King's College London

Environmental Research Group

Monitoring Data Analysis and PM_{10} Source Apportionment at Scrubs Lane

May 2006

Title	Monitoring Data Analysis and PM_{10} Source Apportionment at Scrubs Lane

Customer	

Customer Ref	

File Reference	\erg2\AIRQUALI\LONDON\LA\HAMS&FUL\HF3 Source apportionment

Report Number	

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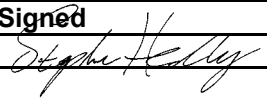
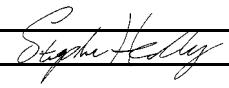
Reviewed by	Stephen Hedley		May 2006
Approved by	Stephen Hedley		May 2006

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Summary

This report details analysis of air pollution measurements made at the Hammersmith and Fulham 3 monitoring site. This site was located on Scrubs Lane near the junction with Waldo Road between 28th March 2005 and 27th October 2005. Specifically the report estimates the likely pollution concentrations that would have been experienced at the site during the full calendar year and quantifies the sources of PM_{10} that affected monitoring site.

The Hammersmith & Fulham 3 monitoring site is very likely to have exceeded the daily mean Air Quality Strategy Objective for PM_{10} and the annual mean objective for NO_2. The location is very likely to have attained the hourly mean NO_2 Objective and the annual mean Objective for PM_{10}.

No single source was responsible for the daily mean concentrations in excess of 50 μgm^{-3} TEOM*1.3 and therefore for the breach of the daily mean AQS Objective for PM_{10}. The majority of the PM_{10} measured at the site arose from background sources. Local sources accounted for only 34% of the mean concentration. These local sources were almost equally divided between primary PM_{10} from transport sources (18%) and other local PM_{10} (16%). The local - other sources at Hammersmith & Fulham 3 had a mean concentration of 5.7 (9.8 – 3.9) μgm^{-3} TEOM*1.3. (2σ). A reduction of between 50% and 75% in the concentration of the local – other source would be required to attain the AQS Objective, if this source is the sole subject of control.

The concentration of the local – other PM_{10} at the Hammersmith & Fulham 3 site was around 1/5th of the concentrations experienced near to other industrial sites and was close to the expected uncertainty of the source apportionment technique. It was therefore difficult to draw firm conclusions about the local origins of this pollution.

The local – other PM_{10} contributed to the measured concentrations at the site during 'normal' working hours; starting during hours 6 or 7 GMT (hours 7 or 8 BST) and declining during hours 16 or 17 GMT (hours 17 or 18 BST) on weekdays. The local – other source was also active on Saturday mornings declining during hours 10 and 11 GMT (11 and 12 BST). This suggested that the source was linked to a commercial activity.

The quantification of the mean concentration of the PM_{10} from the local – other source by wind direction suggested that the local – other source may have had two origins; the majority of the PM_{10} arose from emissions on Scrubs Lane and up to 10 % arising from a source, on a bearing of between 210^o and 230^o from the monitoring site.

Monitoring at other LAQN sites close to waste management facilities suggests that these facilities may be significant local sources of PM_{10} due to the resuspension of deposited road dust and suspension of dust from dirty vehicles and their loads. It is possible that the local – other PM_{10} that arose from emissions on Scrubs Lane was caused by this mechanism. Residential exposure is present on Scrubs Lane between the Hammersmith & Fulham 3 monitoring site and the waste facilities. Given that concentrations of PM_{10} arising from resuspension should decrease with distance from the source, the PM_{10} concentrations at this housing is likely to be higher than that measured at the monitoring site.

Although such a link between the local – other PM_{10} and traffic activity along Scrubs Lane is suggested by the analysis of mean PM_{10} concentrations averaged by wind direction, the source apportionment of PM_{10} by day of week and hours of day suggests that the link between traffic emissions and the local – other source is complex. If this link needs to be investigated in more detail, further information should be collected, particularly with regard to the traffic flow and vehicle composition on Scrubs Lane.

To investigate the local – other sources of PM_{10} it is recommended that the council:

1) Determine the operating periods of the local industry to attempt to match local sources to the daily activity pattern of the local – other PM_{10} source.

2) Enter a dialogue with local industry and regulators where necessary with the aim of minimising and controlling local PM_{10} emissions

Background

This report provides detailed analysis of air pollution measurements made at the Hammersmith and Fulham 3 monitoring site which was located on Scrubs Lane near the junction with Waldo Road between 28th March 2005 and 27th October 2005. Specifically the report estimates the likely pollution concentrations that would have been experienced at the site during the full calendar year and quantifies the sources of PM_{10} that affected the monitoring site.

Previous Air Quality Assessments

The council completed its Updating and Screening Assessment (USA) of the seven Local Air Quality Management (LAQM) pollutants during March 2004. The USA findings for particles (PM_{10}) confirmed that there were dust complaints, which possibly included a PM_{10} fraction, from sources in the north of the borough. Subsequent examination of the area indicated that the potential sources of fugitive and other emissions included a metal recycling plant off Hythe Road and a separate waste transfer station (off Scrubs Lane) as shown in Figure 1. The conclusion of the USA work was that the council needed to undertake a Detailed Assessment.

The council has also previously modelled this area, most recently for its Stage 4 further assessment in March 2002. Relevant exposure for the purposes of air quality management arises on this road. The daily mean prediction exceeds the current Air Quality Strategy Objective (AQS) along the road centre line for part of the road and the annual mean objective exceeds the 2010 London objective of 23 ugm^{-3} along the whole road and to a greater extent. (Note – both Objectives were modelled using worst-case meteorology and the 1999 London Atmospheric Emissions Inventory (LAEI) for 2004/5. Minor roads in the area were modelled as area sources and the sources identified in the subsequent USA were not specifically modelled).

Based on its earlier findings in the review and assessment process, the council declared an Air Quality Management Area (AQMA) in 2000 across the whole of its area for both PM_{10} and nitrogen dioxide.

Reports and other material related to the council's air quality management responsibilities can be found on the council's web site at:

http://www.lbhf.gov.uk/Directory/Environment/Pollution/Air_quality/43955_Air_Quality_Main.asp

Requirements

The Council required the following analysis of monitoring data from its Scrubs Lane monitoring site:

1) A calculation/estimation of the 2005 annual PM_{10} levels and the number of days in the year when 50 µg m^{-3} was likely to be exceeded and the 2005 annual NO_2 levels and the number of hours in the year when 200 µg m^{-3} was likely to be exceeded (with reference to the Air Quality Strategy Objectives).

2) Analysis of the data for any diurnal or weekday patterns to identify any periods of elevated PM_{10} measurements and to determine the likelihood of any elevated emissions being the result of local non-traffic sources.

3) A comparison of Scrubs Lane data with other LBHF data and data from other sites (preferably London) particularly where monitoring has been undertaken in the vicinity of waste transfer stations and other material handling industrial sites.

4) A source apportionment study of the PM_{10} levels on Scrubs Lane in the vicinity of the monitoring location to determine the contribution made to local PM_{10} emissions by local traffic, local industry etc. We are particularly interested in defining the local 'non-traffic' contribution to particulate levels.

5) The analysis of exposed TEOM filters (if this may provide any useful information)

6) If local industry is determined to be contributing significant emissions, recommendations should be made for inclusion in the Council's Air Quality Action Plan on how to minimise these emissions

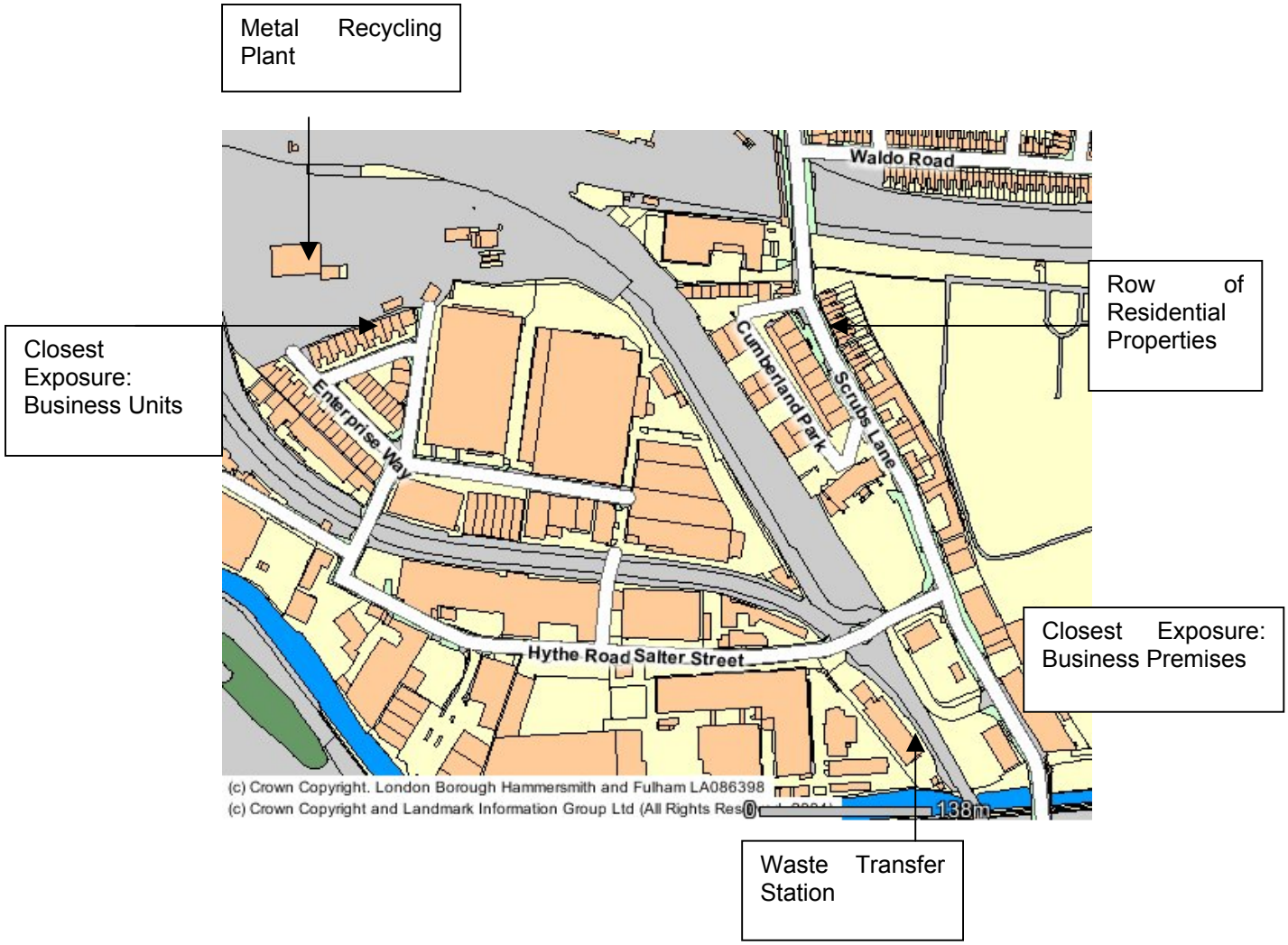

Figure 1 Fugitive sources in north of the borough as indicated by the Council

Site Visit

KCL staff undertook a site visit to the Scrubs Lane area on the 7th November 2005 accompanied by Paul Baker from Hammersmith & Fulham Council. The visit included the location of the Hammersmith & Fulham 3 monitoring site and nearby industrial premises.

