes (for definition of the term 'moderate' see Section 4.1.1.1).

Table H11 Maximum 15 mean PM₁₀ concentrations during the Buncefield incident thought by ERG to be due to the plume grounding (Kings College London, 2006)

Date	Time of max Concentration	Area	Site	Max 15 mean Conc $\mu\text{g m}^{-3}$ (grav)
11-Dec	16:15	Surrey & Sussex	Mole Valley 3 - Dorking	156
11-Dec	17:45	Surrey & Sussex	R'gate & Bans 1 - Horley	133
11-Dec	19:15	Surrey & Sussex	Lewes 2	217
11-Dec	22:45	Surrey & Sussex	Horsham 2	290
11-Dec	20:30	Hertfordshire	St Albans - Fleetville	133
11-Dec	18:30	North London	Haringey 2 - Priory Pk*	102
11-Dec	18:45	North London	Haringey 1 - Tottenham	122
11-Dec	19:15	North London	Islington 2 - Holloway Rd	137
12-Dec	02:30	North London	Brent 5 - Neasden	130
14-Dec	03:00	North London	Barnet 2	98
14-Dec	07:30	Hertfordshire	Watford	114

* = Beta Attenuation Monitor (BAM) which has only hourly measurement resolution. The remaining concentrations were measured by Tapered Element Oscillating Microbalance (TEOM). Concentrations are expressed as gravimetric corrected; a conversion factor of 1.3 was applied to TEOM measurements and a correction factor of 0.81 was applied to BAM measurements.

Throughout the period of the fire, 'moderate' PM₁₀ particulate concentrations were measured at several roadside sites in London. These were due to road transport sources and were not directly related to the smoke from the oil depot fire. 'Moderate' PM₁₀ concentrations at the Chichester 1 site were due to nearby road resurfacing.

On Tuesday 13th, an email data feed was established between KCL's operation centre and the CHaPD. This feed summarised the latest pollution measurements from regional network sites in London and the south-east. This 24 hourly data feed was supported by analysis from KCL's operations centre between 08.00 hours and 18.00 hours each working day.

H4.4.3 Monitoring in Hemel Hempstead

On Tuesday 13th, KCL, the fire brigade's scientific advisors and Dacorum Borough Council established a NO_x and PM₁₀ monitoring site in Hemel Hempstead. PM₁₀ measurements were available from Wednesday 14th December. Concentrations remained 'low' for the remainder of the period of the fire and were similar to those measured at nearby St Albans.

H4.5 Air quality monitoring by local authorities in Surrey

In addition to using information from the air quality networks mentioned above, information was also obtained on air quality in Surrey. Using the local Health Protection Unit's (HPU) links with local authorities, CHaPD were able to view information on air quality in Surrey. This link was established

on the 14th of December. This did not indicate that the incident was causing any deterioration in air quality.

H5 Soil and Grass sampling conducted by CHaPD (Birmingham)

H5.1 Introduction

In response to the Buncefield Fuel Depot fire of the 11th December 2005, the Health Protection Agency undertook an initial screening investigation of surface soils and grasses downwind of the fire in order to determine whether there was (1) any evidence of significant plume grounding and (2) a need for more detailed sampling. During the 14th and 15th December, teams from the HPA's Centre for Radiation, Chemicals and Environmental Hazards (CRCE) collected a total of 72 samples from 33 locations (including a control site and a site located upwind of the fire). Several wipe samples of dust and soot were also collected. All samples were collected before substantial rainfall in the area thereby avoiding the possibility of rain washing away any pollution attached to soil, vegetation or property.

H5.2. Methods

H5.2.1 Sampling

As recommended by Defra (1999), a single soil and grass sample was collected at each sample location with *ad hoc* samples being taken as required. One background and one upwind sample site were also included in the sampling strategy.

The sampling teams focused on two main areas:

- a) The predicted point of maximum ground-level deposition using available plume dispersion models, particularly AERMOD/ADMS models developed by the EA, NAME models produced by the Met Office and CHEMETs requested by the Emergency Services during the fire (see Appendix E).
- b) Areas with documented visible plume at ground level or where there was possible fall-out from the fire (soot, debris *etc*).

