King's College London

Environmental Research Group

PM_{10} Source Apportionment at Bexley 4, Manor Road, Erith

King's College London
University of London

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Environmental Research Group
King's College London
Franklin-Wilkins Building
150 Stamford St
London SE1 9NN
Tel 020 7848 4044
Fax 020 7848 4045

	Name	Email	Date
Author	Gary Fuller	gary.fuller@erg.kcl.ac.uk	January 2008

Reviewed by	Timothy Baker	tim.baker@erg.kcl.ac.uk	February 2008

Approved by	Timothy Baker	tim.baker@erg.kcl.ac.uk	February 2008

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1. Summary

This report provides a detailed analysis of air pollution measurements made at the Bexley 4 monitoring site.

The Bexley 4 monitoring site is located on Manor Road, Erith. This report compares measured PM_{10} concentrations at the site to the UK Air Quality Strategy (AQS) Objectives / EU Limit Values and quantifies the sources of PM_{10} that affected the monitoring site.

The Bexley 4 monitoring site has consistently exceeded the EU Limit Value / AQS Objective for PM_{10} since 2000 by a wide margin. The annual number of days with mean PM_{10} above 50 µg m^{-3} TEOM*1.3 at Bexley 4 increased from 77 in 2001 to 116 days by the end of 2006. This was considerably above the EU Limit Value / AQS Objective of 35 days per year. The annual number of days with mean PM_{10} above 50 µg m^{-3} TEOM*1.3 peaked during 2004 and the site also exceeded the annual mean EU Limit Value at this time. Since monitoring began at the site, PM_{10} concentrations at Bexley 4 were considerably above nearby roadside and background sites suggesting that a local source was affecting the site.

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

- **Background secondary and natural** – background PM_{10} that was not linked to NO_X.
- **Background primary** – background PM_{10} that was linked to NO_X.
- **Local primary** – PM_{10} estimated from the elevation in local NO_X concentration, above background. This source included both primary tail pipe PM_{10} and also expected PM_{10} from resuspension, tyre and brake wear sources determined from average conditions throughout the London Air Quality Network (LAQN) area, as determined from network wide regressions.
- **Local - other** – PM_{10} not accounted for by the model. This included 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 applied by the TEOM to all measured mass concentrations.

Source apportionment showed that 18 (+/- 5, 2σ) µg m^{-3} TEOM *1.3 or 42 (+/- 12, 2σ) % of the annual mean PM_{10} measured at the site came from local – other PM_{10} sources.

The daily mean concentration of PM_{10} at Bexley 4 showed considerable day to day fluctuation reaching a peak daily mean concentration of 197 µg m^{-3} TEOM*1.3. The vast majority of the days with mean PM_{10} concentration above 50 µg m^{-3} TEOM*1.3 were due to PM_{10} from the local – other source which exceeded the local primary PM_{10} by a factor of 16. If the local – other PM_{10} source was not present during 2006, the site would have almost certainly achieved the AQS Objective / EU Limit Value for the year. It was estimated that the mean concentration of local – other PM_{10} at Bexley 4 needed to be reduced by 75 % (50 – 100%, 2σ) for the site to have met the AQS Objective during 2005.

The local – other PM_{10} source exhibited greatest concentrations during working hours on weekdays and on Saturday mornings. The mean concentration of both the local – other PM_{10} and local primary PM_{10} also increased sharply during the same hour each weekday. It is likely therefore that the local – other PM_{10} originated from sources that operated at these times and were linked to the local primary sources. It was found that 80 % of the changes in the mean local – other PM_{10}, when averaged by hour of day and day of week, could be explained by the variations in the local primary concentration.

The local – other PM_{10} had the largest concentrations when the wind originated from a broadly northerly direction between (280° to 150°). These directions agreed with the orientation of Manor

Road with respect to the monitoring site. The mean concentration of local primary PM_{10} was analysed and this also showed very good agreement with the orientation of Manor Road relative to the monitoring site. There was good agreement between the concentration of local – other PM_{10} and primary PM_{10} when averaged by wind direction. It was found that 87 % of the changes in the mean local – other PM_{10}, when averaged by wind direction, could be explained by the changes in the local primary concentration.

The local – other source also exhibited a substantial seasonal variation with greatest concentrations being measured during summer.

Comparing the results from the source apportionment study to that obtained in previous studies; the concentration of local – other PM_{10} at Bexley 4 was consistent with the monitoring site being close to the entrance / exit from a waste facility; the Bexley 4 monitoring sites was approximately 30m from the entrance to Erith Waste Management Ltd.

Although the local – other PM_{10}sources were linked to road traffic, the concentrations could not be accounted for by tailpipe emissions and expected mechanical tyre and brake wear. It was therefore likely that the local – other PM_{10} originated from the resuspension of silt from the road surface or direct suspension of material from 'dusty' vehicles. Silt may be carried from waste facilities onto Manor Road by vehicles leaving the site. All traffic on Manor Road would have the potential to resuspend material deposited on the road. There is some evidence to suggest that the local – other PM_{10} may come from two separate activities, one linked to local primary and hence to transport and another activity. This other activity may be a fugitive source (though none was found in the analysis) or wind blown resuspension of locally deposited silt.

The following recommendations were made:

- The findings of this report should be incorporated into the Council's Air Quality Action Plan.
- The council should work with the operators of Erith Waste Management Ltd and the Environment Agency to reduce the concentration of PM_{10} arising from the waste activity. Determining what changed at the waste site during 2004 (when concentrations were greatest) and what has changed over the last 6 years may be key to managing the PM_{10} problems affecting Manor Road
- The concentration of PM_{10} has increased at the monitoring site over the last 6 years and reached a peak during 2004. Clearly greater understanding how the local – other PM_{10} has changed over this time may help with the management of the source(s) of local – other PM_{10}. This analysis may focus on characterising the local – other PM_{10} at different time periods to determine what caused the local – other PM_{10} concentration to change. PM_{10} concentrations could be examined:
    - With respect to season to determine what caused the seasonal variation in local – other PM_{10}.
    - By time period; e.g. 2004 (when concentrations were greatest), pre-2004 and post 2004.
    - By weekday and weekend.
- The Council should continue to monitor concentrations of NO_X and PM_{10} to assess the concentration reductions achieved by any abatement measures installed at the waste facilities. It should however be recognised that the day to day variation in the concentration of local – other PM_{10} and the seasonality exhibited by the local – other PM_{10} source may confound this assessment in the short – term. This source apportionment study should be repeated bi-annually to quantify changes in local – other PM_{10} or in response to any large changes in the PM_{10} concentration measured at the monitoring site.
- The local – other PM_{10} appeared to arise from both sources linked to vehicle movements and another source. Further investigation of the other source should be undertaken. Opportunity exists to undertake analysis of PM_{10} at the site using bi-variate polar plots. This analysis will

allow greater differentiation of sources by characterising them with respect to both wind direction and wind speed, and therefore has the potential to separate possible wind blown and fugitive sources.

- Although PM_{10} mass concentrations have a crucial regulatory significance it is recognised that the mass concentration of PM_{10} may be a poor surrogate for the health impact. There is mounting evidence that the toxic effects of PM_{10} are driven by the oxidation reactions. Determination of the oxidative potential of the PM_{10} from Manor Road would assist in understanding the possible toxic impacts of the local PM_{10} in the Manor Road area.

- It is likely that the local – other PM_{10} affects the overall PM_{10} composition at the site and may therefore introduce additional uncertainty in the 1.3 'correction' factor applied to the TEOM measurements for assessment of the EU Limit Value at the site. Gravimetric measurements of PM_{10} have been made at Manor Road and these should be processed into daily mean concentrations. These measurements would help to determine an appropriate 'correction' factor for the TEOM to gravimetric conversion at this site.

- We understand that Erith Haulage also have PM_{10} measurements. Analysis of these measurements in combination with those from Bexley 4 should be undertaken. This may allow triangulation on the local sources of PM_{10} in the area.

2. Introduction

This report is intended to assist the Bexley Council with its continuing Local Air Quality Management (LAQM) duties through quantifying and understanding PM_{10} in Manor Road, Erith.

The report provides a detailed analysis of air pollution measurements made at the Bexley 4 monitoring site. The Bexley 4 monitoring site was situated on the south side of Manor Road, close to several industrial sites. The report compares measured PM_{10} concentrations to the UK Air Quality Strategy Objectives and quantifies the sources of PM_{10} that affected the monitoring site.

The report presents an overview of PM_{10} measurements made at the site from 2000 and detailed analysis of measurements made during 2005 and 2006.

Previous Air Quality Assessments

As part of its LAQM responsibilities, the London Borough of Bexley completed the previous rounds review and assessment (R&A) of air quality. These reports presented a staged approach whereby the seven air pollutants in the Government's Air Quality Strategy related to LAQM, were assessed and screened within the Council's area.

An Air Quality Management Area (AQMA) was declared along Manor Road, Erith due to measured and predicted breaches of the Air Quality Strategy Objectives PM_{10}. An air quality management plan for Manor Road was finalised in 2006 and included measures to control the amount of mud and dirt on the surface of Manor Road and a 20 mph speed limit to reduce the re-suspension of this material.

King's have undertaken 2 previous studies of air pollution in Manor Road. The first study in 2001 (Fuller and Baker 2002), concluded that local tail pipe sources of PM_{10} were found to be relatively minor and that the vast majority of local PM_{10} was found to originate from non tail pipe sources and was closely linked to vehicle activity on Manor Road. The diurnal pattern of local non tail pipe PM_{10} matched that of nearby industry and also suggested that the elevated PM_{10} arose from a combination of re-suspension from the road and from dust being lifted directly from dirty vehicles.

A second study by King's looked at the toxicity of the PM_{10} at Manor Road relative to that at a background site in Greenwich. Baker et al (2003) hypothesised that given the proposed nature of this re-suspended material although the mass concentration of PM_{10} in Manor Road was high, its toxicity per unit mass may be lower than other neighborhood sites. Contrary to expectation, the data obtained indicated that particles collected from the Manor Road site had a greater oxidative activity (on an equal mass basis), and was therefore more toxic, than particles collected from the Greenwich site during the working week. If Manor Road was considered in isolation a significant pattern could be seen in the oxidant activity with activity being greatest on weekdays, lower on Saturday and lowest on Sunday suggesting that PM_{10} at Manor Road is more oxidatively active when local sources are making a contribution. Oxidant activity was linked with iron, lead and total transition metals at Manor Road but not at the Greenwich background site, further indicating different mechanisms for the oxidant activity at each site. At Manor Road the concentrations of iron, lead and total transition metals suggested that they may have originated from the same source(s) and showed a similar daily pattern to the local PM_{10} at the site.

Reports and other information related to the Council's LAQM responsibilities can be found on the Council's web site at:

http://www.bexley.gov.uk/service/publicprotection/air.html

3. The site

As part of this study Gary Fuller from King's visited the Bexley 4 monitoring site on 16th November 2007.

The Bexley 4 monitoring site is located at a roadside location on the south side of Manor Road. Manor Road runs approximately east west. The monitoring site is located on a grass verge within in the grounds of an engineering training centre. It is approximately 5 m from the kerb of Manor Road.

To the west of the monitoring site Manor Road is largely residential. To the east of the monitoring site Manor road is largely industrial. Vehicles using the industrial premises have to access Manor Road from the west, passing both the monitoring site and through the residential area. Large waste recycling and metals reclamation yards are located to the north of the monitoring site. A storage area for off road vehicles is located immediately to the south east of the monitoring site.

Figure 1 Aerial photograph of the Manor Road area. The location of the Bexley 4 monitoring site is indicated by a red arrow.

The entrance and exit to a waste transfer business, Erith Waste Recycling Ltd is located approximately 30 m to the east of the monitoring site. The location of the monitoring site in relation to Manor Road and Erith Waste Recycling is shown in Figure 2. The entrance and exit to Erith Waste Recycling is shown in Figure 3 and Figure 4.