The presence of a waste transfer facility was noted around 450 m south of the monitoring site near the junction with Hythe Road. Soiling of the road was noted around the entrance to the waste transfer facility (Figure 2) but this did not extend north to the location of the monitoring site. KCL staff also viewed the metal fragmentising site and associated storage area which lies between south west and west of the monitoring site at a distance of between 300 and 600m. This is shown in Figure 3.

Figure 2 Roadway soiling around the entrance to the waste transfer facility.

Figure 3 Metal fragment storage area.

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Method

Air pollution measurements

Air pollution monitoring equipment was hired by the Council from the Transport Research Laboratory. The site was installed on the east site of Scrubs Lane near the junction with Waldo Road and operated between 28th March and 27th October 2005. The sample inlet was approximately 2m above the ground and 1m from the kerb

Automatic measurements of PM_{10} were made using the Tapered Element Oscillating Microbalance (TEOM) method. Measurements of NO_X used in this study were made using the chemiluminescent method with automatic equipment subject to fortnightly calibration traceable to National Metrological Standards. All measurements were logged using a Campbell Scientific data logger and collected by KCL each hour. Measurements from the monitoring site were validated by KCL using the most upto date calibration factors and disseminated in near real time on the LAQN web page (www.londonair.org.uk).

The NO_X and PM_{10} instruments were subject to UKAS accredited audit by the National Physical Laboratory (NPL) towards the end of the monitoring period on the 23rd September 2005. The TEOM K0 factor measured during the audit was found to be different to that configured in the TEOM control unit.

A final measurement data set was produced by KCL following retrospective ratification of the measurements using procedures, which exceed the requirements detailed in LAQM TG03 (DEFRA, 2003) and the latest guidance released in 2006. During ratification information from regular calibrations, audits and daily manual validation were used to establish an operational and calibration history of the instruments and the pollution measurements were corrected to establish traceability to National Metrological Standards. During ratification a mathematical correction was also applied to the PM_{10} data set to account for the incorrect TEOM K0 factor. A minor logger analogue to digital converter error was indicated at ratification with respect to the PM_{10} measurements. This was quantified and corrected. Such errors are an inherent risk with this type of site configuration.

Details of the monitoring site and the final dataset may be found at www.londonair.or.uk and specifically at:

http://www.londonair.org.uk/london/asp/PublicDetails.asp?region=0&site=HF3&details=general&mapview=all&la_id=16

The EU limit value requires PM_{10} to be measured using the gravimetric method. However, the vast majority of PM_{10} measurements in and around London are made using TEOMs. Allen et al., (1997); Smith et al., (1997); Green et al., (2001); Charron et al., (2004) and others have observed that the TEOM produced a lower measurement of PM_{10} than that derived gravimetrically due to greater sampling losses of semi-volatile particulate and particle bound water from the TEOM. A 'correction' factor of 1.3 is recommended in the UK for comparison of TEOM PM_{10} measurements with the EU Directive (DETR, 1999). It is recognised that the 'correction' factor will depend on PM_{10} particle composition (Charron et al., 2004) and this is therefore likely to lead to inaccuracies when applied to PM_{10} from different sources and to different size fractions of airborne particulate. The application of a consistent 1.3 factor to PM_{10} from all sources is however required to ensure consistency between measured concentrations and the model results and to allow both to be compared to the EU Limit Values / AQS Objectives.

Estimation of 2005 PM_{10} and NO_2 concentrations at Scrubs Lane and comparison to the AQS Objectives

The AQS Objectives for NO_2 and PM_{10} require that measurements be ideally undertaken for a calendar year with an overall data capture of 90%. The Hammersmith and Fulham 3 monitoring site measured PM_{10} and NO_2 concentrations over a period of 214 days; 59% of a calendar year. This is an insufficient measurement period to compare directly to the AQS Objectives. Instead estimations of the likely annual concentration of PM_{10} and NO_2 at Scrubs Lane were required before comparison to

the AQS Objectives. Several methods for making such estimates are described in the DEFRA guidance LAQM TG03 (DEFRA 2003).

The HF3 monitoring site is part of the London Air Quality Network (LAQN), the world's largest citywide air pollution network. The LAQN comprises over 90 monitoring sites in and around London with over 40 monitoring sites located in roadside locations. The techniques for estimating annual pollution concentrations described in LAQM TG03 were employed by KCL using the unique measurement resource of the LAQN. Estimates of annual mean concentrations of NO_2 and PM_{10} and breaches of the short-term AQS Objectives for these pollutants were made on a *pro rata* basis using measurements from all LAQN monitoring sites that attained a 90% data capture rate during both the operating period of the Scrubs Lane site and the whole calendar year. Regression analysis was undertaken using RMA regression reflecting the observations of Ayres (2001) and recognising the inherent uncertainty in both the determinate and dependent variables.

PM_{10} Source apportionment methodology

The PM_{10} modelling methodology described in Fuller et al., (2002) divided PM_{10} by source through analysis of measurements of annual mean NO_X, PM_{10} and $PM_{2.5}$ across a network of monitoring sites. Similar source apportionment techniques have been applied elsewhere in the UK and to a lesser extent in Europe (Deacon et al.,1997; Harrison et al., 1997; APEG 1999; Kukkonen et al., 2001 and Stedman et al., 2001).

Fuller et al., 2002 identified PM_{10} as arising from three source components: primary (associated with NO_X), secondary (mainly the $PM_{2.5}$ not associated with NO_X) and natural (coarse component not associated with NO_X). The model assumed that the secondary and natural components do not vary across the London region (over distances of around 100 km) for medium term averaging periods; a day or more. The total PM_{10} at any monitoring site was therefore a combination of the regional secondary and natural PM_{10} with an additional local primary component from combustion sources. The local primary component from combustion sources was determined from the local NO_X concentration.

The KCL model has been successfully employed elsewhere to determine PM_{10} arising from local non-vehicle sources including building works, road works (Fuller and Green 2004) and industrial process (Fuller and Tremper 2004). The model has also been successfully applied to source apportion PM_{10} arising in the vicinity of waste handling facilities (Fuller and Baker 2001).

This modelling exercise deployed the model in a simplified form where the secondary and natural components were not separated and therefore the co-located measurements of $PM_{2.5}$ required by the full method were therefore not needed. To model the PM_{10} concentration at Hammersmith and Fulham 3 the concentration of the regional secondary and natural components was derived from five background LAQN monitoring sites. These five background / suburban monitoring sites (termed base sites) were selected because of their proximity to Hammersmith and Fulham 3 and their freedom from local non-NO_X sources of PM_{10}. The base sites are listed in Table 1.

Local events that are not associated with NO_X will not be predicted by this model since it has no knowledge of them. Using the approach employed in Fuller and Green (2004) the difference between measured and modelled PM_{10} enabled the quantification of the PM_{10} arising from local sources that were not sources of NO_X. In this study this approach is used to identify both local sources that are not sources of NO_X and local sources that may be linked to NO_X that are not expected on the basis of NO_X and PM_{10} relationships derived from other sites in London and the south east.

However, the difference between measured and modelled PM_{10} can also be due to model uncertainty. To estimate model uncertainty in this study, the model was also used to predict PM_{10} at six test sites in addition to Hammersmith and Fulham 3. The uncertainty in the model performance at the test locations was then used to estimate the uncertainty in the estimate of the concentration of the local - other sources at Hammersmith and Fulham 3. The test sites were selected as the closest roadside sites to Hammersmith and Fulham 3. The tests sites are listed in Table 1. Further details of the monitoring sites used in the study can be found on the LAQN web site at www.londonair.org.uk

Site name	Site type
Base Sites	
Barnet 2	Urban background
Ealing 7	Urban background
Hammersmith & Fulham 2	Urban background
Kensington & Chelsea 1	Urban background
Richmond 2	Suburban
Test Sites	
Brent 3	Roadside
Brent 4	Roadside
Ealing 2	Roadside
Hammersmith & Fulham 1	Roadside
Hounslow 4	Roadside
Richmond 1	Roadside

Table 1 Base and test sites used in the source apportionment model

Model Inputs and Outputs

The model was applied separately to measurements of NO_X and PM_{10} averaged in three ways to look at possible characteristics of the local PM_{10} source at Hammersmith &Fulham 3. The following model inputs (and therefore outputs) were chosen:

- Daily mean concentrations for comparison to the EU Limit Value and to identify the date on which local PM_{10} incidents occurred. Daily mean concentrations of NO_X and PM_{10} were calculated from 15 minute mean measurements for each day with a daily data capture of greater than 75%.

- Mean concentrations averaged by day of week and hour of day to determine any pattern in concentration of the local non-NO_X PM_{10} source(s). Mean PM_{10} concentrations were averaged by day of week and time of day. For instance the mean NO_X and PM_{10} measurements for each Wednesday at 13:15 h were averaged as input data, followed by each Wednesday at 13:30 h and so on.

- Mean concentrations averaged by wind direction, to create pollution roses, to identify the direction of local PM_{10} source(s), relative to the Hammersmith and Fulham 3 site. The selection of appropriate wind direction measurements for Hammersmith and Fulham 3 is discussed below. Care should be taken when interpreting the results of this analysis since equal weighting is given to the concentration measurements in each 10 degree averaging bin. However the wind does not blow with equal frequency from all directions. The apportionment from this analysis cannot therefore be compared directly to the overall apportionment, apportionment of daily mean concentration or that undertaken with respect to day of week and hour of day.