The investigation focused on priority 'sensitive' sites, including schools, hospitals, housing estates, parks and nurseries. In total, 72 samples were collected from 33 locations. One sample was a control (located in an urban area outside the affected region); one was located 2 km upwind of Buncefield and the other 31 located between 2 and 13 km downwind.

Grass samples were taken from a 1m² area at each sampling point. Soil core samples were taken at a diameter of 3.5 cm to a depth of 10 cm below ground level. Wipe samples for soot and dust were collected by wiping a piece of moistened sterilized paper over a representative hard upturned surface such as a car roof or letter box. All samples were double-bagged, labelled and kept refrigerated prior to analysis. Map 1 shows the sampling locations.

Location of environmental sampling points following Buncefield Oil Depot fire, over OS 1:10 000 scale mapping



Map 1. Sample locations

H5.2.2 Analysis

Five groups of pollutants were selected for analysis based upon both scientific concerns (atmospheric sampling at the scene, knowledge of the materials involved, potential for formation within the plume and potential health impacts) and political/public concerns:

- Polycyclic aromatic hydrocarbons. These are reported for both 'total' PAH (US EPA Method 610) and benzo(a)pyrene.
- Polychlorinated dibenzo-p-dioxins (dioxins) and polychlorinated dibenzofurans (furans).
- Heavy metals (V, Ni, Cd, Cr, Cu, Pb, Zn)
- Perfluorooctane sulphonate (PFOS, associated with foam used to fight the fire)
- Fluoride (produced from thermal decomposition of PFOS).

Samples were analysed at two UKAS accredited laboratories: the Environment Agency's National Laboratory Service (Leeds) and the commercial laboratory, TES Bretby (Burton on Trent).

H5.3. Results

H5.3.1 Heavy Metals

Vanadium and nickel were considered the most appropriate markers of oil combustion. The mean vanadium and nickel concentrations in soil and grass samples were unexceptional and comparable to that reported in the control and upwind sites and well within typical UK ranges for urban soils and grasses (Table G.12). Reported concentrations of other heavy metals were also unexceptional.

Table H12: Summary of heavy metals data. All values are mg kg⁻¹ (dry weight).

Heavy metal	SGV ¹	UK soil Median range	Soil samples				
			Minimum	Maximum	Mean	Median	Control
Vanadium	---	34.7-83.0 ²	28	59	43	40	44
Nickel	50	15 - 47 ³	8.0	40.8	21.9	16.7	29.0
Cadmium	1	0.3 - 2.0 ³	0.1	2.91	0.8	0.39	1.01
Chromium	130	43 - 108 ³	23.9	43.9	30.8	27.0	29.2
Copper	---	2 - 250 ⁴	8.2	41.2	24.7	21.4	38.5
Lead	450	45 - 225 ³	43.6	103	69.3	60.2	44.4
Zinc	---	5 - 816 ⁵	44.0	257.0	156.1	138.0	146.0
Heavy metal	Maximum recommended concentration for productive grass species	Grass samples					
		Minimum	Maximum	Mean	Median	Control	
Vanadium	---	1.0	22.2	8.8	9.3	5.9	
Nickel	---	2.7	18.1	7.8	7.33	5.1	
Cadmium	---	0.1	0.721	0.2	0.175	0.45	
Chromium	---	1.06	29.4	11.6	10.8	7.18	
Copper	250 ⁶	10.9	105	32.0	25.6	10.4	
Lead	---	2.72	62.7	19.4	15	15.6	
Zinc	1000 ⁶	26.3	90.5	53.7	50.7	54.5	
Heavy metal		Wipe samples (mg wipe ⁻¹)					
		Minimum	Maximum	Mean	Median	Control	
Vanadium		12.5	12.5	12.5	12.5	---	
Nickel		17.2	25.8	21.5	21.5	---	
Cadmium		4.09	17.9	11.0	11.0	---	
Chromium		27.0	31.7	29.3	29.3	---	
Copper		55.9	82.4	69.2	69.2	---	
Lead		38.3	76.6	57.4	57.4	---	
Zinc		525	3360	1942.5	1942.5	---	