King's staff visits the Bexley 4 monitoring site each two weeks and substantial road silting was often observed. Silt was present in the road immediately adjacent to the monitoring site during the site visit on 16th November and is shown in Figure 5.

Figure 2 The Bexley 4 monitoring site looking east along Manor Road. The entrance to Erith Waste Recycling Ltd can be just seen beside the lorry with the exit just beyond.

Figure 3 Entrance to Erith Waste Recycling.

Figure 4 Exit from Erith Waste Recycling.

Figure 5 Silt on Manor Road immediately adjacent to the monitoring site.

4. Source apportionment method

Air pollution measurements

The Bexley 4 monitoring site was installed on the south side of Manor Road in 1999. The site is located in a roadside situation with inlets located approximately 5 m from the kerbside at a height of approximately 2.5 m.

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 by the instruments themselves and collected by King's each hour. Measurements from the monitoring site were validated by King's using the most up to date calibration factors and publically 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) twice yearly.

A final measurement data set to the end of 2006 was produced by King's 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. Details of the monitoring site and the final dataset can be found at www.londonair.org.uk.

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 and AQS Objectives.

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 King's 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 an 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, Fuller and Hedley 2006, Fuller et al 2007).

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 not needed. To model the PM_{10} concentration at Bexley 4 the concentration of the regional secondary and natural components was derived from ten background LAQN monitoring sites. These ten background / suburban monitoring sites (termed base sites) were selected because of their proximity to the Bexley 4 monitoring site and their freedom from local non-NO_X sources of PM_{10}. The base sites are listed in Table 2.

Local events that were not associated with NO_X would not be predicted by this model since it had no knowledge of them. Fuller and Green (2004) established that the difference between measured and modelled PM_{10} could be used to quantify the PM_{10} arising from local sources that were not sources of NO_X. The same approach was used for this study 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 southeast.

Model Inputs and Outputs

The model was applied separately to measurements of NO_X and PM_{10}, which were averaged in three ways to look at possible characteristics of the local PM_{10} sources at the Bexley 4 monitoring site. The following model inputs (and therefore outputs) were chosen:

- Daily mean concentrations for comparison to the EU Limit Value and to identify the dates on which local PM_{10} incidents occurred. Daily mean concentrations of NO_X and PM_{10} were calculated from hourly 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 PM_{10} source(s). For instance the mean NO_X and PM_{10} measurements for each Wednesday at 13 h were averaged as input data, followed by each Wednesday at 14 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 Bexley 4 site. This analysis used wind direction measurements made at the Bexley 4 monitoring site. (Care should be taken when interpreting the results of this analysis since equal weighting is given to concentration measurements in each 10 degrees 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 measurement 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 Bexley 4 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 was not linked to NO_X.

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

- **Local primary** – PM_{10} estimated from the elevation in local NO_X concentration, above background. This source included 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.

- **Local - other** – PM_{10} not accounted for by the model. This included 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 µg m^{-3} (raw TEOM) applied by the TEOM to all measured mass concentrations (Patashnick and Rupprecht (1991, 1992, 1996), 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 µg m^{-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.

Uncertainty Estimates

The method of calculating the local – other PM_{10} relies on the difference between measured and modelled PM_{10}. This difference may however also be due to artefacts arising from uncertainty in the measurement and modelling process.

The uncertainty associated with the calculation of the local – other PM_{10} was assessed using the GUM (Guide to the Expression of Measurement Uncertainty in Measurement) approach (ISO, 1995).

The GUM approach requires a measurement equation to link the output quantity with the various input quantities and then provides a methodology to link the uncertainty in the inputs to the uncertainty in the output. The GUM approach provides two methods for estimating the uncertainty associated with each input quantity: type A estimates from statistical analysis and type B estimates from other methods (e.g. instrument specifications). The data sources for the uncertainty estimates of each of the model inputs are listed Table 1.

Input Source	Source for input uncertainty	Type
TEOM measurement of PM_{10}	Harrison 2006	B
NO_X measurement	KCL 2002	B
Ratio of NO_X to primary PM_{10} concentration	RMA regression of annual mean concentrations from 86 monitoring sites in London and SE see Fuller and Green 2006.	A
Background secondary and natural PM_{10}	Standard deviation of estimates from 10 sites	A

Table 1 Sources for input uncertainty.

The GUM approach assumes that the estimates of the uncertainty associated with each input quantity are considered to be normally distributed about the value of the input quantity. They are therefore approximated as statistical variances and are characterised by their standard deviation. The uncertainty in the input quantities are combined as variances, along with sensitivity coefficients determined from the partial derivative of the measurement equation, with respect to each of the input quantities, to derive a combined standard uncertainty. Additional terms in the calculation of the combined standard uncertainty are required if input quantities are correlated. Finally, the combined standard uncertainty is multiplied by a coverage factor (k) to approximate to a required confidence interval expressed as a number of standard deviations. In this study, a k value of 2 was chosen to approximate to a 95% confidence interval.

Implementation of the GUM uncertainty analysis involved creation of an uncertainty model that was 'run' in parallel to the main model and produced estimates for the uncertainty of each output result. In

this way a separate uncertainty estimate was available for each model output e.g. daily mean concentration, diurnal average etc.

In addition to using the GUM model to estimate model uncertainty, the model was also used to predict PM_{10} at six test sites in addition to Bexley 4. The modelled concentrations and estimated uncertainty at the test sites were used to check the validity of the GUM uncertainty estimates and to check for significant model bias. The test sites were selected as the closest roadside sites to Bexley 4. The tests sites are listed in Table 2. 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	
Bexley 1	Suburban
Bexley 2	Suburban
Ealing 7	Urban background
Greenwich 4	Suburban
Hammersmith & Fulham 2	Urban background
Hounslow 2	Suburban
Kens & Chelsea 1	Urban background
Richmond 2	Suburban
Thurrock 1	Urban background
Tower Hamlets 1	Urban background
Test Sites	
Croydon 4	Roadside
Crystal Palace	Roadside
Greenwich Bexley 6	Roadside
Greenwich 7	Roadside
Havering 3	Roadside
Lewisham 2	Roadside

Table 2 Base and test sites used in the source apportionment model

Additionally a sensitivity test was carried out to assess the impact of assuming a worst tail pipe PM_{10} emissions scenario. Emissions rates for HGV vehicles (both fixed and articulated) were examined to determine the highest feasible NO_X: primary PM_{10} emissions ratio. This was then used as a model input instead of the NO_X: primary PM_{10} concentration ratio determined from measurement sites across London and southeast England.

5. Source apportionment results

Air pollution measurements

Air pollution measurements for 2005 and 2006 from the Bexley 4 monitoring site are shown in Table 3 and Table 4 which also shows measurements at base and test sites. For additional comparison measurements from 3 industrial roadside sites (type 'I' in Table 3) close to waste transfer facilities are shown along with measurements from the Marylebone Road kerbside site. Measurements up to the end of 2006 were fully ratified. Measurements during 2007 were validated but subject to full ratification at the time of writing.

Measurements from each monitoring site were compared to the UK AQS Objectives for PM_{10}, which are identical to the EU Limit Values. There are two EU Limit Values for PM_{10}. The first is an assessment of long – term exposure and takes the form of an annual mean concentration, which should not exceed 40 μg m^{-3}. The second Limit Value is based on short-term exposure and is expressed in terms of the frequency of pollution episodes; the daily mean concentration of PM_{10} should not exceed 50 μg m^{-3} on more than 35 days per year.

Table 3 and Table 4 are ordered by PM_{10} concentration and clearly indicate the concerns regarding the PM_{10} concentrations at the sites close to waste facilities. Each of these sites exceeded the daily mean EU Limit Value during this period (35 days with mean PM_{10} above 50 μg m^{-3} TEOM*1.3). The EU Limit Value was also exceeded at the Marylebone Road kerbside site. The source apportionment scheme in Fuller et al. (2002), determined that primary PM_{10} emissions are linked to NO_X and thus high levels of PM_{10} would be expected at Marylebone Road.

Such an explanation does not account for the PM_{10} concentrations measured at Brent 5, Bexley 4 and to a lesser extent at Sutton 5; thus a non tail pipe source of PM_{10} obviously affected these sites.

Site	Type	PM_{10} Capture %	PM10 μg m^{-3} TEOM*1.3 Mean	Daily mean > 50	Full year projected daily mean >50*	NO_X Annual mean μg m^{-3}
Ealing 8	I	84	84	230	274	
Brent 5	I	96	62	180	188	127
Marylebone Road	K	96	43	118	123	293
Bexley 4	**I**	**98**	**44**	**105**	**107**	**71**
Greenwich Bexley 6	R	98	30	31	32	115
Lewisham 2	R	99	30	24	24	143
Greenwich 7	R	98	30	22	22	124
Croydon 4	R	88	29	11	13	122
Tower Hamlets 1	U	95	24	7	7	59
Crystal Palace 1	R	90	28	7	8	112
Kens & Chelsea 1	U	99	24	6	6	66
Bexley 2	S	83	23	6	7	53
Hams & Fulham 2	U	97	24	6	6	64
Ealing 7	U	95	23	5	5	56
Greenwich 4	S	78	22	4	5	46
Richmond 2	S	99	22	4	4	51
Havering 3	R	95	23	4	4	94
Hounslow 2	S	94	22	3	3	67
Bexley 1	S	70	23	2	3	63

Table 3 Measurements of air pollution at Bexley 4 and nearby sites during 2005. Measurements are ordered by the number of days with mean PM_{10} above 50 μg m^{-3} TEOM*1.3. * Projections made pro rata based on data capture.

Type: I = Industrial roadside, K= kerbside, R = roadside, U = urban background, S = suburban.

Site	Type	PM10 µg m^{-3} TEOM*1.3				NO_X
		PM_{10} Capture %	Mean	Daily mean > 50	Full year projected daily mean >50	Annual mean µg m^{-3}
Ealing 8	I	99	74	224	226	
Brent 5	I	99	70	191	193	125
Marylebone Road	K	97	47	151	156	308
Bexley 4	**I**	**94**	**43**	**106**	**113**	**70**
Greenwich Bexley 6	R	95	31	33	35	120
Greenwich 7	R	99	32	30	30	117
Kens & Chelsea 1	U	99	26	16	27	60
Greenwich 4	S	96	24	12	27	45
Lewisham 2	R	80	30	21	26	145
Croydon 4	R	99	30	17	17	102
Richmond 2	S	99	25	17	17	49
Tower Hamlets 1	U	95	25	16	17	60
Crystal Palace 1	R	89	28	14	16	113
Hams & Fulham 2	U	99	25	9	15	60
Ealing 7	U	39	25	4	10	54
Bexley 2	S	99	25	10	10	52
Bexley 1	S	99	25	10	10	52
Havering 3	R	95	24	7	8	87
Hounslow 2	S	93	23	4	4	63

Table 4 Measurements of air pollution at Bexley 4 and nearby sites during 2006. Measurements are ordered by the number of days with mean PM_{10} above 50 µg m^{-3} TEOM*1.3. * Projections made pro rata based on data capture.

Measurements in Table 3 and Table 4 show that the PM_{10} concentrations at the Bexley 4 monitoring site exceeded both the daily and annual mean EU Limit Values during 2005 and 2006.