In each case appropriately averaged measurements at the base sites were apportioned between primary and non-primary sources. To undertake this apportionment, the concentration of primary PM_{10} was calculated using the NO_X concentration at each base site and regression gradients as described in Fuller et al., (2002). The modelled total PM_{10} at Hammersmith & Fulham 3 and at the test sites was then calculated by adding the mean non-primary PM_{10} from the base sites to the primary PM_{10} calculated from NO_X measurements from each site.

The source apportionment technique divided the measured concentration of PM_{10} into the following sources:

- **Background secondary and natural** – background PM_{10} that is not linked to NO_X

- **Background primary** – background PM_{10} that is linked to NO_X.

- **Local primary** – PM_{10} estimated from the elevation in NO_X concentration, above background. This source includes both primary tail pipe PM_{10} and also expected PM_{10} from resuspension, tyre and brake wear sources determined from average conditions throughout the LAQN, as determined from network wide regressions. PM_{10} emissions from diesel trains should also be associated with NO_X and would be included within this source category.

- **Local - other** – PM_{10} not accounted for by the model. This will include local sources that are not linked to NO_X and also the local sources that may be linked to NO_X but were not expected on the basis of NO_X and PM_{10} relationships derived from other sites in London and the south east, abnormal quantities of resuspended particulate for example.

- **TEOM offset** - the measurement offset of +3 μgm^{-3} (raw TEOM) applied by the TEOM to all measured mass concentrations (Patashnick and Rupprecht 1991, Rupprecht and Patashnick Co. Inc. 1992, Rupprecht and Patashnick Co. Inc. 1996) was included as another 'source' within the apportionment scheme. Following the application of the 1.3 'correction' factor this offset had a value of 3.9 μgm^{-3}. Retention of the offset within the model ensured comparability between the source apportionment method and TEOM measurements and enabled the source apportioned TEOM measurements to be compared to the EU Limit Value

Wind direction measurements

Pollution roses show the mean concentration of pollution averaged according to wind direction.

PM_{10} pollution roses were calculated using mean NO_X and PM_{10} concentration averaged for each 10 degree wind sector. Wind direction is not a scalar quantity but is related to the wind vector. For this reason vector averaged 15 minute wind direction measurements were used along with contemporaneous pollution measurements.

Wind direction measurements were not available at the Hammersmith and Fulham 3 site Wind direction measurements were therefore taken from the nearby Ealing 7 base site. The Ealing 7 site is in an open location. The ability of the wind direction measurements at Ealing 7 to represent those over a wider area were tested by comparing Ealing 7 measurements to those made at monitoring sites in Bexley in south east London.

Analysis of TEOM filters

Analysis of the acid digestible metal content of PM_{10} at Manor Road, Bexley was undertaken in a previous study (Baker et al., 2003) and this did not yield useful information to enable the identification of local sources of PM_{10}. On the basis of this previous analysis, a chemical analysis PM_{10} from Hammersmith and Fulham 3 did not form part of our proposal.

Results and discussion

Air pollution measurements

Air pollution measurements from the Hammersmith & Fulham 3 monitoring site are shown in Table 2. Table 2 also shows measurements at the nearby base and test sites. For additional comparison measurements from 3 industrial sites close to waste transfer facilities are also shown along with measurements from the Marylebone Road kerbside site. Measurements from all sites are shown for the operating period of the Hammersmith & Fulham site.

Table 2 clearly indicates the concerns regarding the PM_{10} concentrations at the 3 sites close to waste facilities. Each of these sites exceeds the short-term EU Limit Value during this period (35 days with mean PM_{10} above 50 μgm^{-3} TEOM*1.3). The EU Limit Value was also exceeded at the Marylebone Road kerbside site and at the Brent 4 roadside site. Both Marylebone Road and Brent 4 are alongside major roads, as indicated by their NO_X concentrations, which rank 1st and 2nd respectively amongst the sites in Table 2 (NO_X is not measured at Ealing 8). The source apportionment scheme in Fuller et al.,(2002), suggests that primary PM_{10} emissions are linked to NO_X and thus high levels of PM_{10} would be expected at Marylebone Road and Brent 4. Such an explanation does not account for the PM_{10} concentrations measured at Brent 5 and Bexley 4 and thus a non tail pipe source of PM_{10} is obviously affecting these sites.

The Hammersmith & Fulham 3 site did not exceed the EU Limit Value during its operating period. However the mean PM_{10} and the number of days with mean PM_{10} greater than 50 μgm^{-3} TEOM*1.3 is greater than would be expected from the NO_X measurements at the site. The NO_X measurements at Hammersmith & Fulham 3 suggested that PM_{10} concentration at the site should have been closer to that measured at Ealing 2 and Brent 3; a mean PM_{10} concentration closer to 30 μgm^{-3} TEOM*1.3, rather than 36 μgm^{-3} TEOM*1.3 and less than 11 days with mean PM_{10} greater than 50 μgm^{-3} TEOM*1.3 rather than 29 days .

28th March – 27th October 05	PM_{10} μgm^{-3} TEOM*1.3			NO_2 μgm^{-3}			NO_X μgm^{-3}	
	Capture %	Daily mean > 50	Mean	Capture	Hours > 200	Mean	Mean	Rank
Ealing 8*	99	172	93	-	-	-	-	-
Brent 5*	97	114	68	96	0	40	98	8
Bexley 4*	99	82	51	94	0	30	57	10
Marylebone Rd	97	76	44	94	423	108	277	1
Brent 4	94	47	43	75	0	68	259	2
Hams & F 3	**97**	**29**	**36**	**97**	**3**	**41**	**114**	**6**
Hams & F 1	94	25	37	92	14	72	187	3
Hounslow 4	99	13	31	97	8	71	156	4
Ealing 2	99	11	29	97	4	57	121	5
Ken & Chelsea 1	99	4	25	97	0	35	49	11
Brent 3	87	3	30	89	0	53	106	7
Barnet 2	97	3	24	96	0	32	45	13
Hams & F 2	96	2	25	97	0	36	49	12
Ealing 7	96	2	23	97	0	30	42	14
Richmond 1	97	1	25	96	0	35	62	9
Richmond 2	97	0	23	82	0	25	34	15

Table 2 Measurements of air pollution at Hammersmith & Fulham 3 and nearby sites. Measurements at 3 industrial sites close to waste facilities have also been included and marked with *, along with measurements from the Marylebone Road kerbside site. Measurements are ordered by the number of days with mean PM_{10} above 50 μgm^{-3} TEOM*1.3. The ranking with respect to mean NO_X concentration is also shown.

Estimation of 2005 PM_{10} and NO_2 concentrations at Scrubs Lane and comparison to the AQS Objectives

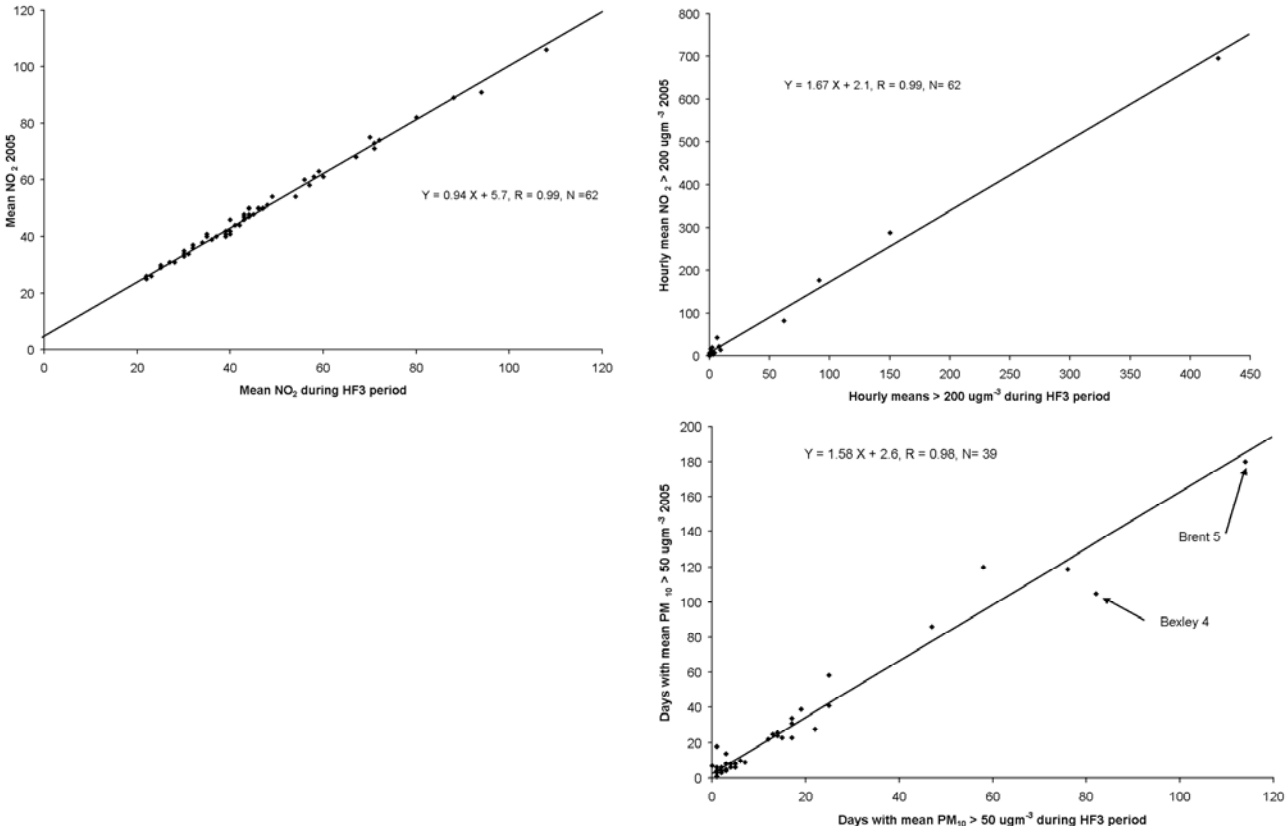
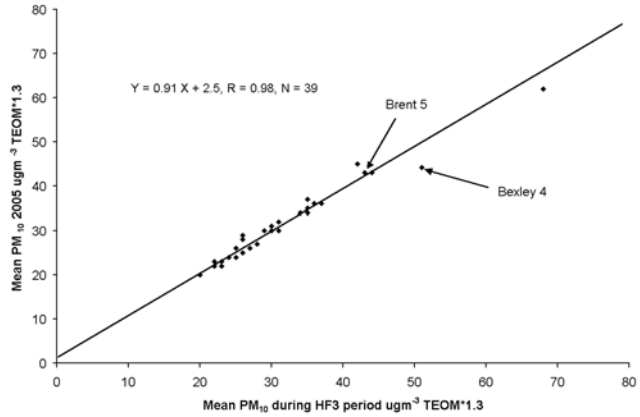


Figure 4 Relationships between measurements of NO_2 and PM_{10} during the operating period of the HF3 monitoring site and the calendar year 2005. Measurements have been used from all LAQN monitoring sites that attained 90% capture for both periods.