- ¹ residential with plant uptake
² both urban and rural sites Lark *et al* (2006)
³ urban sites Fordyce *et al* (2005)
⁴ both urban and rural sites Bowen (1985)
⁵ both urban and rural Adriano (1986)
⁶ DETR (1996)

H5.3.2 Polycyclic Aromatic Hydrocarbons (PAH)

Total PAH concentrations in the majority of soils sampled downwind of the fire were within typical urban levels reported in the scientific literature and comparable with concentrations recorded at the control site and the upwind sites (Table G.13). Concentrations reported in soils around Buncefield were also comparable with data collected by the Environment Agency in their unpublished Soil and Herbage Survey.

Table H13: Summary of total of 16 US EPA (Method 610) parent PAH data. All values are mg kg⁻¹ (dry weight).

Media ΣPAH	UK urban (range)	Typical kerbside (range)	Buncefield samples				
			Min	Max	Mean	Median	Control
Soil ¹ n=13	0.95 - 4.42	9.75 - 20.00	0.92	239	36.82	3.10	3.98
Grass ² n=16	0.09 - 0.15	0.19	0.14	171	2.47	0.831	1.55

¹ Smith *et al*, 1995; Butler *et al*, 1984

² Meharg *et al*, 1998; Crepineau and Rychen, 2003

Three soil and two grass samples collected in South Watford (approximately 10 kilometres to the south of the depot) did show evidence of elevated PAH concentrations. However, it was concluded that on the balance of evidence, it was thought that this contamination was unlikely to be a result of the fire. It is not considered credible that the high concentrations in soil and grass could have been caused by grounding of the plume. There is no evidence of plume grounding, neither visually or from nearby air monitoring stations, in this area and no evidence of contamination by other pollutions that could be associated with the fire, such as nickel and vanadium. Historical contamination is a more probable cause and at one of these sites there is a plausible source of contaminated land (a nearby former power station).

H5.3.3 Dioxins and Furans

Reported soil concentrations around Buncefield were consistent with published background data for soils and are comparable with concentrations reported at the control site (Table H14). Both the mean and median values fall within the typical range reported in UK rural environments and are also within the ranges for both urban and rural herbage reported by the EA's Soil and Herbage Survey (Barraclough, personal communication).

Table H14: Summary of dioxin and furan data (expressed as ng TEQ WHO kg⁻¹ dry weight).

Media ΣI-TEQ	Typical UK urban (range)	Typical UK rural (range)	Buncefield samples				
			Min	Max	Mean	Median	Control
Soil ¹ n=5	0.87 – 87.00	0.78 – 20.00	2.46	7.92	4.94	4.71	3.01
Grass ² n=5	---	0.47 - 5.00	0.52	2.14	1.57	1.87	1.57

¹ Roots *et al*, 2004;

² Eduljee and Gair, 1996 (expressed as ng TEQ NATO kg⁻¹ dry weight).

H5.3.4 Perfluorooctylsulphonate (PFOS) and Fluoride

With the exception of two samples, PFOS and other PFAS concentrations were below the detection limit of 0.2 µg kg⁻¹. Measured concentrations of fluorides in soil downwind from Buncefield are consistent with urban environments and are more than an order of magnitude below reported maximum soil concentration limits (500 mg kg⁻¹) and are lower than the much stricter grass guideline (30 mg kg⁻¹) for agricultural land (DETR, 1996).

H5.4 Conclusion of soil and grass sampling

Overall, it was concluded that the fire at the Buncefield Oil Depot did not result in substantial pollution of soil and grasses. A large number of measurements found that pollutant levels were, in general, unexceptional and typical of UK urban environments. While localised plume grounding cannot be discounted, this investigation supports the view that prolonged plume grounding downwind of the fire did not occur.

H6 Monitoring carried out by the local authority started on the 27th December 2005

Following the acute response stage of the incident the local authority carried out benzene sampling at various locations close to the site starting on 27th December and continuing for 4 weeks. The results displayed in table H15 indicate that concentrations of benzene were lower than the long term Environmental Assessment Levels (EALs), set by the Environment Agency and were below the National Air Quality Strategy objectives for benzene (annual running mean of 16.25 µg/m³).