The time series of annual PM_{10} measurements at Bexley 4 are shown in Figure 6 and Figure 7.As clearly shown in Figure 6 the number of days with mean PM_{10} above 50 µg m^{-3} TEOM*1.3 at Bexley 4 has consistently exceeded that at the suburban site Bexley 2 and the roadside Greenwich Bexley 6 site. Further the Bexley 4 monitoring site has exceeded the EU Limit Value by a wide margin since monitoring began. PM_{10} concentrations at all 3 sites have shown variation between 2000 and 2007; effects of pollution episodes during 2003, which lead to a breach of the EU Limit Value at the Greenwich Bexley 6 roadside site can be clearly seen. The PM_{10} concentration at the Greenwich Bexley 6 roadside site also increased steadily since 2005 to exceed the EU Limit Value by the end of 2006. The number of days with mean PM_{10} above 50 µg m^{-3} TEOM*1.3 at Bexley 4 increased from 77 days in 2001 to 116 days by the end of 2006. The PM_{10} concentrations at the Bexley 4 monitoring site were clearly affected by the pollution episodes during 2003, in line with concentrations at Greenwich Bexley 6 and Bexley 2. Peak PM_{10} concentrations at Bexley 4 were measured during 2004. Provisional measurements of PM_{10} concentrations during 2007 indicate slight improvements in concentrations at the Bexley 2 background site and at the Greenwich Bexley 6 roadside site but a sharp deterioration at Bexley 4.

Annual mean PM_{10} concentrations shown in Figure 7 show that the Bexley 4 monitoring site has largely attained the annual mean EU Limit Value and that annual mean concentrations also increased between 2001 and 2007. Further insight in to the PM_{10} concentrations at the Bexley 4 site can obtained from an examination of monthly mean concentrations which are shown along with annual mean concentrations in Figure 8. The monthly mean concentrations at all sites exhibit a clear fluctuation about the annual mean concentration although the monthly mean concentrations and their fluctuation were greater at Bexley 4 when compared with the other two sites. Elevated monthly mean concentrations, due to pollution episodes in 2001 and 2003, can be clearly seen in the time series of measurements from Greenwich Bexley 6 and Bexley 2, which both measured a maximum monthly mean concentration during 2003, but no seasonality is apparent. Maximum monthly mean concentrations were measured at Bexley 4 during 2004 and the site appears to exhibit seasonal

behaviour with monthly mean concentrations attaining a minimum each winter. Importantly the monthly and annual mean concentrations at Bexley 4 are above those measured at the nearby Bexley 2 suburban site indicating a local source and further the fluctuation in the monthly mean PM_{10} concentrations at Bexley 4 cannot be explained by fluctuations in the monthly mean concentrations at Bexley 2.

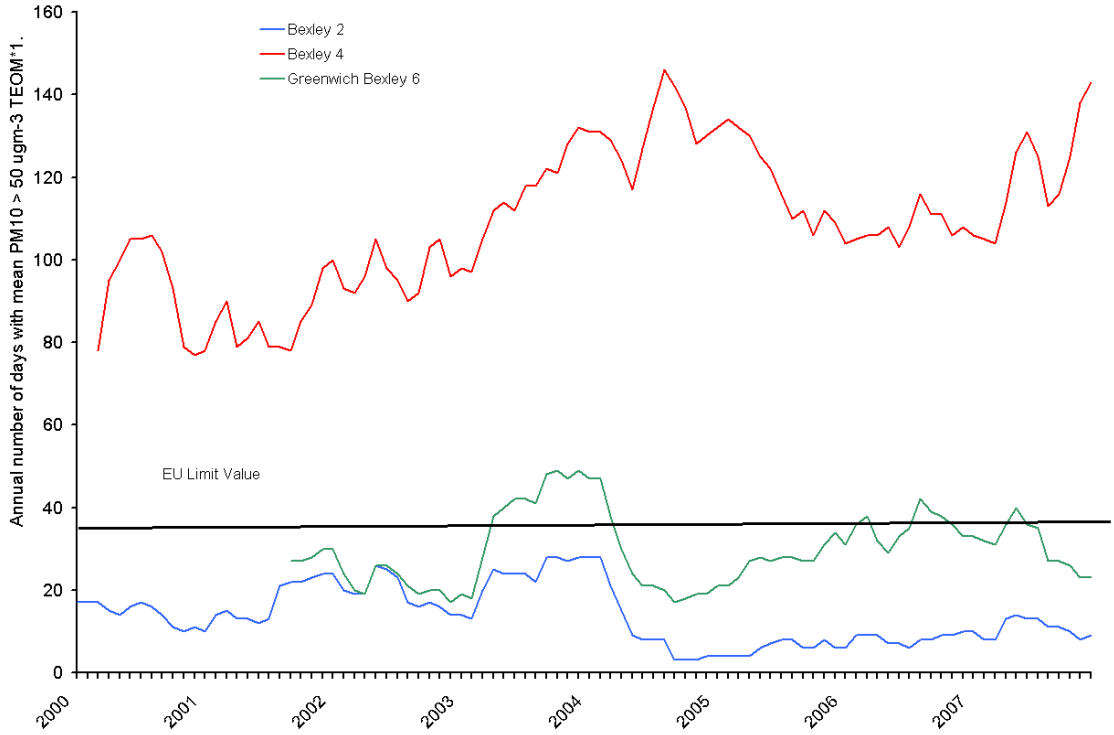

Figure 6 Annual number of days with mean PM10 above 50 µg m-3 TEOM*1.3 at Bexley 4. Measurements at the roadside site Greenwich Bexley 6 (A2 Falconwood) and the suburban site Bexley 2 (Belvedere) are also shown. Measurements from 2007 were provisional.

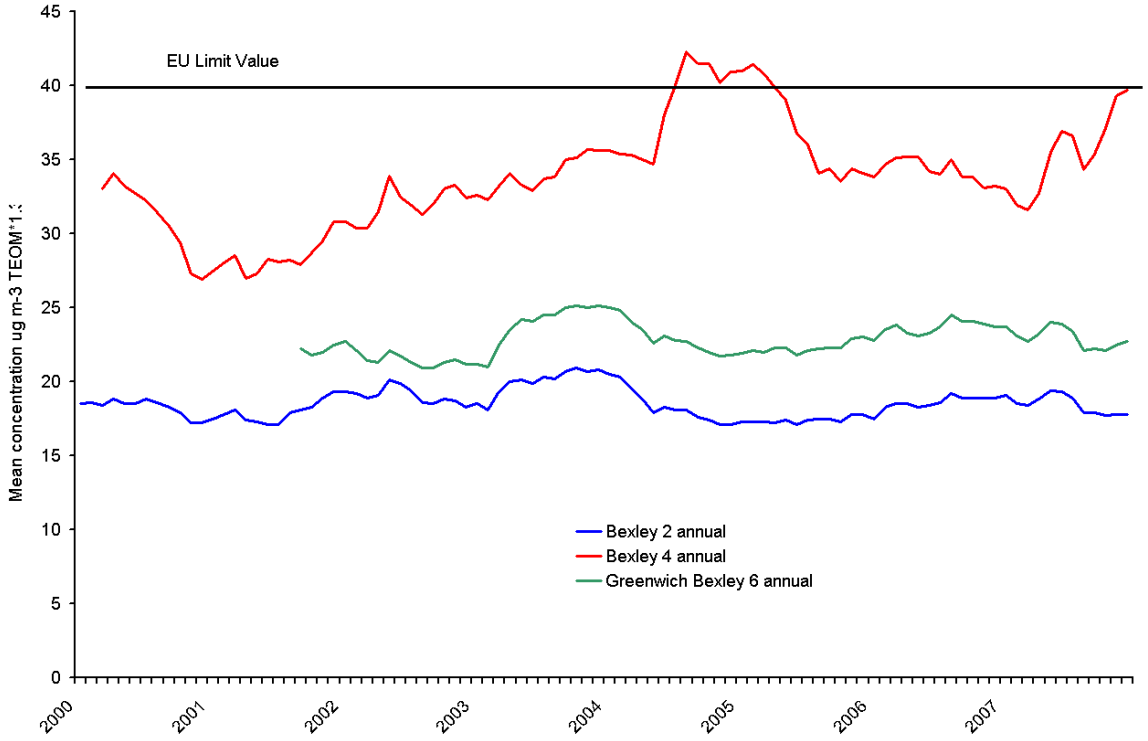

Figure 7 Annual mean PM10 at Bexley 4. Measurements at the roadside site Greenwich Bexley 6 (A2 Falconwood) and the suburban site Bexley 2 (Belvedere) are also shown. Measurements from 2007 were provisional.

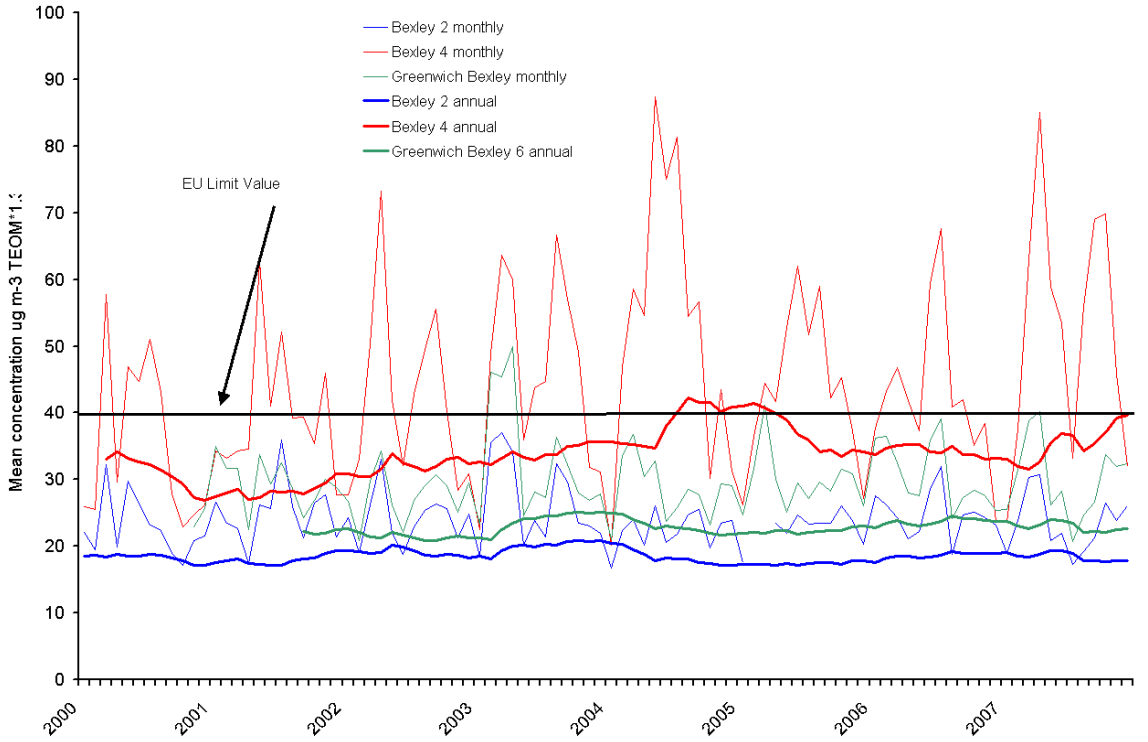

Figure 8 Annual and monthly mean PM10 at Bexley 4. Measurements at the roadside site Greenwich Bexley 6 (A2 Falconwood) and the suburban site Bexley 2 (Belvedere) are also shown. Measurements from 2007 were provisional.

Comparison of measured and modelled concentrations

Measured and modelled annual mean PM_{10} concentrations at Bexley 4 and each of the roadside test sites are shown in Figure 9. Overall the model performed well at each of the six test sites with measured concentrations close to model predictions and within the uncertainty estimates. Measured annual mean concentrations at Bexley 4 however exceeded the modelled concentrations by 18 µg m^{-3} TEOM*1.3, a margin that exceeded the uncertainty estimate of 5 µg m^{-3} TEOM*1.3, 2σ. A local – other source of PM_{10} was therefore affecting the monitoring site.