Estimates of annual mean concentrations of NO_2 and PM_{10} and breaches of the short-term AQS Objectives for these pollutants were made using measurements from all LAQN monitoring sites that attained 90% data capture during both the operating period of Hammersmith and Fulham 3 and the calendar year. Regression analysis was undertaken using RMA regression reflecting the observations of Ayres (2001) and recognising the inherent uncertainty in both the determinate and dependent variables and is shown in Figure 4. It can be seen from Figure 4 that relationships for mean concentrations have gradients of 0.94 for NO_2 and 0.91 for PM_{10} indicating a slight seasonality of



these pollutants with lower concentrations being measured during the period when the HF3 monitoring site was not working. The gradients for the short-term AQS Objectives were 1.67 for NO_2 and 1.58 for PM_{10}. These gradients reflect that these metrics are based on counts of breaches and thus we would expect a ratio in approximate proportion to the fraction of the year that the Hammersmith & Fulham operated (1.7). In each case R values of 0.98 or better were obtained. Figure 4 also indicates the two monitoring sites Brent 5 and Bexley 4 that are close to waste facilities (Ealing 8 was only installed in February 2005 and thus could not achieve the 90% data capture to be used in the analysis).

Based on the relationships derived from the regression analysis in Figure 4 estimations of the annual measurements of NO_2 and PM_{10} at Hammersmith & Fulham 3 are shown in Table 3 along with confidence estimates at 2 σ. Table 3 shows that the location is very likely to have exceeded the daily mean objective for PM_{10} and the annual mean objective for NO_2. The location is very likely to have attained the hourly mean NO_2 Objective and the annual mean Objective for PM_{10}. Bexley 4 is an obvious outlier in the PM_{10} relationships shown in Figure 4. However the recalculated the results with both Bexley 4 and Brent 5 excluded from the PM_{10} RMA regressions are within the estimated uncertainty limits obtained from the relationship using all sites.

Pollutant	AQS Objective		Estimated Result (CI 2 σ)	Units
	Type	Value		
PM_{10}	Days with mean > 50 μgm^{-3} TEOM*1.3	40	48 (53 – 44)	Days
	Annual mean	35	35 (38 – 33)	μgm^{-3} TEOM*1.3
NO_2	Hours > 200 μgm^{-3}	17	7 (5 - 9)	Hours
	Annual mean	40	44 (43 - 45)	μgm^{-3}

Table 3 Comparison of estimated pollution concentrations at Hammersmith & Fulham 3 for 2005 with AQS Objectives. Confidence limits are shown at 2 σ.

Source apportionment of mean PM_{10} concentration

Results of the source apportionment of the mean concentration of PM_{10} at Hammersmith & Fulham 3 are shown in Figure 5. PM_{10} from all background sources accounted for the majority of the measured concentration (55%) and the TEOM offset accounted for a further 11%. The 34% of PM_{10} arising locally was estimated to be almost equally divided between primary PM_{10} from transport sources (18%) and other local PM_{10} (16%).

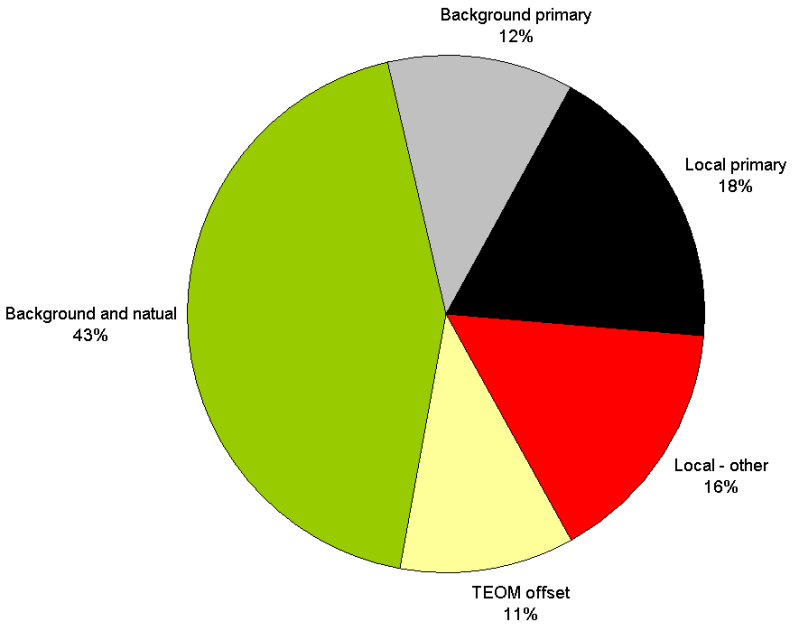


Figure 5 Source apportionment of mean PM_{10} concentration at Hammersmith and Fulham 3.

PM_{10} source apportionment was undertaken previously in the borough as part of the council's Stage 4 Review and Assessment of Air Quality (ERG 2002). ERG, 2002 apportioned PM_{10} concentrations at 12 roadside locations in the borough on the basis of source categories within the LAEI and the source locations. In this study the measured concentration of PM_{10} at Hammersmith & Fulham 3 was apportioned on the basis of categories that could be identified by their association with NO_X and the location at which they were measured. Other differences between the approaches arise due to the TEOM offset that is a component of the measured concentration but is not a component of the PM_{10} at the site. A detailed comparison between the results of the apportionment of the measured concentrations at Hammersmith & Fulham 3 and that in ERG, 2002 is therefore not possible. However, ERG, 2002 suggests that the mean PM_{10} at the 12 roadside locations in the borough consists of 33% primary PM_{10} and 67% non-primary PM_{10}. The apportionment at Hammersmith & Fulham 3 in this study suggests PM_{10} concentrations to be 36% primary and 64% non-primary excluding the local - other PM_{10} from the apportionment scheme and including the TEOM offset within the non-primary PM_{10} as would have been assumed in ERG, 2002. The apportionment at Hammersmith & Fulham 3 and is therefore in line with ERG, 2002.

Quantification of the local - other source of PM_{10} is a key objective of the study. The PM_{10} concentration arising from the local - other source was calculated from the difference between the measured and modelled PM_{10} concentration at Hammersmith & Fulham 3. The uncertainty in the concentration of PM_{10} from this source was determined from the performance of the model at the test sites. This is shown in Table 4. The local - other sources at Hammersmith & Fulham 3 had a mean concentration of 5.7 (9.8 – 3.9) μgm^{-3} TEOM*1.3 during the monitored period.

Site	Measured Mean	Modelled Mean	Measured - modelled
Brent 3	29.6	29.6	0.0
Ealing 2	28.8	31.3	-2.4
Hounslow 4	30.9	34.5	-3.7
Richmond 1	25.1	25.4	-0.3
Brent 4	43.2	44.0	-0.8
Hams & Fulham 1	37.1	37.3	-0.2
Mean (CI at 2σ)	32.5	33.7	-1.2 +/- 3.0

Hams & Fulham 3	**35.6**	**29.9**	**5.7 (9.8 – 3.9)**

Table 4 Model performance (mean concentration) at test sites and Hammersmith and Fulham 3 (μgm^{-3} TEOM*1.3).

Source apportionment of daily mean PM_{10} concentration

The daily mean time series of source apportioned PM_{10} concentration at Hammersmith & Fulham 3 is shown in Figure 6. Source apportionment was possible on each of the 205 days when PM_{10} was measured at the site. Daily mean concentrations in excess of 50 μgm^{-3} TEOM*1.3 were measured throughout the monitoring period with a greater frequency of events being measured at the end of the monitoring period. The time series of the daily mean concentration of PM_{10} from local - other source is shown in Figure 7, which indicates increased concentrations of PM_{10} from this source at the end of the monitoring period during October, reaching a peak daily mean concentration of 37 μgm^{-3} TEOM*1.3 on Thursday 6th October 2006.

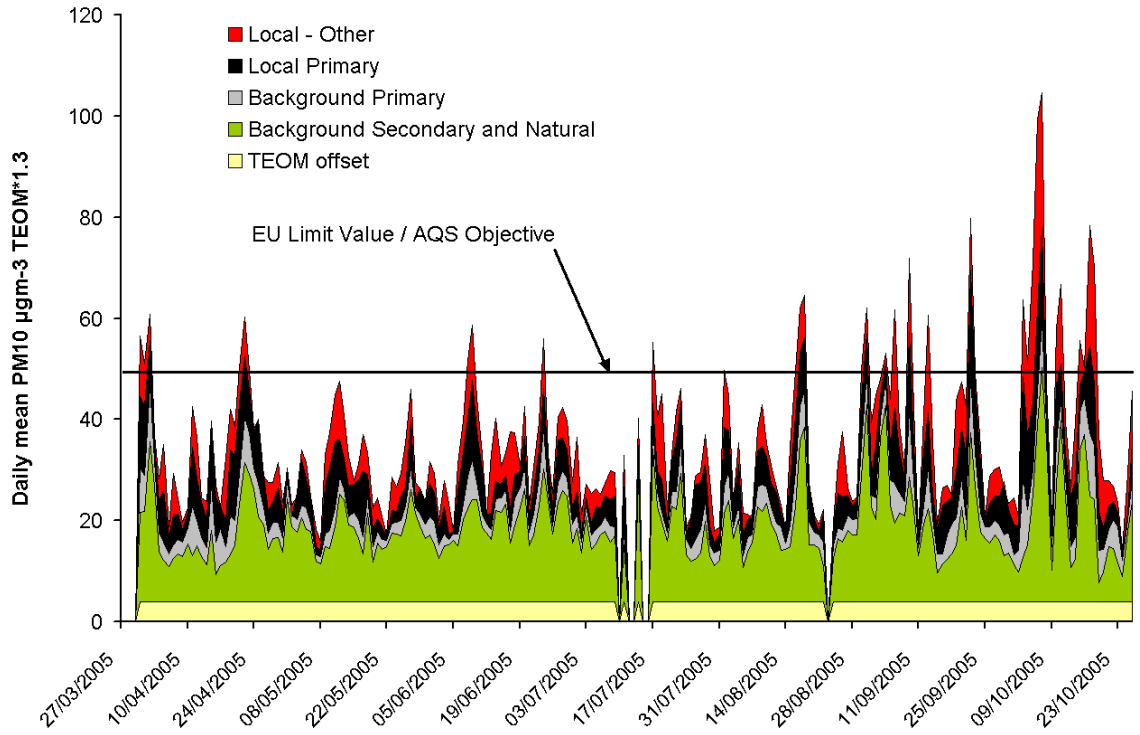


Figure 6 Time series of daily mean PM_{10} concentrations.