Table H15 Concentrations of benzene monitored starting on 27th December and continuing for 4 weeks

Location	Concentrations of benzene (µg/m ³)
Hunters Oak Hemel	1.05
Finway Road, Hemel	1.74
Woodlane End, Hemel	1.81
Boundary Way, Alcon, Hemel	2.29
Boundary Way, Northgate, Hemel	2.41
Eaton Lodge	1.72
Punchbowl Lane Jct	2.36
Southend Farm	1.38
Old Jeromes	1.43
Hoggend Lane	1.27

H7 Occupational exposure monitoring during site clean up at Buncefield oil depot 29 - 30 December 2005

The exposures of the employees working on the site clean up to VOCs were monitored by the HSL. Personal monitoring was conducted using passive (diffusive) label mounted sorbent tubes. For each worker sampled, parallel sampling was conducted with both Tenax TA (TA) and Chromosorb106 sorbent material (106) (Health and Safety Laboratory, 2006d). Samples from twelve workers were measured on the afternoon of 29th December and 16 workers were measured in the morning of 30th December. The results are displayed in tables H16 and H17.

Table H16 Occupational monitoring results from 29th December (Health and Safety Laboratory, 2006c)

Sample information			Results (parts per million)				
Type	Subject	Period	Benzene	Toluene	Xylenes	Trimethyl benzenes	C ₇ – C ₁₂ HCs
TA	Worker 1	12:03 – 15:45	0.03	0.05	0.10	0.05	0.05
106	Worker 1	12:03 – 15:45	0.05	0.46	0.10	<0.01	<0.01
TA	Worker 2	12:05 – 15:45	0.04	0.04	0.07	0.03	0.04
106	Worker 2	12:05 – 15:45	0.01	<0.01	0.08	<0.01	<0.01
TA	Worker 3	12:06 – 15:45	0.03	0.07	0.13	0.11	0.09
106	Worker 3	12:06 – 15:45	0.08	0.33	0.46	0.72	0.70
TA	Worker 4	12:08 – 15:45	0.06	0.07	0.14	0.10	0.08
106	Worker 4	12:08 – 15:45	0.02	0.03	0.12	1.11	2.46
TA	Worker 5	12:14 – 15:45	0.03	0.08	0.80	0.89	1.90
106	Worker 5	12:14 – 15:45	0.06	0.38	0.87	0.72	1.62
TA	Worker 6	12:15 – 15:45	0.20	0.13	1.20	0.70	1.53
106	Worker 6	12:15 – 15:45	0.03	0.11	0.76	1.30	0.26
TA	Worker 7	12:18 – 15:45	0.01	0.06	0.98	1.16	2.56
106	Worker 7	12:18 – 15:45	0.03	0.07	0.94	1.56	3.10
TA	Worker 8	13:35 – 15:45	0.18	0.10	0.21	0.07	0.26
106	Worker 8	13:35 – 15:45	0.10	0.25	0.23	0.32	0.41
TA	Worker 9	13:38 – 15:45	0.07	0.11	0.33	0.16	0.38
106	Worker 9	13:38 – 15:45	0.04	0.07	0.22	<0.01	0.18

Sample information			Results (parts per million)				
TA	Worker 10	13:40 – 15:45	0.08	0.10	0.54	<0.01	1.73
106	Worker 10	13:40 – 15:45	0.06	0.06	0.38	<0.01	1.41
TA	Worker 11	13:48 – 15:45	SE	SE	SE	SE	SE
106	Worker 11	13:48 – 15:45	<0.01	0.22	<0.01	<0.01	<0.01
TA	Worker 12	13:49 – 15:45	0.06	0.29	0.07	0.04	0.11
106	Worker 12	13:49 – 15:45	0.08	0.13	0.08	0.04	0.12
TA	Blank		0.01	0.01	<0.01	<0.01	<0.01
106	Blank		0.02	0.01	<0.01	<0.01	<0.01
TA	Blank		0.05	0.02	0.02	0.02	0.01
106	Blank		<0.01	0.02	0.06	0.01	0.02