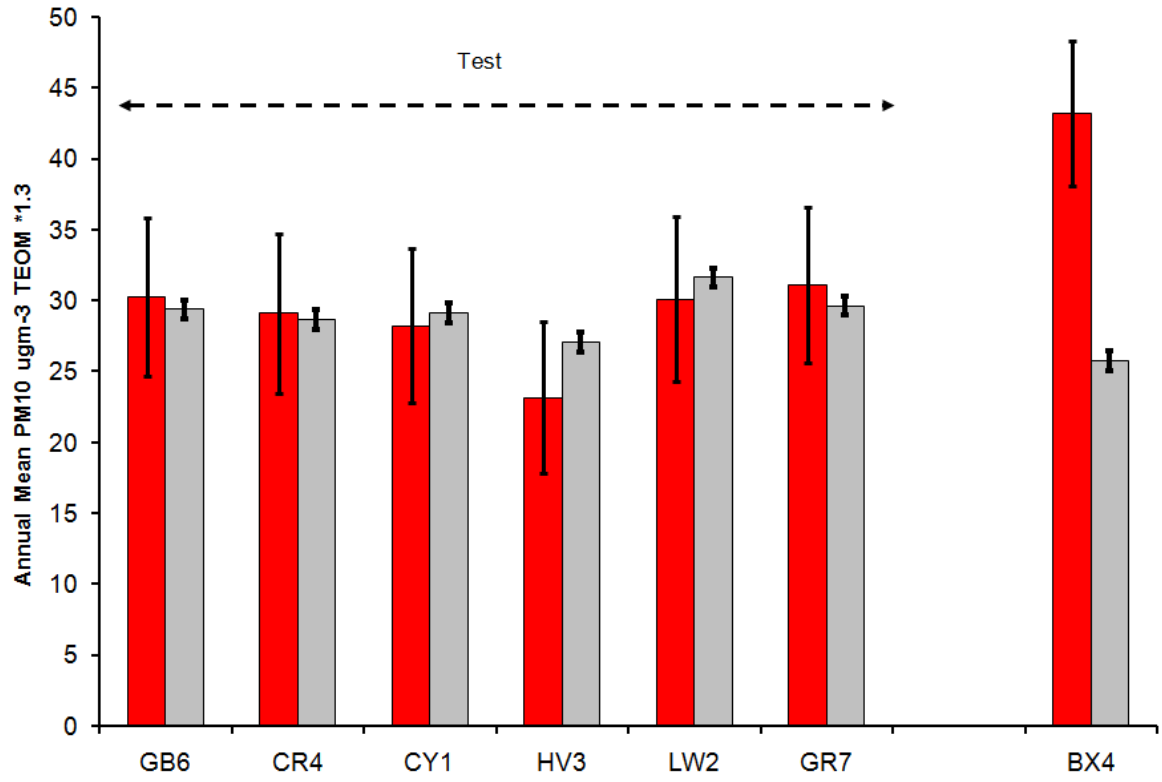

Figure 9 Measured and modelled 2006 annual mean PM10 concentrations at Bexley 4 (BX4) and the 6 roadside test sites. Uncertainty estimates are shown at 2 σ. Measured concentrations are shown grey and modelled concentrations are shown in red.

Source apportionment of mean PM_{10} concentration

Results of the source apportionment of the mean concentration of PM_{10} at Bexley 4 are shown in Figure 10 and Table 5. The local – other PM_{10} source made the largest contribution to the mean concentration at the site; 18 (+/- 5, 2σ) µg m^{-3} TEOM *1.3 or 42 (+/- 12, 2σ) % during 2006. The background secondary and natural sources were the second largest contributor to mean PM_{10} concentrations measured at the site.

All background sources accounted for 46% and the TEOM offset accounted for a further 9% of the annual mean concentration. The vast majority of the 45% of PM_{10} arising locally was from the local – other source which exceeded the local primary by a factor of 16.

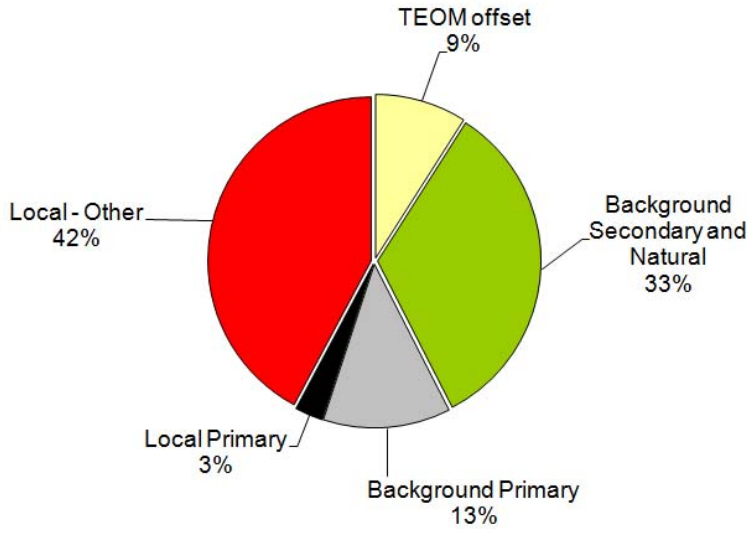

Figure 10 Source apportionment of mean PM10 concentration at Bexley 4 during 2005 and 2006.

Source	Mean concentration $\mu g\ m^{-3}$ TEOM *1.3 2005 & 2006
TEOM offset	4
Background Secondary and Natural	14
Background Primary	5
Local Primary	1
Local - Other	18
Total	**43**

Table 5 Source apportionment of mean PM_{10} concentration at Bexley 4 during 2005 and 2006.

The ratio of NO_X : primary PM_{10} emissions from the London Atmospheric Emissions Inventory was used to determine a worst case ratio as a sensitivity test. The worst case emitter was found to be a pre-Euro rigid HGV with NO_X: primary PM_{10} of 0.21 $\mu g\ m^{-3}\ ppb^{-1}$ (including an estimate for non-exhaust emissions such as tyre and brake wear) compared with 0.14 $\mu g\ m^{-3}\ ppb^{-1}$ determined from the NO_X: primary PM_{10} concentration ratio at sites across London and south east England during 2005 and 2006. Use of the worst case ratio in the model reduced the local – other PM_{10} to 40% of the total measured mean concentration, a change of less than 1 $\mu g\ m^{-3}$ TEOM *1.3 and within the uncertainty estimate of 5 $\mu g\ m^{-3}$ TEOM *1.3. Local primary PM_{10} increased to 18%, background primary remained at 3% and PM_{10} from background secondary and natural sources reduced to 29%. The ratio of local primary PM_{10} to the total local PM_{10} reduced to 13.

Source apportionment of daily mean PM_{10} concentration

The daily mean time series of source apportioned PM_{10} concentration at Bexley 4 is shown in Figure 11. Source apportionment was possible on 691 days during 2005 and 2006. Source apportionment was not possible on the remaining days due to the absence of NO_X and / or PM_{10} measurements at these times.

It is evident from Figure 11 that the daily mean PM_{10} concentration measured at the site was not constant but varied from day to day. Several different types of pollution episode can be seen in Figure 11.

A - the combination of background and natural, local and background primary sources caused the daily mean PM_{10} concentration to exceed 50 µg m^{-3} TEOM*1.3. This episode would have affected large parts of London.

B - the daily mean PM_{10} concentration exceeded 50 µg m^{-3} TEOM*1.3 due to the local - other PM_{10}. If the local – other source were not present, the daily mean PM_{10} would not have exceeded the EU Limit value concentration. This type of episode accounts for the vast majority of days when the mean PM_{10} concentration at the site exceeded 50 µg m^{-3} TEOM*1.3.

C - the background and natural sources alone caused the daily mean PM_{10} concentration to exceed 50 µg m^{-3} TEOM*1.3. This episode would have affected large parts of London.

D – PM_{10} from Guy Fawkes bonfires and fireworks caused the daily mean PM_{10} concentration to exceed 50 µg m^{-3} TEOM*1.3. At this time local non-NO_X sources affected many of the base monitoring sites, therefore the calculation of background secondary and natural PM_{10} became unreliable and the apportionment incurred a high uncertainty.

E – This was a primary pollution episode that affected all of London. PM_{10} concentrations at Bexley 4 approached but did not exceed 50 µg m^{-3} TEOM*1.3. During this episode concentrations of NO_X at many of the background base sites in inner London exceeded the NO_X concentrations at roadside sites in the south London suburbs. This affected the apportionment of primary PM_{10} between background and local sources at Bexley 4. This episode highlighted a potential weakness in the apportionment scheme caused by the absence of input measurements from suitable background sites in suburban south and east London.

During 2005 and 2006 the maximum daily mean PM_{10} concentration at Bexley 4 was 197 µg m^{-3} TEOM*1.3 and 41 days had mean concentrations of over 100 µg m^{-3} TEOM*1.3. If the local other source was removed the daily mean PM_{10} concentration was projected to have exceeded 50 µg m^{-3} TEOM*1.3 on only 6 (1 – 35, 2σ) days during 2005 and the site would almost certainly have achieved the EU Limit Value / AQS Objective for the year.

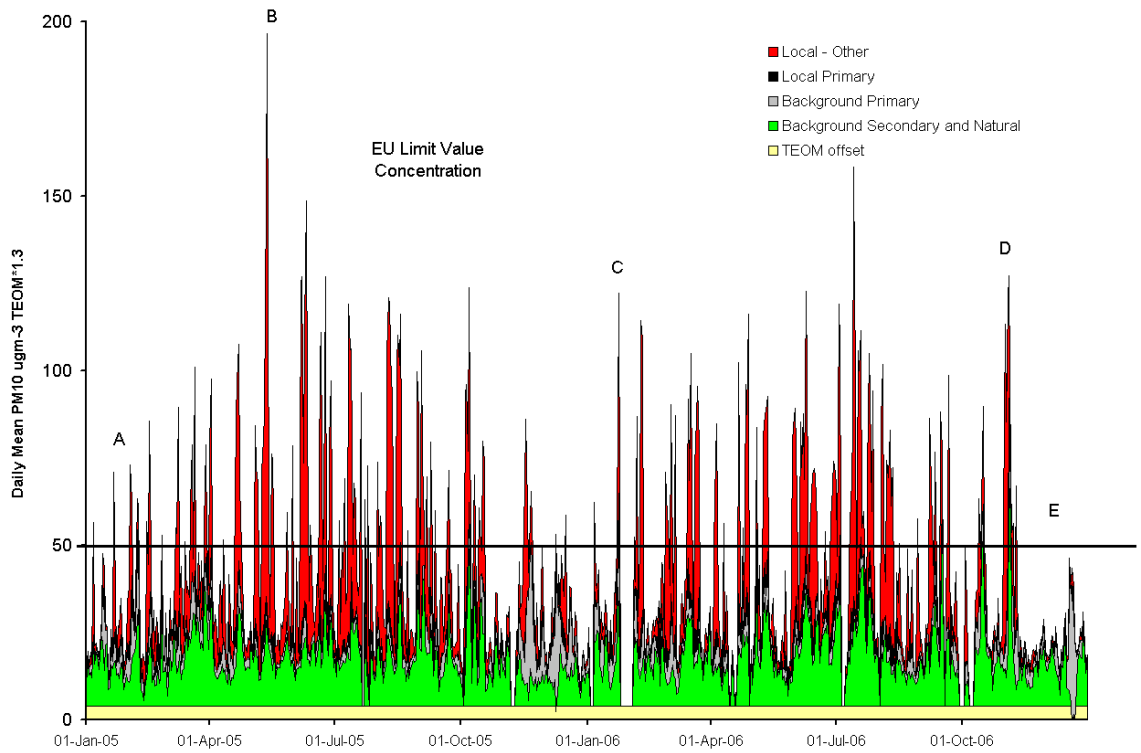

Figure 11 Time series of daily mean PM10 concentrations at Bexley 4 during 2005 and 2006. Different types of pollution episodes are marked A to E and are discussed in the text.