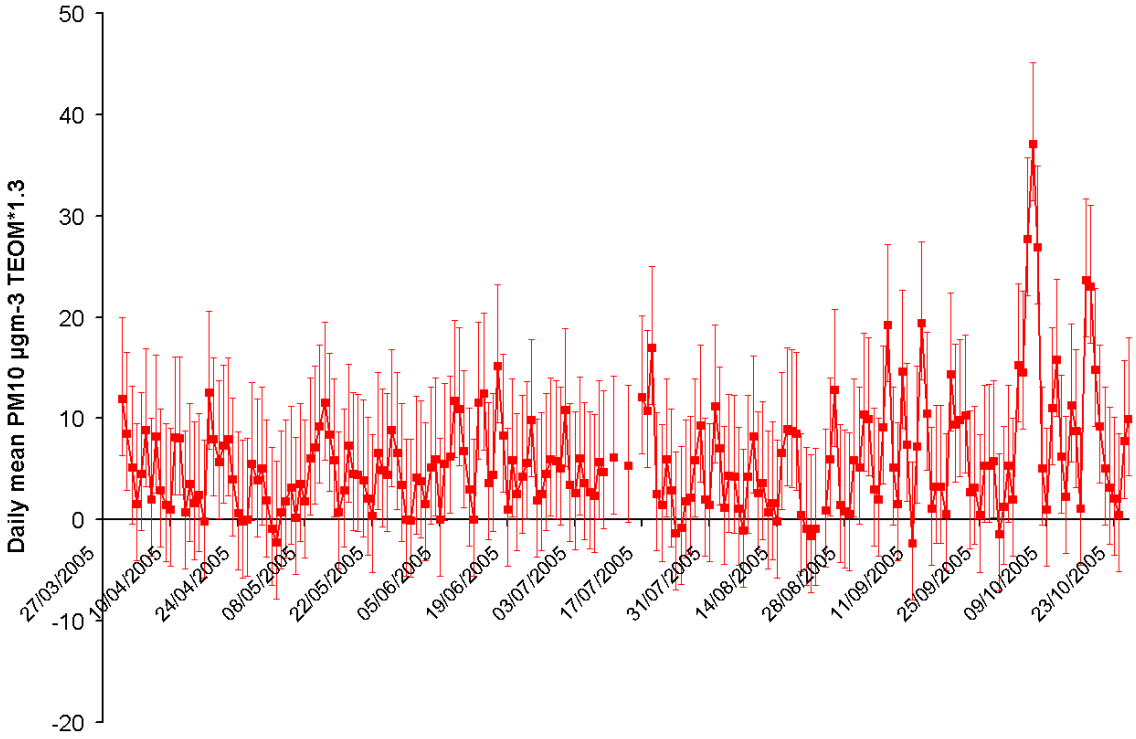


Figure 7 Time series of the daily mean PM_{10} concentration from the local - other source. Uncertainty is shown at 2σ.

Source apportionment of PM_{10} concentration averaged by day of week and hour of day

Averaging pollution concentration by day of week and hour of day can lead to insight into the behaviour of the emissions sources affecting a monitoring site. Figure 8 shows the source apportioned concentration of PM_{10} at the Hammersmith & Fulham 3 site averaged by day of week and hour of day. Times are shown in GMT however BST applied to almost the entirety of the monitoring period. Clear differences in the total mean PM_{10} total concentration can be seen between weekdays and weekends with the total mean concentration being greater on weekdays than on Saturday and Sunday. From concentration minima during hour 2 GMT (hour 3 BST), mean PM_{10} concentrations rose rapidly during hour 5 GMT (hour 6 BST) each weekday morning and peaked during or before hour 9 GMT (hour 10 BST) before falling steadily for the remainder of the day. The total mean PM_{10} concentration showed little evidence of an evening traffic peak. A morning peak was also evident on Saturdays albeit a lower concentration compared with that experienced on weekdays. The total mean PM_{10} on Sundays showed comparatively little variation through the day.

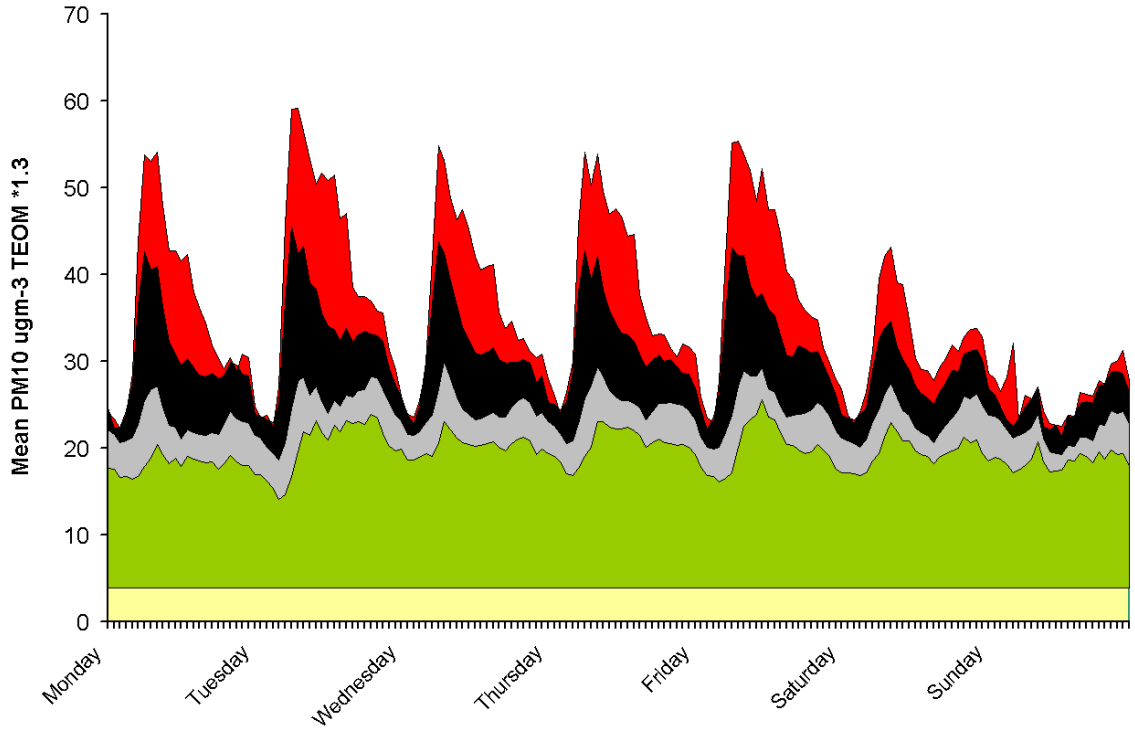


Figure 8 Source apportioned concentrations of PM_{10} at Hammersmith & Fulham 3 averaged by day of week and hour of day. Times were based on GMT.

As expected from the overall source apportionment the largest single contribution to the total mean PM_{10} concentration was due to the PM_{10} from background secondary and natural sources. The time frame for the atmospheric reactions that lead to secondary PM_{10} are of the order of hours and days and thus it was expected that the concentrations of PM_{10} from this source would exhibit less day of week variation than other sources.

Figure 9 shows the concentration of primary sources of PM_{10}. Background primary PM_{10} sources at the site show evidence of PM_{10} emissions from both the morning and evening traffic peaks and a further peak on Saturday night. By contrast the local primary source showed evidence of the emissions from the weekday morning peak only with concentrations then declining during the day. The local primary source did not exhibit the same diurnal variation when compared with primary PM_{10} emissions elsewhere in London. This may be due to tidal traffic flow on Scrubs Lane producing greater emissions during the morning peak. The Hammersmith & Fulham 3 monitoring site was located adjacent to the south bound lane and it would therefore be more sensitive to emissions from

this lane when compared with emissions from the northbound lane. It is possible that the morning only peak is caused by tidal flow on the road causing greater southbound traffic emissions in the morning.

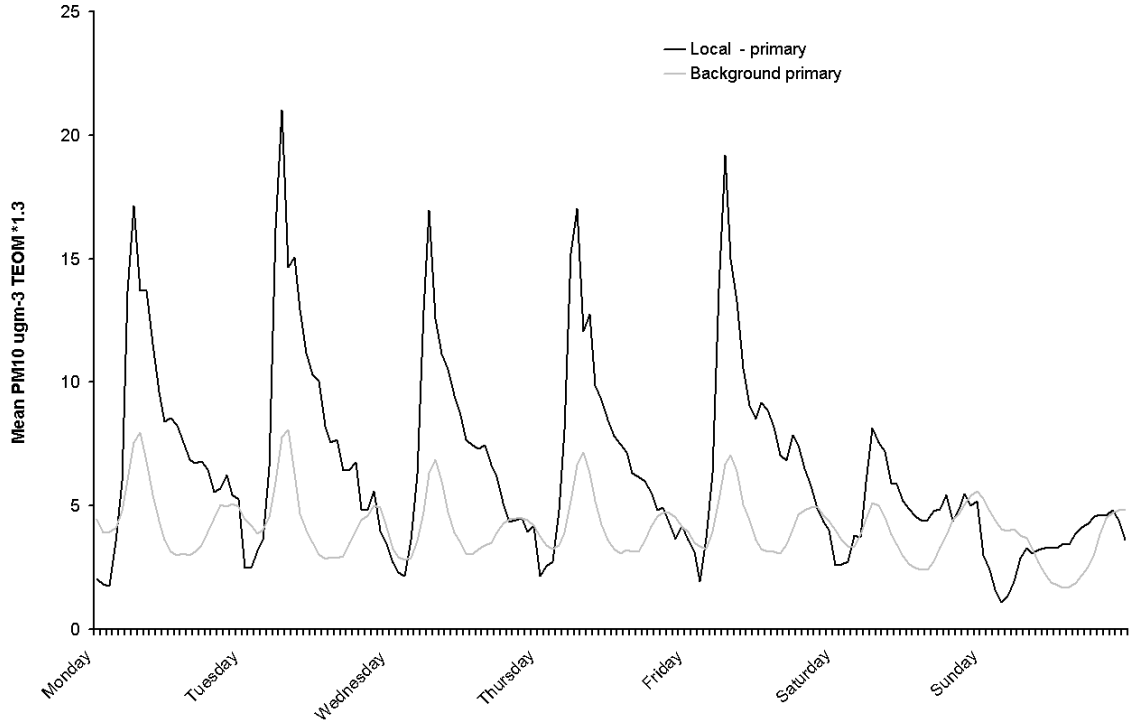


Figure 9 Concentrations of PM_{10} from primary sources at Hammersmith & Fulham 3 averaged by day of week and hour of day. Times are shown in GMT.