Table H17 Occupational monitoring results from 30th December (Health and Safety Laboratory, 2006c)

Sample information			Results				
Type	Subject	Period	Benzene	Toluene	Xylenes	Trimethylbenzenes	C ₇ – C ₁₂ HCs
TA	Worker 1	07:15 – 13:50	0.01	0.04	0.10	0.10	0.10
106	Worker 1	07:15 – 13:50	<0.01	0.04	0.05	0.01	0.02
TA	Worker 2	07:16 – 13:04	0.01	0.03	0.04	0.01	0.03
106	Worker 2	07:16 – 13:04	0.01	0.01	0.03	<0.01	0.03
TA	Worker 3	07:17 – 13:52	0.01	0.03	0.06	0.06	0.13
106	Worker 3	07:17 – 13:52	<0.01	<0.01	<0.01	<0.01	<0.01
TA	Worker 4	07:18 – 13:06	0.02	0.09	0.10	0.04	0.09
106	Worker 4	07:18 – 13:06	0.01	0.04	<0.01	<0.01	<0.01
TA	Worker 5	07:21 – 14:07	0.01	0.03	0.06	0.09	0.13
106	Worker 5	07:21 – 14:07	0.01	0.01	0.03	0.01	0.08
TA	Worker 6	07:24 – 13:36	0.02	0.08	0.11	0.04	0.10
106	Worker 6	07:24 – 13:36	0.02	0.06	0.05	0.01	0.04
TA	Worker 7	07:33 – 13:42	0.01	0.01	0.09	0.05	0.10
106	Worker 7	07:33 – 13:42	0.01	0.02	0.05	0.01	0.03
TA	Worker 8	07:35 – 13:45	0.01	0.03	0.04	0.02	0.06
106	Worker 8	07:35 – 13:45	0.01	0.03	0.01	<0.01	0.02
TA	Worker 9	07:35 – 13:46	0.01	0.03	0.05	0.02	0.06
106	Worker 9	07:35 – 13:46	0.05	0.04	0.02	0.01	0.01
TA	Worker	07:37	0.01	0.07	0.57	0.27	0.57

Sample information			Results				
	10	- 14:07					
106	Worker 10	07:37 - 14:07	0.01	0.03	0.33	0.10	0.35
TA	Worker 11	07:40 - 14:07	0.01	0.03	0.12	0.08	0.12
106	Worker 11	07:40 - 14:07	<0.01	0.01	0.04	0.01	0.05
TA	Worker 12	07:47 - 13:50	0.02	0.07	0.28	0.10	0.65
106	Worker 12	07:47 - 13:50	<0.01	<0.01	0.14	<0.01	0.08
TA	Worker 13	07:52 - 12:34	0.01	0.01	0.02	0.01	0.03
106	Worker 13	07:52 - 12:34	<0.01	<0.01	<0.01	<0.01	<0.01
TA	Worker 14	08:04 - 13:41	0.01	0.05	0.11	0.08	0.11
106	Worker 14	08:04 - 13:41	<0.01	0.01	0.04	<0.01	0.18
TA	Worker 15	08:07 - 13:24	0.02	0.05	0.29	0.24	0.44
106	Worker 15	08:07 - 13:24	0.02	0.04	0.09	0.04	0.25
TA	Worker 16	08:07 - 13:21	0.01	0.07	0.91	0.84	1.84
106	Worker 16	08:07 - 13:21	0.03	0.05	0.77	0.86	1.71
TA	Blank		0.01	0.01	ND	ND	ND
106	Blank		0.01	0.1	ND	ND	ND
TA	Blank		0.01	ND	ND	ND	ND
106	Blank		ND	ND	ND	ND	ND

The results are all lower than the Workplace Exposure Limits (WELs). The HSL concluded "that on 29th and 30th December, the hydrocarbon exposure by inhalation of the workers clearing spillages at the Buncefield oil depot were low when compared against UK workplace exposure limits" and that "Exposures of this order would not be considered excessive within the petrochemical industry, even under normal production conditions" (Health and Safety Laboratory, 2006c). These results were given to CHaPD on 13th January 2006.