Quantification and characterisation of the local – other PM_{10} is a key objective of the study. Figure 12 shows the daily mean concentration of the local – other PM_{10} with uncertainty is shown at 2σ. The local – other PM_{10} alone frequently exceeded the EU Limit Value concentration of 50 µg m^{-3} TEOM*1.3. The maximum daily mean concentration of local – other PM_{10} during the study period was 165 (+/- 6, 2σ) µg m^{-3} TEOM*1.3. The source apportionment model produced negative concentrations for the local – other PM_{10} on 42 days during the two year study period. However, the negative concentration on each of these days was within the expected model uncertainty on 41 of these 42 days, which was consistent with the 95 % confidence limit for the estimated uncertainty. A seasonality was apparent during the concentration of the local – other PM_{10} with greatest concentrations being measured during the summer months and lower concentrations during winter.

Figure 13 shows the daily mean concentration of local primary PM_{10}. The daily mean concentration of PM_{10} from the local primary source was less than the local - other PM_{10}. The uncertainty model accurately detected the increased uncertainty during episode E from Figure 11 when considerable NO_X concentration gradients were present across London. Further episodes of this type were indicted by very high uncertainty estimates. The uncertainty model also detected increased uncertainty during Guy Fawkes Night 2006 (episode D).

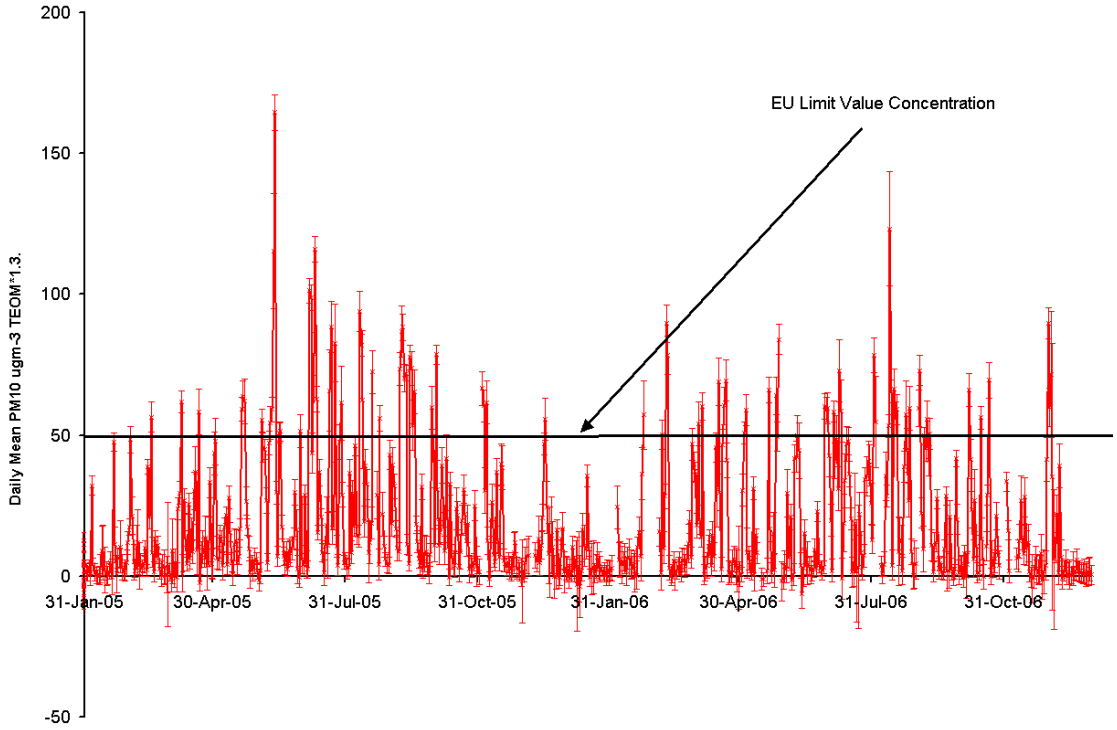

Figure 12 Time series of the modelled daily mean PM10 concentration from the local - other source at Bexley 4 during 2005 and 2006. Uncertainty is shown at 2σ.

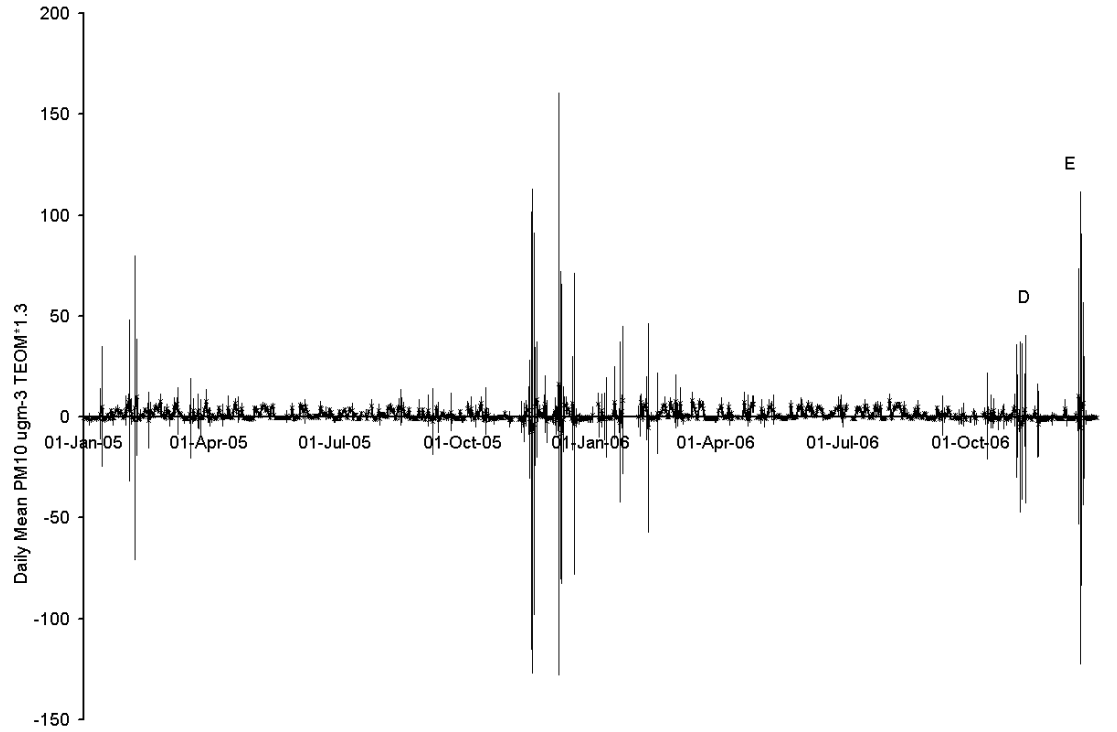

Figure 13 Time series of the modelled daily mean PM10 concentration from the local primary source at Bexley 4 during 2005 and 2006. Uncertainty is shown at 2σ.

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 provide insight into the behaviour of emissions sources affecting a monitoring site. Figure 14 shows the source-apportioned concentration of PM_{10} at Bexley 4 averaged by day of week and hour of day. Times are shown in GMT (with no correction for BST). Clear differences in the total mean PM_{10} concentration were seen between weekdays and weekends with the total mean concentration being greater on weekdays than on Saturday and Sunday. From concentration minima during hour 3 GMT (hour 4 BST), mean PM_{10} concentrations rose rapidly during hour 5 or 6 GMT (hour 6 or 7 BST) each weekday morning. The timing of the peak concentration was always during normal working hours and concentrations fell rapidly each afternoon. Two peaks were 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.

The mean concentration of the local – other PM_{10}, averaged by day of week and hour of day is shown in Figure 15. Clear differences in the mean local - other PM_{10} were seen between weekdays and weekends with the local - other concentration being greater on weekdays than on Saturday and Sunday. The local – other PM_{10} was below the detection limit of the model each night however the concentration rose rapidly during hour 6 or 7 GMT (7 or 8 BST) each weekday to peak during working hours.

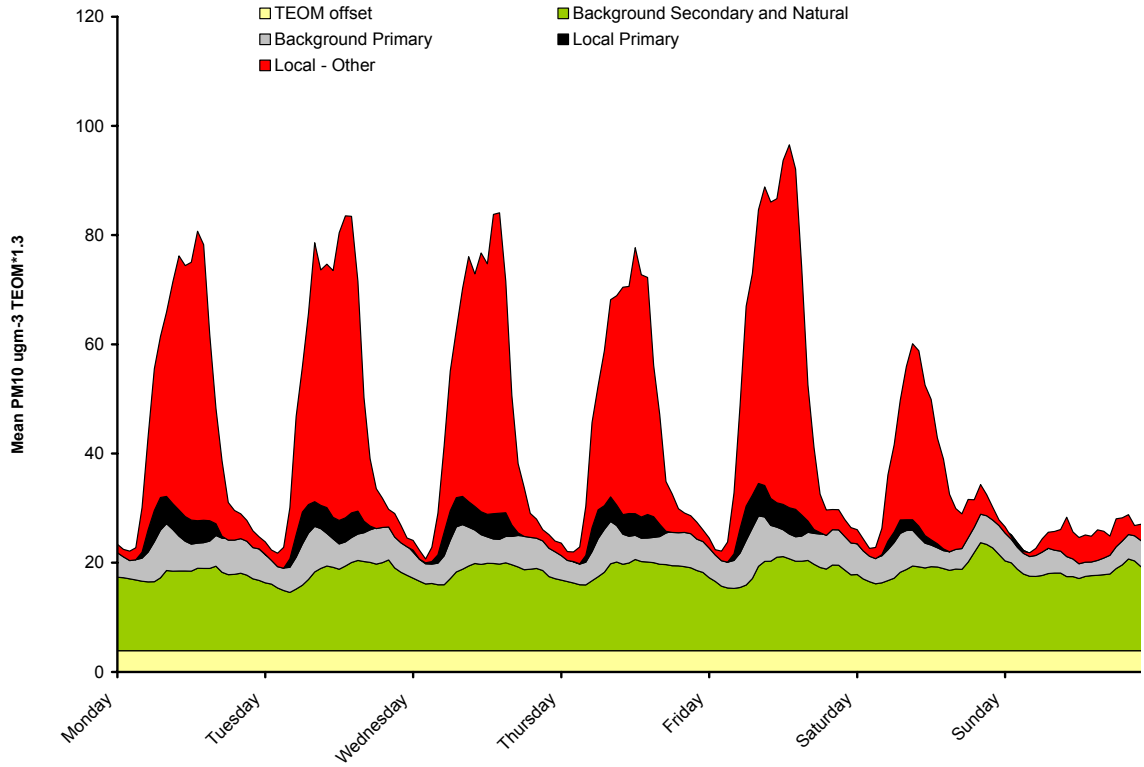

Figure 14 Source apportioned concentrations of PM10 at Bexley 4, during 2005 and 2006, averaged by day of week and hour of day. Times were GMT throughout.