The concentration of PM_{10} from the local – other source is shown in Figure 10 along with estimated uncertainty shown at 2 σ calculated from the model performance at the test sites. The PM_{10} from the local – other source also showed distinct differences in behaviour between weekdays and weekends, with greater concentrations exhibited on weekdays. The elevated mean concentrations were exhibited during working hours on weekdays and on Saturday mornings were greater than the estimated uncertainty of the model and were therefore not due to model artefacts but instead represented a daily variation in the sources of PM_{10} at the monitoring site. The greatest concentration of PM_{10} from the local – other source were experienced on Tuesdays however the differences between the mean concentrations on Tuesdays at other weekdays were within the expected model uncertainties and may not be significant. The concentration of PM_{10} from this source fell to around zero each night. The slight negative concentration of PM_{10} from local – other sources during Sunday was also not significant within the context of the model uncertainty. The peak in the concentration of PM_{10} from local – other sources also showed a significant peak during hour 4 GMT (hour 5 BST). The reason for this peak is not known.

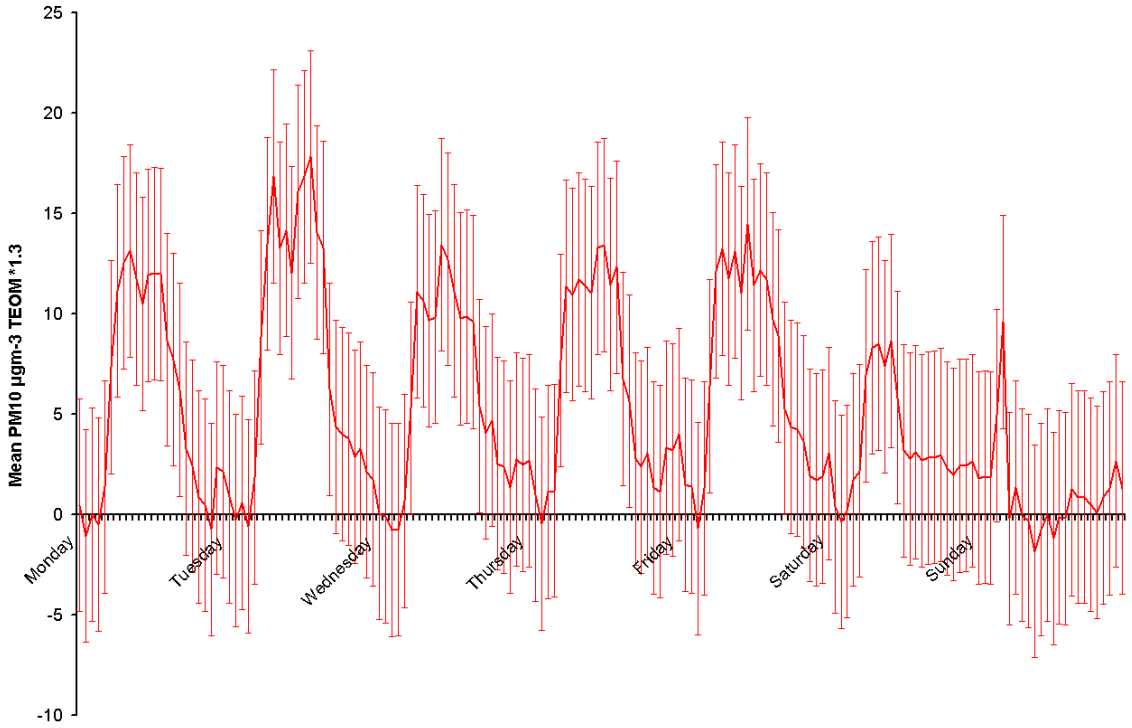


Figure 10 Concentrations of PM_{10} from local - other sources at Hammersmith & Fulham 3 averaged by day of week and hour of day. Times are shown in GMT and uncertainty estimates are shown at 2 σ.

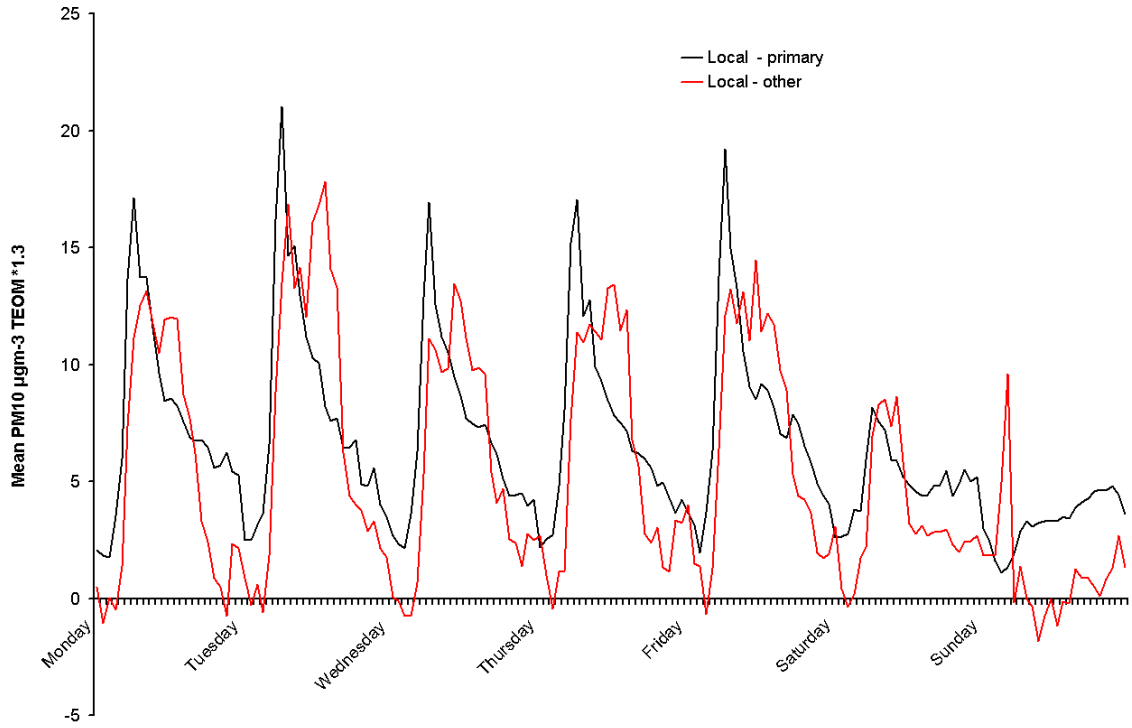


Figure 11 Concentrations of PM_{10} from local sources at Hammersmith & Fulham 3 averaged by day of week and hour of day. Times are shown in GMT.

On initial inspection the variation in the concentration of PM_{10} from both local sources, primary and other, appear similar with the greatest concentrations measured on weekdays and Saturday mornings, and lower concentrations at night and on Sunday.

Figure 11 shows the mean concentration from the local sources and highlights some important differences between the weekday behaviour of the PM_{10} from the local primary and the local - other sources. The mean concentration from both sources increased rapidly at during hour 5 GMT (hour 6 BST) each weekday. The concentration of PM_{10} from the local primary source peaked during hour 6 or 7 GMT (hours 7 or 8 BST) and then declined through the day. By contrast the PM_{10} from the local – other source remained elevated during the working day and fell during hours 16 or 17 GMT (hours 17 or 18 BST). On Saturdays the concentrations from both local sources increased sharply during hours 5 and 6 GMT (hours 6 or 7 BST). The local – other source however only exhibited brief activity on Saturdays and declined during hours 10 and 11 GMT (11 and 12 BST).

Mean PM_{10} by wind direction

Figure 12 shows the mean concentration of PM_{10} at Hammersmith & Fulham 3, averaged by wind direction. The analysis of PM_{10} concentration with respect to wind direction can provide important insight into the location of PM_{10} sources affecting a monitoring site.

Figure 12 shows that the greatest overall mean concentration of PM_{10} arose during easterly winds. This elevation in mean concentration was partially caused by an elevation in the mean concentration of PM_{10} from background secondary and natural sources at this time. This was indicative of long range transport of PM_{10} from continental sources as highlighted by APEG (1999) and Smith (1997). Easterly winds are also often linked to anticyclonic conditions and therefore periods of low wind speeds. Such conditions are not conducive to the dispersion of primary pollutants and therefore we would also expect elevated mean concentrations of PM_{10} from the background primary sources to be associated with easterly winds as also shown in Figure 12.

The lowest mean PM_{10} concentrations were measured at the site during westerly winds. Winds from a westerly direction usually have a maritime origin and do not contain large concentrations of secondary PM_{10}. Higher wind speeds are usually experienced during westerly winds which are linked to greater dispersion of primary pollutants and therefore lower concentration of PM_{10} from background primary sources was experienced at this time.