H8 Other activities being undertaken by the HPA#

In the initial phase following the incident, HPA initiated and/or contributed to activities aimed at documenting and monitoring the possible health and psychosocial impacts of the incident on the population. In the event of any large chemical or environmental incident, it is essential for the agencies involved in health protection to assess rapidly and frequently the possible scope for health impacts, using a variety of approaches based on the experience of responding to previous

incidents, and generally keeping an open mind about the potential scope for health impacts. When information about the hazards posed by the incident becomes clearer, specific decisions can be taken on the appropriate follow up investigations, and those that are not necessary. A HPA lead multiagency Steering Group was set up to review and monitor any health effects following the Buncefield fire on 13th December (Health Protection Agency, 2006b). This group has representatives from many of the organisations involved in assessing and providing advice directly following the fire, including Dacorum and Watford and Three Rivers Primary Care Trusts (PCT). This group agreed early in January that a number of different areas of work would be taken forward:

1. **Risk assessment evaluation:** the first major risk assessment was undertaken when the fire occurred. It concluded that there was negligible environmental risk from the plume.
2. **Case note review:** Records from Watford and Hemel Hempstead A&E departments have been reviewed to identify individuals who presented with health issues related to the fire.
3. **Occupational Health register:** A questionnaire has been developed for the Occupational Health departments of those services who were involved in responding to the fire. This will include fire and rescue services, ambulance services, local authority staff, police departments and those involved in caring for casualties, construction and engineering work and environmental sampling.
4. **Concerns among the public:** To determine any ongoing concerns within the general population a postal questionnaire has been sent to a random sample of 5000 residents of Dacorum PCT and Watford and Three Rivers PCT. This questionnaire was sent out at the end of January.

Potential water contamination

In addition to the above work ChaPD have also been working with the Buncefield Inter-Agency Liaison Group (IALG) looking at the potential for surface and ground water contamination as a result of the Buncefield incident (Health and Safety Executive, 2006).

H9 Conclusions and further work

This annex details the air modelling and monitoring that have played an important part in assessing the potential public health risks from the Buncefield fire. The heat of the fire appears to have punched a hole in the inversion layer allowing the plume to rise to high altitude. The high plume buoyancy and the favourable meteorological conditions resulted in the plume being trapped aloft with minimal mixing to the ground.

Fortunately the explosions and fire resulted in few casualties and no deaths. Dynamic health impact assessment and environmental impact assessment were shared with Strategic Gold Command from 09.00 on 11th to 18.30 hours on 14th December. In addition these data were provided to the Civil Contingencies Secretariat. Information on the health impact of the fire was shared at the time of the incident with members of the public via media reports / press statements and the HPA website

This Defra/Netcen report will be referred to the Committee on the Medical Effects of Air Pollutants for advice of health aspects of this data at their June 2006 meeting.

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References

- Adriano D.C., (1986) Zinc. In: Adriano DC ed. *Trace elements in the terrestrial environment*. New York, Springer, pp 421–469.
- Barraclough D (2006). *Soil and Herbage Survey (extract)*. Environment Agency, personal communication.
- Bureau Veritas. *Bureau Veritas responds to Buncefield Refinery Fire*
<http://www.bureauveritas.co.uk/webapp/servlet/RequestHandler?mode=PT&pageID=23265&nextpage=siteFrameset.jsp> (accessed 20.04.06).
- Bowen HJM (1985) *The natural environment and the biogeochemical cycles*. In: Hutzinger D ed. *Handbook of environmental chemistry*. New York, Basel, Springer- Verlag, pp 1-26.
- Butler J.D., Butterworth V., Kellow S.C. and Robinson H.G. (1984) *Some observations on the polycyclic aromatic hydrocarbon (PAH) content of surface soils in urban areas*. *Science of the Total Environment* 33, 75 - 85.
- Carruthers, D. J., Holroyd, R. J., Hunt, J. C. R., Weng, W. S., Robins A.G., Apsley, D. D., Thomson, D. J., & Smith, J. 1994, UK-ADMS: *A new approach to modelling dispersion in the earth's atmospheric layer*, *Journal of Wind Engineering and Industrial Aerodynamics* 52, 139-153.
- Chemical Hazards and Poisons Division *Environmental Impacts of the Buncefield oil depot explosions of the 11th December 2005* A report produced for the Health Protection Agency by the Chemical Hazards and Poisons Division. In publication.
- Colville, R. N., Briggs, D., & Nieuwenhuijsen, M. 2003, "*Environmental Measurement and Modelling: Introduction and Source Dispersion Modelling*," in *Exposure Assessment in Occupational and Environmental Epidemiology*, M. Nieuwenhuijsen, ed., Oxford Medical Publications, pp. 39-53.
- Crepineau C. and Rychen G. (2003) *Assessment of soil and grass polycyclic aromatic hydrocarbons (PAHs) contamination levels in agricultural fields located near a motorway and an airport*. *Agronomie* 23, 345 - 348.
- Department of Health *Emergency planning*.
<http://www.dh.gov.uk/PolicyAndGuidance/EmergencyPlanning/fs/en> (accessed 21.04.06).