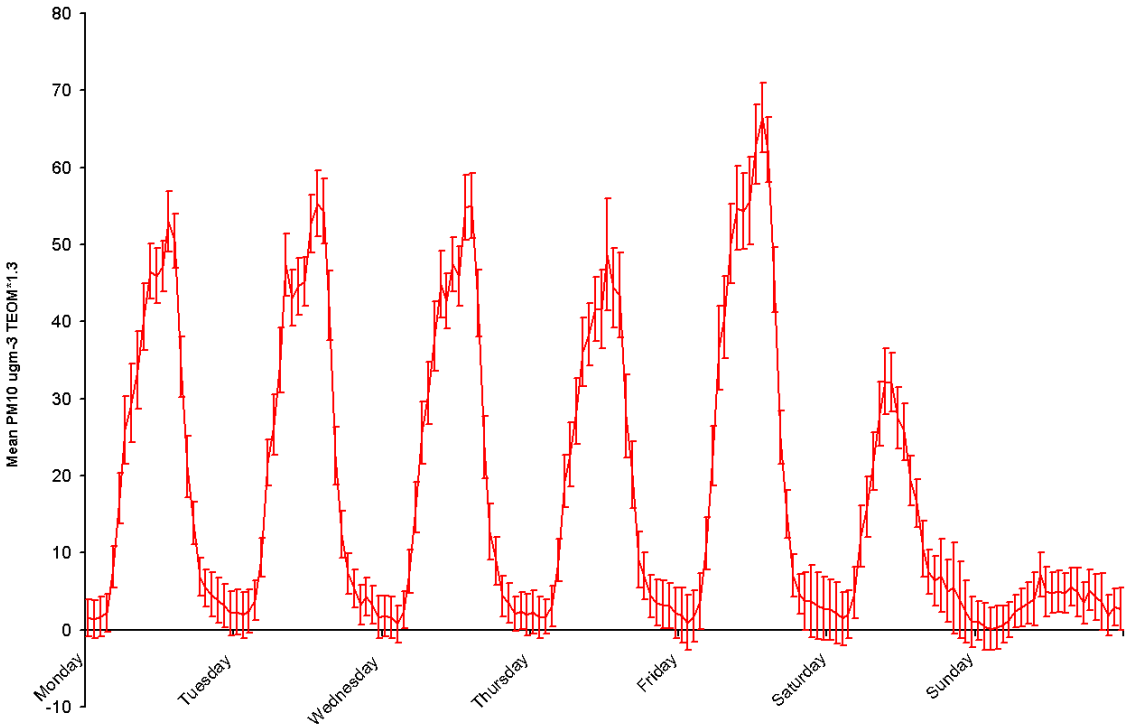

Figure 15 Concentrations of PM_{10} from local - other sources at Bexley 4, during 2005 and 2006, averaged by day of week and hour of day. Times are shown in GMT and uncertainty estimates are shown at 2 σ.

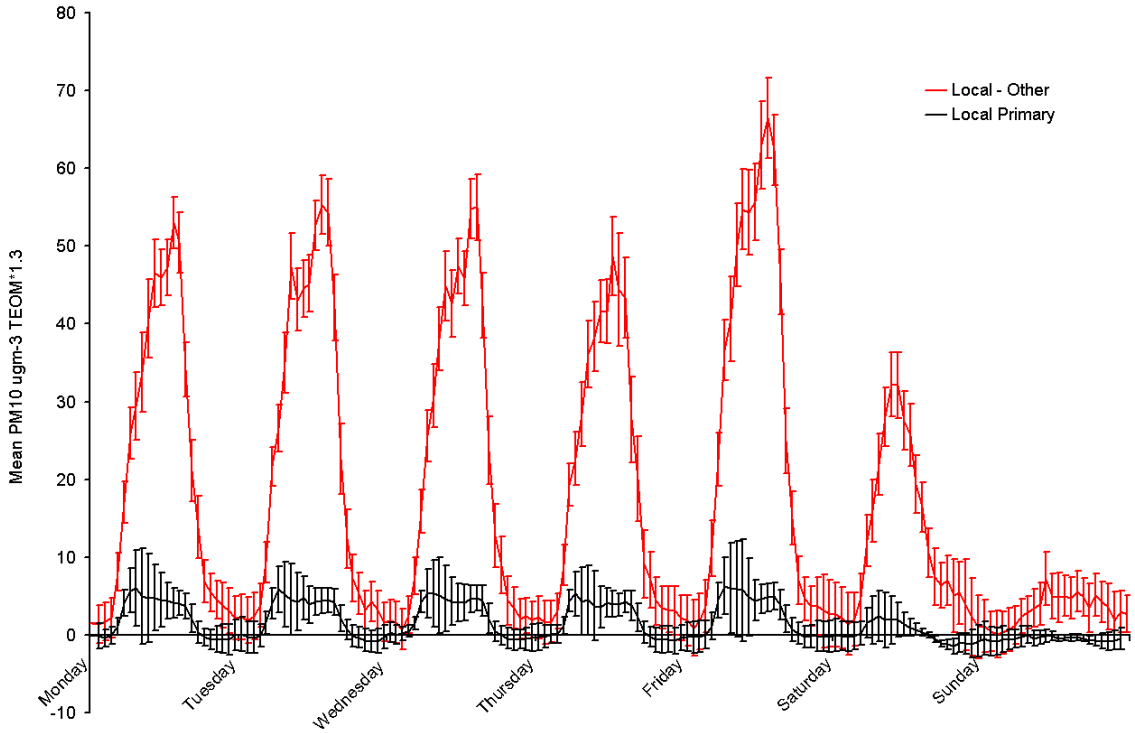

Figure 16 Concentrations of PM_{10} from the local sources at Bexley 4 during 2005 and 2006 averaged by day of week and hour of day. Times are shown in GMT and uncertainty estimates are shown at 2 σ.

Figure 16 shows the mean concentration from the local – other and local primary sources. The mean concentration of local primary PM_{10} showed a clear difference between weekdays and weekends with the mean concentration being greater on weekdays than on Saturday and Sunday, in line with

behaviour of the mean concentration of local – other PM_{10}. Most notably the mean concentration of local primary and local other PM_{10} sources exhibited rapid concentration increases at the same time on weekday mornings, although the local primary PM_{10} peaked earlier each day. Both sources also showed reduction during weekday afternoons and evenings. The similar diurnal pattern suggested a link between these sources. The extent to which the local primary PM_{10} may explain the variance in the local – other PM_{10} concentration is explored in Figure 17 which shows a scatter plot of the mean concentration of the two sources averaged by hour of day and day of week. Figure 17 suggested a relationship between the two PM_{10} sources. The correlation coefficient (r^2) of 0.8 suggested that 80% of the averaged hour of day and day of week variance in the concentration in local – other PM_{10} may be explained by the variance in the local primary PM_{10} concentration. The linear regression indicated a positive intercept of around 7 µg m^{-3} TEOM*1.3 Please note however that it was not possible to include uncertainty estimates in this regression analysis.

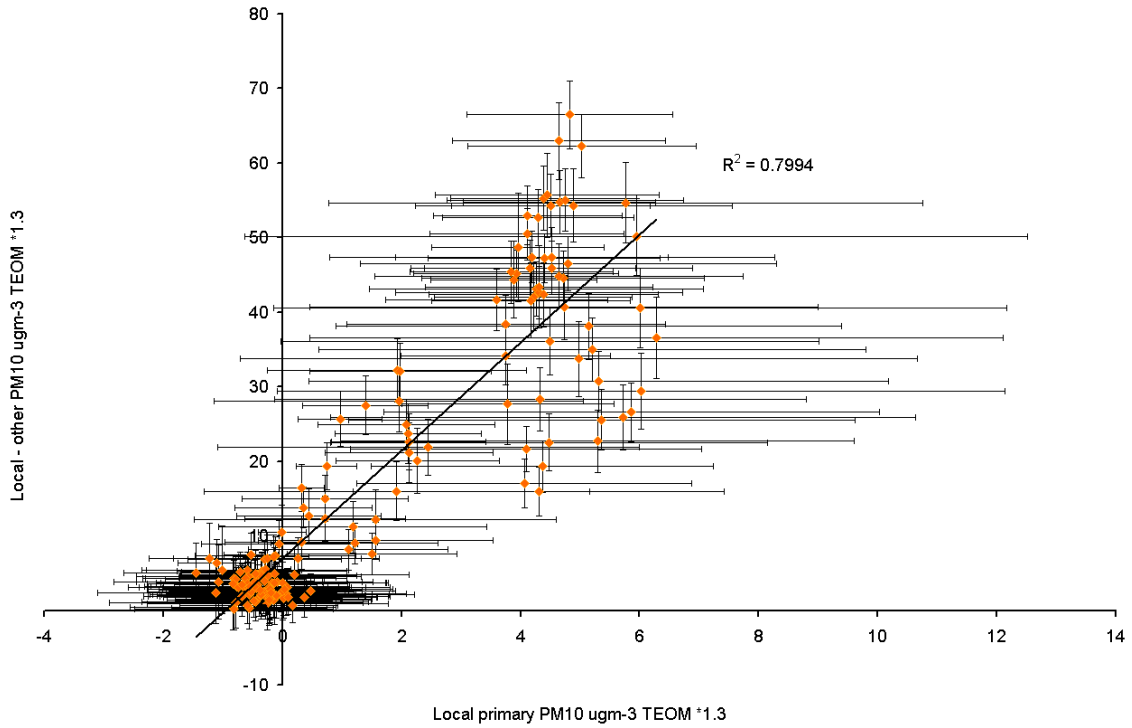

Figure 17 Scatter plot of local – other PM10 vs local primary PM10 at Bexley 4 during 2005 and 2006. Both sources were averaged by hour of day and day of week. Uncertainty estimates are shown at 2 σ

Mean PM_{10} by wind direction

Figure 18 shows the mean concentration of PM_{10} at Bexley 4, averaged by wind direction. This analysis provided important insight into the location of PM_{10} sources affecting the monitoring site.

The greatest overall mean concentration of PM_{10} arose during winds from a broadly northerly direction between (280° to 150 °). This mean concentration was caused by an elevation in the local – other PM_{10} from these wind directions. The concentration of PM_{10} from background secondary and natural sources was elevated during easterly winds and peaked during winds from 110°. This was indicative of long range transport of PM_{10} from continental sources and was consistent with the expected behaviour of secondary PM_{10} sources as highlighted by APEG (1999) and Smith (1997).

The lowest mean PM_{10} concentrations from background sources were measured at the site during wind directions between west and north. Winds from this quarter usually have a maritime origin and would not normally contain large concentrations of secondary PM_{10}.

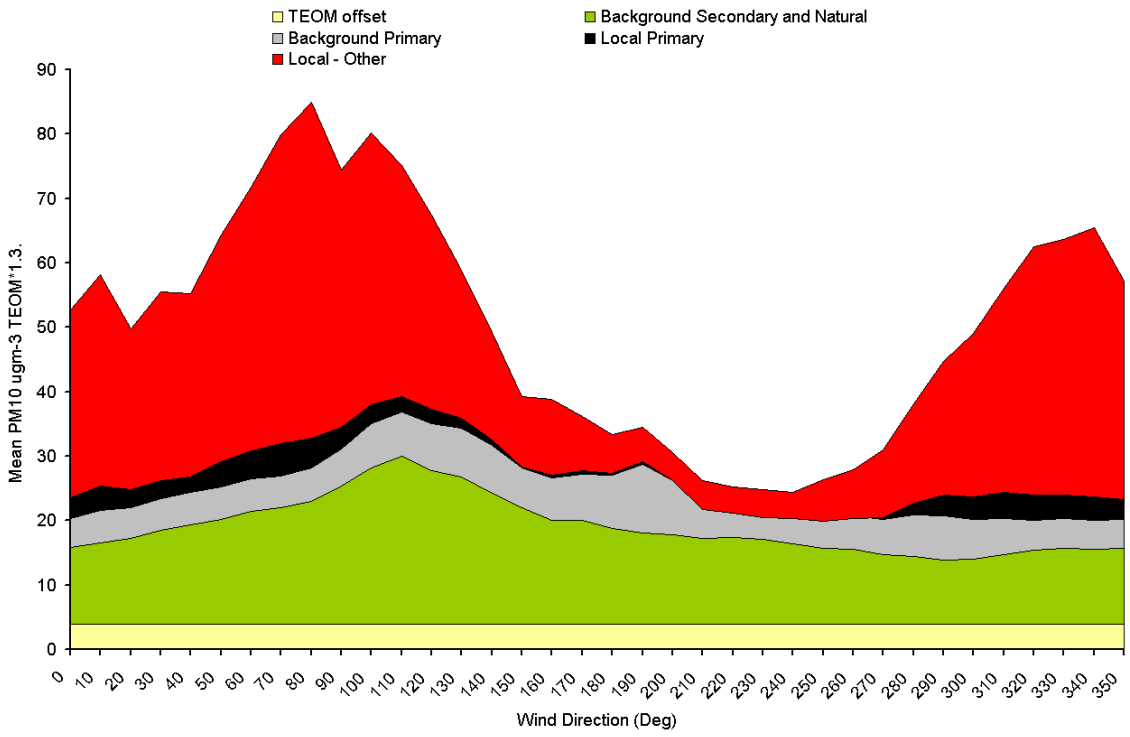

Figure 18 Source apportioned PM_{10} at Bexley 4, during 2005 and 2006, averaged by wind 10° direction sectors.