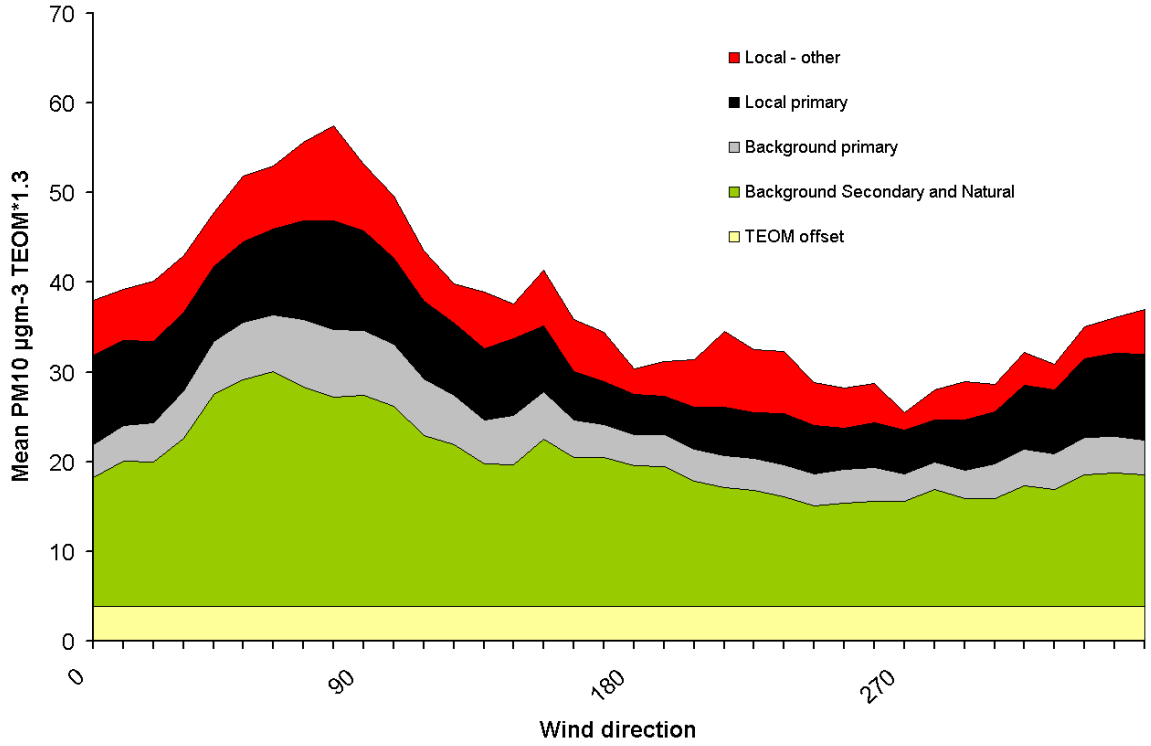


Figure 12 Source apportioned PM_{10} averaged by wind 10^{o} direction sectors.

The contrasting pollutant concentrations with respect to easterly and westerly winds are typical of background PM_{10} sources in London. However the behaviour of PM_{10} from local sources can be additionally affected by the location of local sources and buildings; the orientation of local roads with respect to wind direction and the geometry of street canyons are important in determinants. Figure 13 shows the mean concentration of local PM_{10} sources averaged by 10^{o} wind sectors. Local primary PM_{10} sources exhibited greatest concentrations when wind originated from directions between 330^{o} and 140^{o}. Specifically greatest local primary PM_{10} concentration was measured when winds originated from the east, perpendicular to Scrubs Lane, from the north in the approximate direction of the junction between Scrubs Lane and the A404 and from the south-south east. The elevated concentrations of local primary PM_{10} from the east may reflect the low wind speeds from this direction and also the canyon re-circulatory effects caused by the adjacent housing on this side of Scrubs Lane. The elevated concentrations from the north are most likely due to the additional emissions density and possible congestion around the junction with the A404. The lowest concentration of PM_{10} from local primary sources was experienced on westerly winds which may reflect the open nature of the land to the west of Scrubs Lane and the higher mean wind speeds from this direction. Figure 13 also shows the mean concentration of the PM_{10} from local – other sources. The blue broken line denotes wind direction bins where the concentration of PM_{10} from this source exceeds the expected model uncertainty (2σ) as estimated from the test sites and can therefore be regarded as significant. Significant concentrations of PM_{10} from local – other sources was experienced when wind originated from directions between 0^{o} and 110^{o}, 130^{o}, between 150^{o} and 170^{o} and between 210^{o} and 230^{o}. The significant concentrations of PM_{10} from the local – other source between 0^{o} and 170^{o} and the peak from 80^{o} reflects the distribution of the local primary PM_{10} and suggest a similar source: traffic on Scrubs Lane and the nearby junction with the A404. The significant mean concentrations of PM_{10} from the local – other sources from wind directions between 210^{o} and 230^{o} may denote a point source in this direction. PM_{10} from the local – other source from wind directions between 210^{o} and 230^{o} accounted for 10% of the overall mean concentration of PM_{10} from the local – other source.

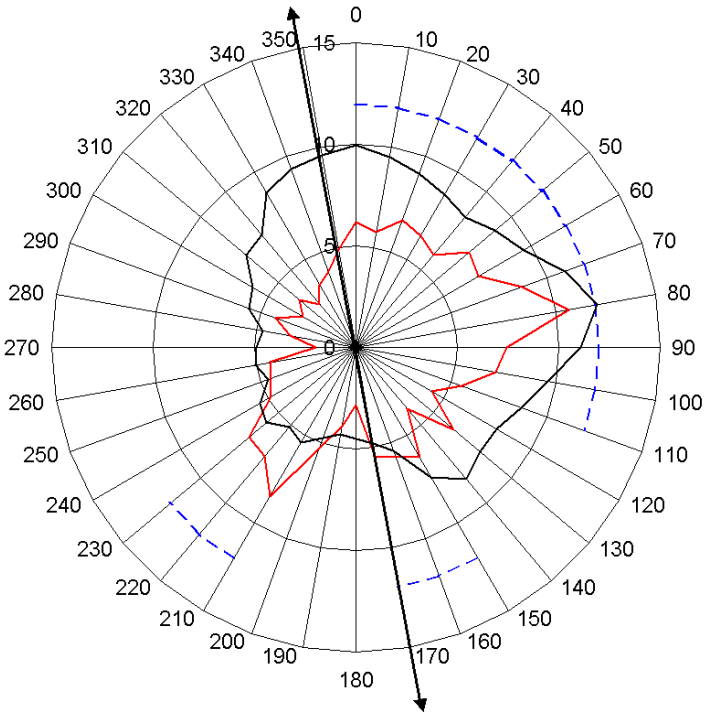


Figure 13 Source apportioned mean concentrations of PM_{10} from local sources at Hammersmith & Fulham 3 averaged by 10° wind sector. Local primary sources are shown in black, local - other sources are shown in red and the blue dotted line denotes concentrations of PM_{10} from local – other sources that are greater than the expected model uncertainty at 2σ. The arrow denotes the orientation of Scrubs Lane. Mean concentrations are shown in μgm^{-3} TEOM*1.3.

Comparison with other PM_{10} monitoring sites near industrial sources

Table 2 earlier, showed the PM_{10} concentration measured at Hammersmith & Fulham 3 and at 3 other sites close to waste transfer and industrial facilities. The mean concentration at these sites is shown in Figure 14 along with the estimated mean concentration of PM_{10} from local – other sources for the operational period of the Hammersmith & Fulham 3 site. The mean PM_{10} concentration at Ealing 8, Brent 5 and Bexley 4 exceeded that measured at Hammersmith & Fulham 3 and these three sites also exceeded the annual mean EU Limit Value concentration of 40 μgm^{-3} TEOM*1.3. The mean concentration of PM_{10} at Ealing 8 was more than twice the concentration measured at Hammersmith & Fulham 3.

The mean concentration of PM_{10} from local – other sources was calculated for Brent 4 and Bexley 5 using the same wind direction averaged source apportionment model as Hammersmith & Fulham 3. The concentration of PM_{10} from local – other sources at these sites was found to be approximately 5 times the concentration measured at Hammersmith & Fulham 3. The concentration of the PM_{10} from the local – other source at Brent 4 and Bexley 5 was close to the total PM_{10} concentration at Hammersmith & Fulham 3.

The selection of the model base sites for this study focused on measurements around Hammersmith & Fulham 3 and not Brent 5 or Bexley 4. This may induce additional uncertainty in the estimate of the concentration of local – other PM_{10} at these sites though this will be far less than the factor of 5 difference in the concentration. Apportionment of PM_{10} concentrations at Ealing 8 is not possible using this technique due to the absence of NO_X measurements at the site.

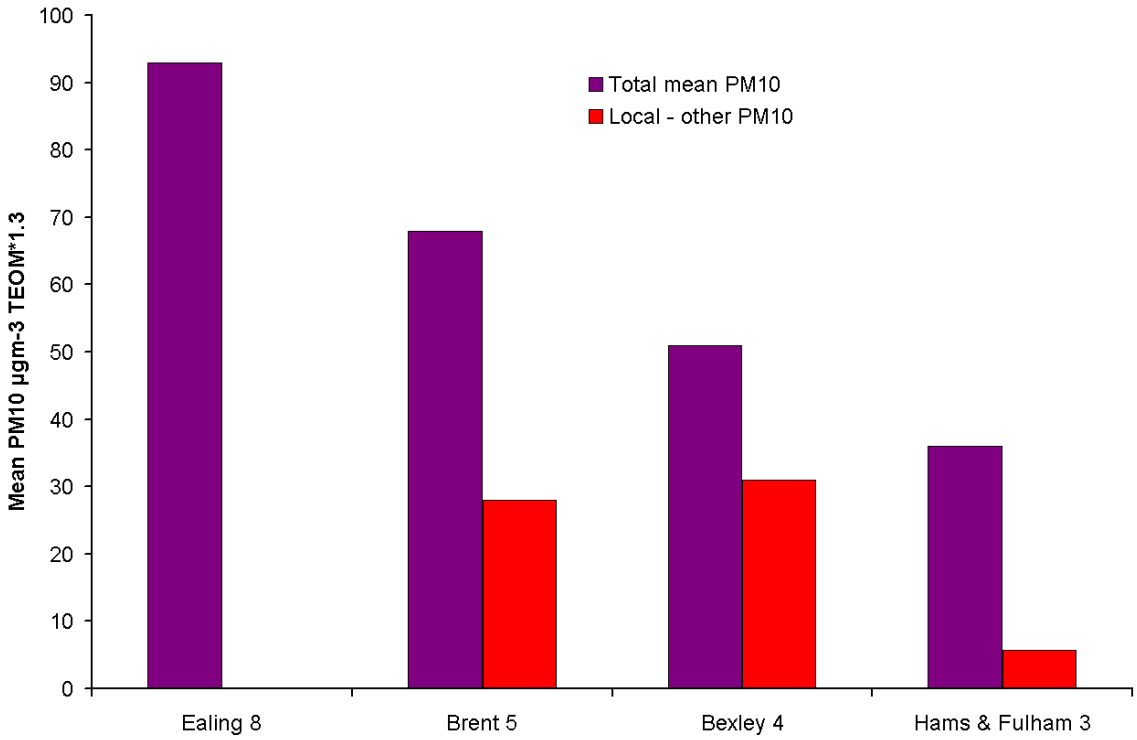


Figure 14 Mean concentration of PM_{10} at Hammersmith & Fulham 3 and 3 other monitoring sites close to waste and industrial facilities for the operating period of the Hammersmith & Fulham 3 monitoring site. The mean concentration of the local – other PM_{10} is also shown at each of these sites.