Department for Environment, Food and Rural Affairs *Environmental sampling following a chemical accident*.
<http://www.defra.gov.uk/environment/chemicals/accident/sampling/> (accessed 20.04.06).

Department for Environment, Transport and the Regions (1996) *Code of Practice for Agricultural Use of Sewage Sludge*. Department of Environment, 1989. Revised 1996.

Eduljee G.H. and Gair A.J. (1996) *Validation of a methodology for modelling PCDD and PCDF intake via the foodchain*. *Science of the Total Environment* 187, 211 - 229.

Fordyce F.M., Brown S.E., Ander E.L., Rawlins B.G., O'Donnell K.E., Lister T.R., Breward N. and Johnson C.C. GSUE: *urban geochemical mapping in Great Britain*. *Geochemistry: Exploration, Environment, Analysis*, Vol. 5 2005, pp. 325–336

Fuller, G., Carslaw, D.C., Lodge, H.W., 2002. *An empirical approach for the prediction of daily mean PM₁₀ concentrations*. *Atmospheric Environment* 36, 1431-1441.

Fuller, G. W. and Green, D., 2004. *The impact of local fugitive PM₁₀ from building work and road work on the assessment of the European Union Limit Value*. *Atmospheric Environment* 38, 4993-5002.

Health and Safety Executive. *The Buncefield Investigation*
<http://www.buncefieldinvestigation.gov.uk/reports/report2.pdf> (accessed 18.04.06b).

Health and Safety Laboratory. *An agency of the Health and Safety Executive. About us*
<http://www.hsl.gov.uk/about-us/index.htm> (accessed 19.04.06a).

Health and Safety Laboratory. *Asbestos fibres in air*. <http://hse.gov.uk/pubns/mdhs/pdfs/mdhs39-4.pdf> (accessed 20.04.06b)

Health and Safety Laboratory. *Exposure monitoring during site clean up at Buncefield oil depot* 2006c. Unpublished document.

Health and Safety Laboratory. *Methods for the Determination of Hazardous Substances*
<http://www.hse.gov.uk/pubns/mdhs/pdfs/mdhs14-3.pdf> (accessed 24.04.06d)

Health Protection Agency. *Chemical Hazards and Poisons Division*
<http://www.hpa.org.uk/chemicals/default.htm> (accessed 19.04.06a)

Health Protection Agency. *Health Surveillance Update and Questions and Answers*
http://www.hpa.org.uk/explosions/Health_surveillance_update_QA.htm (accessed 19.04.06b).

Health Protection Agency. *Local and Regional Services*. http://www.hpa.org.uk/lars_homepage.htm (accessed 19.04.06c).