The contrasting background pollutant concentrations with respect to easterly and westerly winds is typical of sites in London and has been found in previous studies (e.g. Fuller and Hedley 2006). The behaviour of PM_{10} from local sources is also determined by wind direction but 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 determinants.

Figure 19 shows the mean concentration of local- other PM_{10} sources averaged by 10° wind sectors. The mean concentration of the local – other PM_{10} was greater than the uncertainty of the model for wind directions from all wind directions.

Local – other PM_{10} exhibited greatest concentrations when wind originated from directions between 280° to 150°. This showed agreement with the orientation of Manor Road with respect to the monitoring site; low concentrations of local – other PM_{10} were measured on wind directions that did not cross Manor Road before reaching the monitoring site. Additionally it appeared that greater concentrations of local – other PM_{10} arose from east of the monitoring site when compared to the concentration from west of the site.

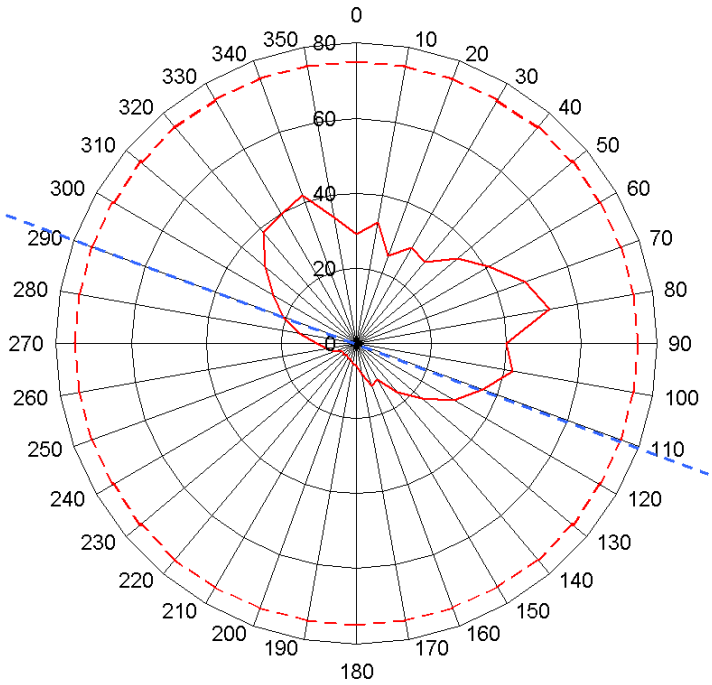

Figure 19 Source apportioned mean concentrations of local - other PM10 at Bexley 4, during 2005 and 2006, averaged by 10o wind sector. The blue dotted line denotes the approximate orientation of Manor Road with respect to the monitoring site. The red dotted line shows the wind sectors where the modelled mean concentration of local – other PM10 exceeded the modelled uncertainty estimates. Mean concentrations are shown in µg m-3 TEOM*1.3.

Figure 20 and Figure 21 show both local primary and the local – other PM_{10}. Figure 20 shows the absolute mean concentrations of both local sources and Figure 21 shows the relative annual mean concentration arising from each 10° wind sector. In both cases the local primary PM_{10} was determined from the local NO_X concentration and was therefore linked to vehicle exhaust sources local to the monitoring site; vehicles using Manor Road and other nearby roads. It can be clearly seen from Figure 20 that the concentration of the local primary was far less than that of the local-other PM_{10}. The mean concentration of local primary PM_{10} was determined by the orientation of Manor Road relative to the monitoring site. Figure 21 shows that the distribution of the mean concentration of local – other PM_{10} with respect to wind direction was very similar to that of the mean local primary PM_{10} concentration. The relationship between the local primary PM_{10} and the local – other PM_{10}, when averaged by wind direction is more clearly shown in Figure 22 which shows a scatter plot of the mean concentration of the two sources. A correlation coefficient (r^2) of 0.87 suggested that 87% of the wind direction averaged variance in the concentration in local – other PM_{10} may be explained by the variance in the local primary PM_{10} concentration. The linear regression indicated a positive intercept of around 8 µg m^{-3} TEOM*1.3. Please note however that it was not possible to include uncertainty estimates in this regression analysis.

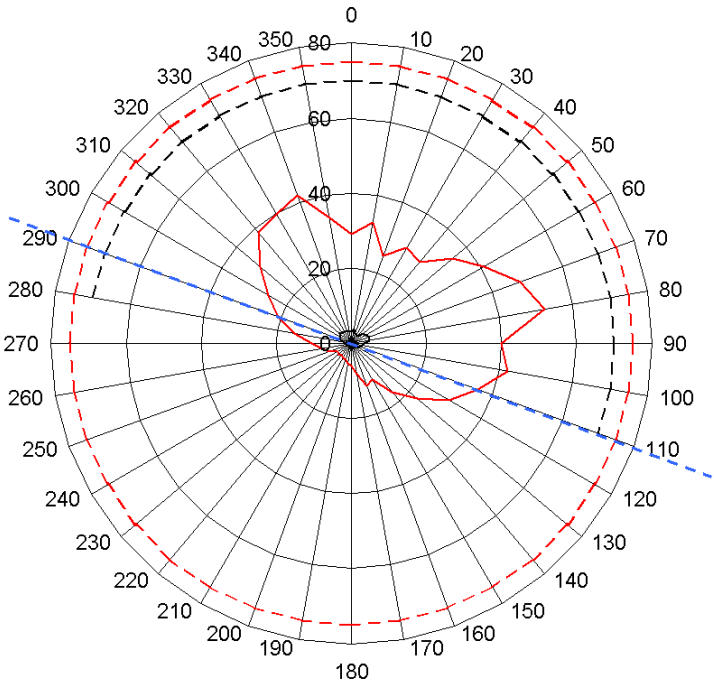

Figure 20 Source apportioned mean concentrations of PM_{10} from local sources at Bexley 4, during 2005 and 2006, averaged by 10° wind sector. The mean concentration of local – other PM_{10} is shown in red and local primary PM_{10} is shown in black. The blue dotted line denotes the approximate orientation of Manor Road with respect to the monitoring site. The red and black dotted lines shows the wind sectors where the modelled mean from the local PM_{10} sources exceeded their respective uncertainty estimates. Mean concentrations are shown in µg m^{-3} TEOM*1.3.

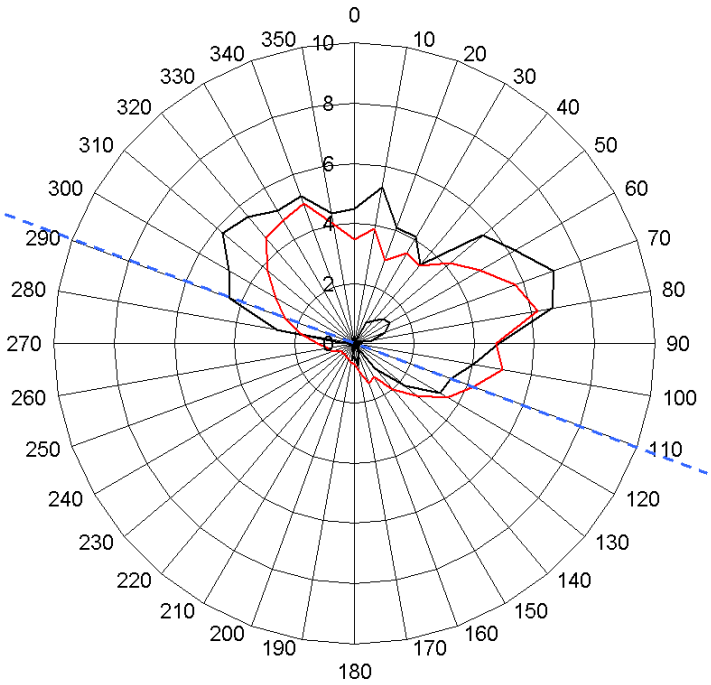

Figure 21 Source apportioned mean concentrations of PM10 from local sources at Bexley 4, during 2005 and 2006, averaged by 10o wind sector. Concentrations are expressed relative to the annual mean. Insignificant negative concentrations are not shown. The mean concentration of local – other PM10 is shown in red and local primary PM10 is shown in black. The blue dotted line denotes the approximate orientation of Manor Road with respect to the monitoring site.

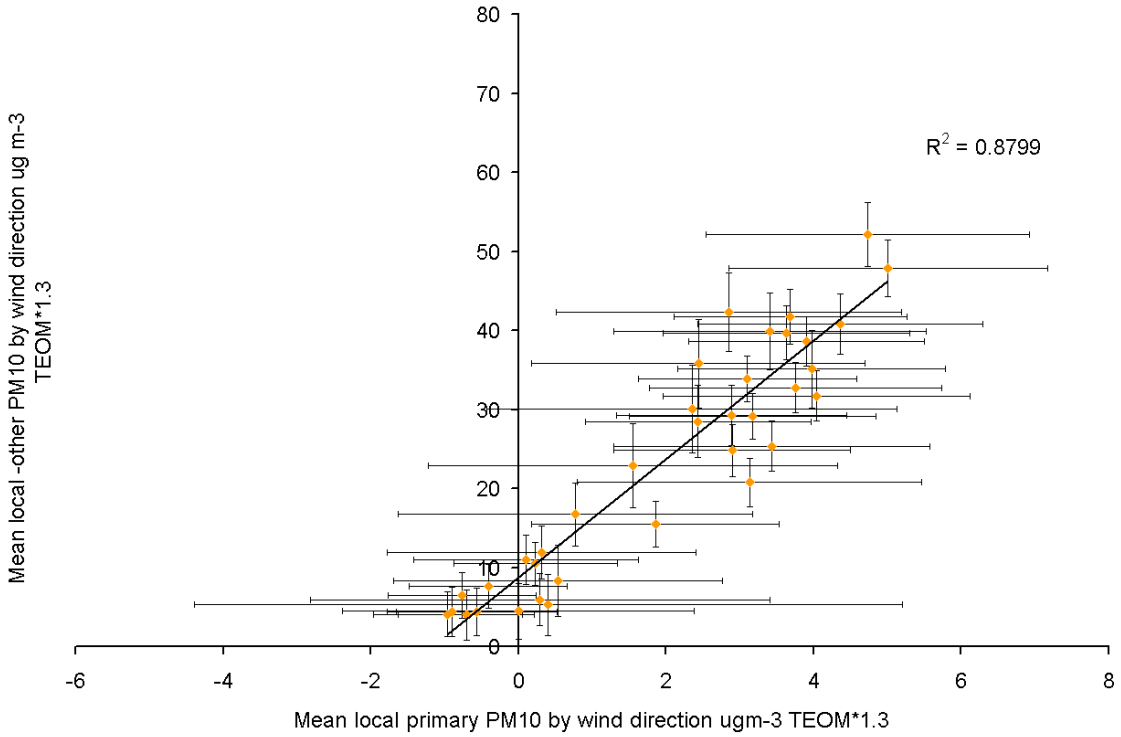

Figure 22 Scatter plot of local – other PM_{10} vs local primary PM_{10} at Bexley 4 during 2005 and 2006. Both sources were averaged by wind direction. Uncertainty estimates are shown at 2 σ

Reduction of local – other PM_{10} required to meet the EU limit value

The measured concentration of PM_{10} at the Bexley 4 monitoring site exceeded the daily mean EU Limit Value during 2005. Source apportionment of daily mean concentrations allowed the assessment of PM_{10} reduction scenarios, for example the reduction in the concentration of the mean local – other PM_{10} required to achieve the daily mean AQS.