The concentration of PM_{10} from the local – other sources at Hammersmith & Fulham 3, Bexley 4 and Brent 5, averaged by 10^{o} wind sector, is shown in Figure 15. The factors affecting the concentration of the PM_{10} from the local – other source can be clearly seen at Bexley 4 and Brent 5.

The Bexley 4 monitoring site is located to the west of a waste transfer facility on a road that runs approximately east-west. This is evident in the mean concentration of PM_{10} from local – other sources that is elevated on wind directions between 230^{o} and 70^{o}. This is commensurate with an earlier study (Fuller and Baker 2001) at the site that concluded that the majority of the local – other PM_{10} arose from the road; the resuspension of deposited material from the roadway and suspension of dust from dirty vehicles using the waste transfer facility. The maximum mean concentration of local – other PM_{10} at Bexley 4 was measured between 20^{o} and 60^{o} which is commensurate with the location of the nearby waste transfer facility, relative to the monitoring site. The Brent 5 is located opposite the entrance to several waste transfer facilities. The peak mean concentration measured at the site reflects the direction of this entrance, around 220^{o}, relative to the monitoring site.

A further study (Fuller and Hedley 2004) has apportioned local PM_{10} alongside a residential road close to a waste handing facility in Hastings. Here the analysis suggested that atypical resuspension of deposited road dust contributed between 5 and 10 μgm^{-3} TEOM*1.3 to the annual mean PM_{10} concentration measured around 1.5 km from the waste facility, beyond the distance where visible deposits from the waste facility were present on road surfaces.

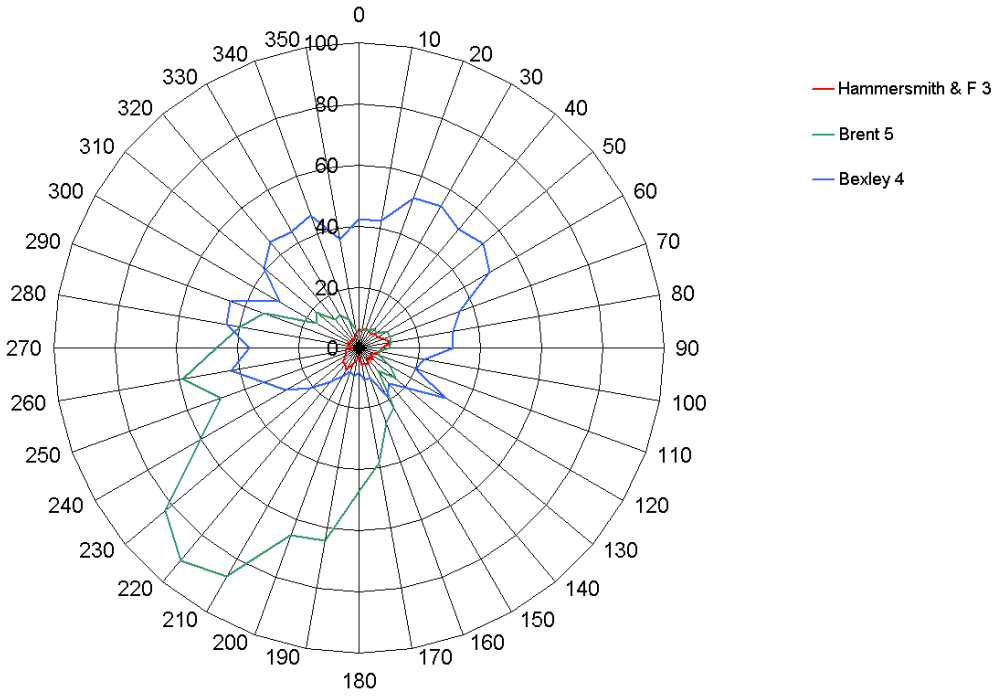


Figure 15 Source apportioned mean concentrations of PM_{10} from local - other sources at LAQN monitoring sites close to industrial sources. Concentrations have been averaged by 10° wind sector.

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Conclusions

In response to the concerns about possible industrial sources of PM_{10}, Hammersmith & Fullham Council set up a temporary air quality monitoring site on Scrubs Lane just north of the junction with Waldo Road. Measurement of PM_{10} and NO_2 concentrations took place at the site (Hammersmith & Fulham 3) between 28th March and 27th October 2005. Annual concentrations of PM_{10} and NO_2 at the Hammersmith & Fulham 3 were projected from the measurements made at other LAQN monitoring sites for comparison to the AQS Objectives. These projections indicate that the site was very likely to have exceeded annual mean objective for NO_2 during 2005, in common with the vast majority of roadside locations in London. The site was also very likely to have exceeded the daily mean objective for PM_{10}, in common with the busiest roadside sites in London and locations close to industrial facilities. The site is also very likely to have attained the hourly mean NO_2 Objective and the annual mean Objective for PM_{10}.

The majority of the PM_{10} measured at the site arose from background sources. Local sources accounted for only 34% of the mean concentration. These local sources were almost equally divided between primary PM_{10} from transport sources (18%) and other local PM_{10} (16%). The local - other sources at Hammersmith & Fulham 3 had a mean concentration of 5.7 (9.8 – 3.9) μgm^{-3} TEOM*1.3. (2σ).

Apportionment of the daily mean concentration of PM_{10} at the site clearly showed the complexity of managing the PM_{10} concentration with no single source being responsible for the daily mean concentrations in excess of 50 μgm^{-3} TEOM*1.3. Greater insight into the impact of the PM_{10} sources affecting the site can be gained by selectively removing sources from the source apportioned time series and recalculating the number of days with mean total PM_{10} concentration in excess of 50 μgm^{-3} TEOM*1.3. Six such scenarios are shown in Table 5. Given that the council cannot realistically affect background concentrations at the site emphasis within the choice of scenarios was placed on the local sources and in particular the local – other sources which form the main investigative aim of the study.

Scenario 1 shows that with background sources only the site was expected to achieve the AQS Objective. Scenario 2 shows that the site was also expected to achieve the Objective with PM_{10} from background sources and the local primary expected from the PM_{10} / NO_X relationships at other sites across London. Four further scenarios (3 to 6) investigated the impact of varying the concentration of PM_{10} from the local – other sources. A reduction of the local – other source to between 25% and 50% of its current concentration is required to attain the AQS Objective, if this source is the sole subject of control.

Scenario Number	TEOM offset	Background secondary and primary	Local - primary	Local - other	Daily mean > 50 μgm^{-3} TEOM*1.3 monitoring period	Daily mean > 50 μgm^{-3} TEOM*1.3 calendar year
1	✓	✓			1	4 (7 - 1)
2	✓	✓	✓		12	22 (25 - 18)
3	✓	✓	✓	25%	16	28 (31 – 24)
4	✓	✓	✓	50%	22	**37 (41 - 34)**
5	✓	✓	✓	75%	23	**39 (43 - 35)**
6	✓	✓	✓	100%	28	**47 (51 - 43)**

Table 5 Recalculation of source apportioned PM_{10} at Hammersmith & Fulham 3 showing 6 scenarios with varying contributions from each source.

The concentration of the local – other PM_{10} at the Hammersmith & Fulham 3 site was around 1/5th of the concentrations experienced near to other industrial sites and was close to the expected uncertainty of the source apportionment technique. It is therefore difficult to draw firm conclusions about the local origins of this pollution.

The local – other PM_{10} contributed to the measured concentrations at the site during 'normal' working hours; starting during hours 6 or 7 GMT (hours 7 or 8 BST) and declining during hours 16 or 17 GMT

(hours 17 or 18 BST). The local – other source was also active on Saturday mornings declining during hours 10 and 11 GMT (11 and 12 BST). This suggests that the source was linked to a commercial activity.

The quantification of the mean concentration of PM_{10} from the local – other source by wind direction suggested that the local – other source may have had two origins; the majority of the PM_{10} arose from emissions on Scrubs Lane and up to 10 % arose from a source, on a bearing of between 210^{o} and 230^{o} from the monitoring site.

Monitoring at other LAQN sites close to waste management facilities suggest that these facilities may be significant local sources of PM_{10} due to the resuspension of deposited road dust and suspension of dust from dirty vehicles and their loads. Source apportionment of PM_{10} measurements at Hastings suggested that material from waste facilities could be deposited on roads hundreds of metres from the entrance to the facility. Deposits of dust from the waste facilities were observed on Scrubs Lane. Although these visible deposits did not extend as far as the Hammersmith & Fulham 3 monitoring site at the time of our visit, it is possible that the local – other PM_{10} that arose from emissions on Scrubs Lane was due to the resuspension of road dust and due to the direct suspension of PM_{10} from dirty vehicles or their loads. This road dust may have originated from the waste facility, or other local industry. It is important to note that residential exposure is present on Scrubs Lane between the Hammersmith & Fulham 3 monitoring site and the waste facilities. Given that concentrations of PM_{10} arising from resuspension should decrease with distance from the source, the PM_{10} concentrations at this housing is likely to be higher than that measured at the monitoring site.

Although such a link between the local – other PM_{10} and traffic activity along Scrubs Lane was suggested by the analysis of mean PM_{10} concentrations averaged by wind direction, the source apportionment of PM_{10} by day of week and hours of day suggested that the link between traffic emissions and the local – other source was complex. It is likely that the local – other PM_{10} arising from resuspension of road dust was emitted from the north bound lane only reflecting the pattern of road soiling observed near the entrance to the waste facilities. The local primary PM_{10} would have been emitted from both sides of the road with the monitoring site being more sensitive to the emissions from the southbound lane by virtue of it's location. If this link needs to be investigated in more detail, further information should be collected, particularly with regard to the traffic flow and vehicle composition on Scrubs Lane.

Evidence from the study confirms that the designation of an Air Quality Management Area in this part of the borough is still relevant and the council should take into account the additional local – other PM_{10} within its Air Quality Management Plan.

Recommendations

To investigate the local – other sources of PM_{10} it is recommended that the council:

- Determine the operating periods of the local industry to attempt to match local sources to the daily activity pattern of the local – other PM_{10} source.
- Enter a dialogue with local industry and regulators where necessary with the aim of minimising and controlling local PM_{10} emissions

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