Health Protection Agency. *What the Health Protection Agency does*.
<http://www.hpa.org.uk/hpa/whatwedo.htm> (accessed 19.04.06d)

Hertfordshire & Bedfordshire Air Pollution Monitoring Network. *Hertfordshire & Bedfordshire Air Pollution Monitoring Network*. www.hertsbedsair.org.uk (accessed 21.04.06)

Kent & Medway Air Quality Monitoring Network. *Reporting Air Quality in Kent and Medway*.
<http://www.kentair.org.uk/kent/asp/home.asp> (accessed 20.04.06)

King's College London. *Air pollution summary for the period of the Buncefield Oil Storage Depot fire from regional air quality networks in London and SE England*.
<http://www.erg.kcl.ac.uk/erg/asp/news.asp> (accessed 25.04.06)

Lark R.M., Bellamy P.H. and Rawlins B.G. (2006) Spatio-temporal variability of some metal concentrations in the soil of eastern England, and implications for soil monitoring. *Geoderma* (in press)

London Air Quality Network. *The London Air Quality Network*.
<http://www.londonair.org.uk/london/asp/home.asp> (accessed 24.04.06)

Meharg A.A, Wright J., Dyke H. and Osborn D (1998) *Polycyclic aromatic hydrocarbon (PAH) dispersion and deposition to vegetation and soil following a large scale chemical fire*. *Environmental Pollution* 99, 29 - 36.

Met Office. News - December 2005 <http://www.metoffice.gov.uk/health/news/december05.html>
(accessed 19.04.06).

NETCEN. *Air Quality Archive* www.airquality.co.uk (accessed 19.04.06).

Roots O, Henkelmann B. and Schramm K.W. (2004) *Concentrations of polychlorinated dibenzo-p-dioxin and polychlorinated dibenzofurans in soils in vicinity of a landfill*. *Chemosphere* 57, 337 - 342.

Smith D.J.T., Edelhauser E.C. and Harrison R.M. (1995) *Polynuclear aromatic hydrocarbon concentrations in road dust and soil samples collected in the United Kingdom and Pakistan*. *Environmental Technology* 16, 45 - 53.

Sussex Air Quality Steering Group. *Air Quality in Sussex*. <http://www.sussex-air.net/> (accessed 22.04.05)

UK resilience. *Management and coordination of local operations*
http://www.ukresilience.info/ccact/errpdfs/err_chap_04.pdf (accessed 19.04.06)

Welch F. *What is CHEMET?* http://www.hpa.org.uk/chemicals/reports/cir26_oct2002.pdf (accessed 20.04.06)

Glossary

AC	Acenaphthene
ACL	Acenaphthylene
ADMS	Atmospheric Dispersion Modelling System
AN	Anthracene
AURN	Automatic Rural and Urban Network
BAAN	Benzo(a)anthracene
BAP	Benzo(a)pyrene
BGHIP	Benzo(g,h,i)peryl
CHaPD	Chemical Hazards and Poisons Division
CHEMET	Chemical meteorological model
CHR	Chrysene and Benzo(k)fluoranthene mixture
CO ₂	Carbon dioxide
COMAH	Control of major accident hazards
CRCE	Centre for Radiation, Chemical and Environmental Hazards
DBAHA	Dibenzo(a,h)anthracene
Defra	Department of Environment, Food and Rural Affairs
EAL	Environmental Assessment Level
EMARC	Emergency Response and Monitoring Centre
ERG	Environmental Research Group
FA	Fluoranthene
FAAM	Facility for Airborne Atmospheric Measurements
FL	Fluorine
GFA	Glass Fibre Absorber
HAT	Health Advice Team
HSE	Health and Safety Executive
HPA	Health Protection Agency
HSL	Health and Safety Laboratory
IOM	Institute of Occupational Medicine
IP	Indeno(1,2,3-c,d)pyrene
LaRS	Local and Regional Services
NA	Naphthalene
NAME	Numerical Atmospheric-dispersion Modelling Environment (NAME)
ND	Not detected
Netcen	National Environmental Technology Centre
NHS	National Health Service
NO _x	Oxides of nitrogen
PAH	Polycyclic aromatic hydrocarbon
PH	Phenanthrene
PM	Particulate matter
PM10	Particles with a diameter of less than 10µm
Py	Pyrene
RPD:	Radiation Protection Division
SCG	Strategic Co-ordinating Group
UKAS	United Kingdom Accreditation Service
VOCs	Volatile organic compounds