Figure 23 shows the number of days with mean concentrations of PM_{10} above 50 µg m^{-3} TEOM*1.3 for progressive reductions in the mean concentration of local – other PM_{10} based on measurements made during 2005. Pro-rata allowance was made for days lost due to incomplete measurement data. It is clear from Figure 23 that the annual number of days with mean PM_{10} above 50 µg m^{-3} TEOM*1.3 was not linearly dependent on the concentration of the local – other PM_{10}. It was estimated that the mean concentration of local – other PM_{10} at Bexley 4 needed to be reduced by 75 % (50 – 100%, 2σ) for the site to have met the AQS Objective during 2005.

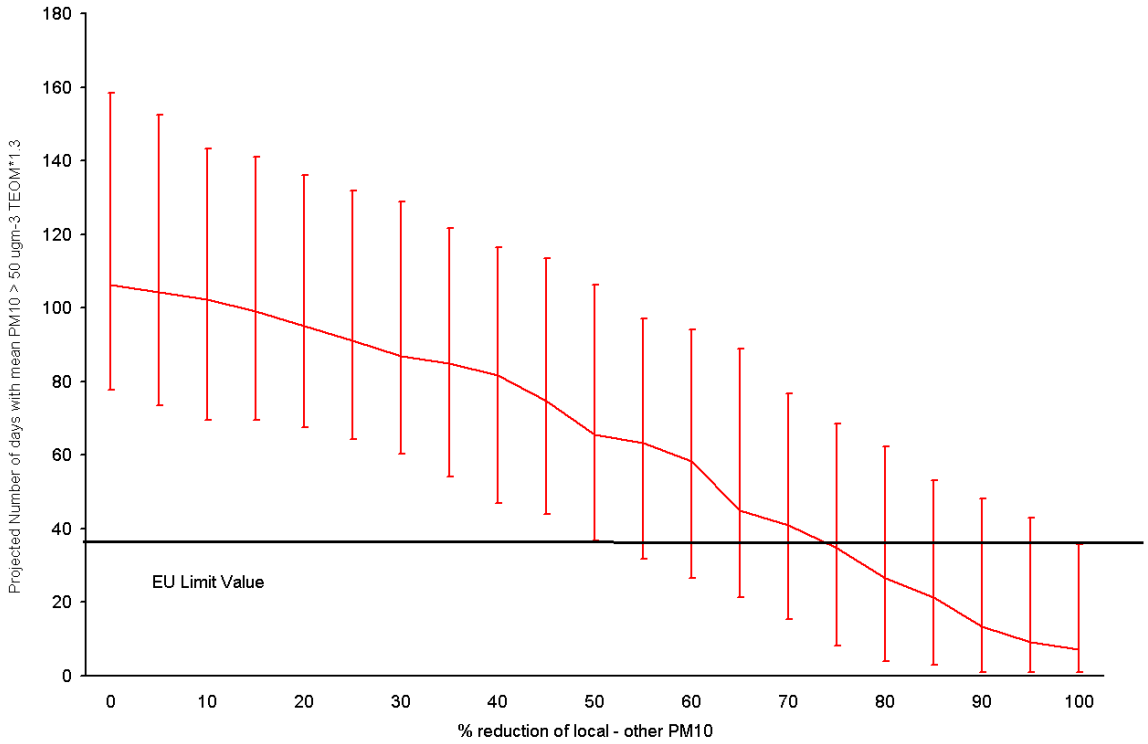

Figure 23 Reduction scenarios for the concentration of local - other PM_{10}, compared to the daily mean EU Limit Value. Analysis was based on 2005 measurements and pro-rata adjustment was made for measurement availability.

Further insight into the PM_{10} concentrations at Bexley 4 may be obtained from considering other studies of PM_{10} on haulage routes from waste facilities. A source apportionment study at the Brent 5 monitoring site, which is close to the entrance to several waste facilities, found concentrations of local –other PM_{10} of up to 33 (+/- 3, 2σ) µg m^{-3} TEOM*1.3. Lower concentrations of local – other PM_{10} were found at three other sites (Hammersmith & Fulham 3, Hastings and Sutton 5) that were several hundred metres from waste facilities. The concentration of local – other PM_{10} at Bexley 4 (17 (+/- 5, 2σ) µg m^{-3} TEOM *1.3) was consistent with the monitoring site being close to the entrance to a waste facility.

Site	Distance from waste site along haul route	Mean local – other PM_{10} µg m^{-3} TEOM*1.3	Reference
Brent 5	~ 15m	33 (+/- 3, 2σ)	Fuller, Hedley and Baker 2007a
Bexley 4	~ 30 m	17 (+/- 5, 2σ)	This study
H'smith & Fulham 3	450 m	6 (10 – 4, 2σ)	Fuller and Hedley 2006
Sutton 5	800	8 (+/- 6, 2σ)	Fuller, Hedley and Baker 2007b
Hastings	1100 m	7 (+/- 2, 2σ)	Fuller, Hedley and Baker 2007c

Table 6 Concentrations of local - other PM_{10} from studies of PM_{10} near waste facilities.

8. Conclusions

The Bexley 4 monitoring site has consistently exceeded the EU Limit Value / AQS Objective for PM_{10} since the site was installed. The annual the number of days with mean PM_{10} above 50 µg m^{-3} TEOM*1.3 at Bexley 4 increased from 77 days in 2001 to 116 days by the end of 2006. This was considerably above the EU Limit Value / AQS Objective of 35 days per year. The annual number of days with mean PM_{10} above 50 µg m^{-3} TEOM*1.3 peaked during 2004 and the site also exceeded the annual mean EU Limit Value at this time. Since monitoring began at the site, PM_{10} concentrations at Bexley 4 were considerably above nearby roadside and background sites suggesting that a local source was affecting the site.

Source apportionment of the measured PM_{10} concentration was required to understand the sources of PM_{10} affecting the site. The source apportionment model performed well. When compared with PM_{10} concentrations at six nearby roadside sites, the model showed good agreement and confirmed that the uncertainty estimates were realistic. However at Bexley 4 the model did not agree with the measured concentrations indicating the presence of a further source of PM_{10} at the site. This source was termed local – other PM_{10}.

Source apportionment showed that 18 (+/- 5, 2σ) µg m^{-3} TEOM *1.3 or 42 (+/- 12, 2σ) % of the annual mean PM_{10} measured at the site came from local – other PM_{10} sources.

The daily mean concentration of PM_{10} at Bexley 4 showed considerable day to day fluctuation reaching a peak daily mean concentration of 197 µg m^{-3} TEOM*1.3. The vast majority of the days with mean PM_{10} concentration above 50 µg m^{-3} TEOM*1.3 were due to PM_{10} from the local – other source which exceeded the local primary PM_{10} by a factor of 16. If the local – other PM_{10} source was not present during 2006, the site would have experienced 6 (1 – 35, 2σ) days during 2005 with mean PM_{10} above 50 µg m^{-3} TEOM*1.3 and therefore would have almost certainly achieved the AQS Objective / EU Limit Value for the year. It was estimated that the mean concentration of local – other PM_{10} at Bexley 4 needed to be reduced by 75 % (50 – 100%, 2σ) for the site to have met the AQS Objective during 2005.

The local – other PM_{10} source exhibited greatest concentrations during working hours on weekdays and on Saturday mornings. The mean concentration of both the local – other PM_{10} and local primary PM_{10} also increased sharply during the same hour each weekday. It is likely therefore that the local – other PM_{10} originated from sources that operated at these times and were linked to the local primary sources. It was found that 80 % of the changes in the mean local – other PM_{10}, when averaged by hour of day and day of week, could be explained by the changes in the local primary concentration.

The local – other PM_{10} had the largest concentrations when the wind originated from a broadly northerly direction between (280^{o} to 150^{o}). These directions agreed with the orientation of Manor Road with respect to the monitoring site. The mean concentration of local primary PM_{10} was analysed and this also showed very good agreement with the orientation of Manor Road relative to the monitoring site. There was good agreement between the concentration of local – other PM_{10} and primary PM_{10} when averaged by wind direction. It was found that 87 % of the changes in the mean local – other PM_{10}, when averaged by wind direction, could be explained by the changes in the local primary concentration.

The local – other source also exhibited a substantial seasonal variation with greatest concentrations being measured during summer.

Comparing the results from the source apportionment study to that obtained in previous studies (Fuller and Hedley 2006, Fuller et al 2007a,b,c), the concentration of local – other PM_{10} at Bexley 4 (18 +/- 5, 2σ µg m^{-3} TEOM *1.3) was consistent with the monitoring site being close to the entrance / exit from a waste facility; the Bexley 4 monitoring sites was approximately 30m from the entrance to Erith Waste Management Ltd.

Within the source apportionment scheme the local primary PM_{10} was related to the NO_X concentration measured at the site and good agreement with this source and the orientation of the road would therefore be expected. Given that the local primary PM_{10} is a marker of road traffic emissions the

similarities in the behaviour of the PM_{10} concentrations that arose from the local primary and local – other sources suggested that the local – other PM_{10} was linked to road traffic.

Although, the local – other PM_{10} was probably linked to vehicle sources it could not be completely accounted for by tailpipe emissions and expected mechanical tyre and brake wear. It was therefore likely that the local – other PM_{10} originated from the resuspension of silt from the road surface or direct suspension of material from 'dusty' vehicles. Silt may be carried from waste facilities onto Manor Road by vehicles leaving the site. All traffic on Manor Road would have the potential to resuspend material deposited on the road which may have accounted for concentrations of local – other PM_{10} outside the times when the waste facilities were open; Sundays for example. These facts all suggested that the local – other PM_{10} was not linked to fugitive emissions from the waste facilities and other sites in the area. Positive intercepts were found in the regression of local – other PM_{10} on but these could not take account of the uncertainties in the local – other and primary PM_{10} concentrations. However these results did suggest that the local – other PM_{10} may come from two separate activities, one linked to local primary, and hence to transport, and another activity. This other activity may be from a fugitive source (though none was found in the analysis) or wind blown resuspension of locally deposited silt.

9. Recommendations and further work

- The findings of this report should be incorporated into the Council's Air Quality Action Plan.

- The council should work with the operators of Erith Waste Management Ltd and the Environment Agency to reduce the concentration of PM_{10} arising from the waste activity. Determining what changed at the waste site during 2004 (when concentrations were greatest) and what has changed over the last 6 years may be key to managing the PM_{10} problems affecting Manor Road

- The concentration of PM_{10} has increased at the monitoring site over the last 6 years and reached a peak during 2004. Clearly greater understanding how the local – other PM_{10} has changed over this time may help with the management of the source(s) of local – other PM_{10}. This analysis may focus on characterising the local – other PM_{10} at different time periods to determine what caused the local – other PM_{10} concentration to change. PM_{10} concentrations could be examined:

    - With respect to season to determine what caused the seasonal variation in local – other PM_{10}.
    - By time period; e.g. 2004 (when concentrations were greatest), pre-2004 and post 2004.
    - By weekday and weekend.

- The Council should continue to monitor concentrations of NO_X and PM_{10} to assess the concentration reductions achieved by any abatement measures installed at the waste facilities. It should however be recognised that the day to day variation in the concentration of local – other PM_{10} and the seasonality exhibited by the local – other PM_{10} source may confound this assessment in the short – term. This source apportionment study should be repeated bi-annually to quantify changes in local – other PM_{10} or in response to any large changes in the PM_{10} concentration measured at the monitoring site.

- The local – other PM_{10} appeared to arise from both sources linked to vehicle movements and another source. Further investigation of the other source should be undertaken. Opportunity exists to undertake analysis of PM_{10} at the site using bi-variate polar plots. This analysis will allow greater differentiation of sources by characterising them with respect to both wind direction and wind speed and therefore has the potential to separate possible wind blown and fugitive sources.

- Although PM_{10} mass concentrations have a crucial regulatory significance it is recognised that the mass concentration of PM_{10} may be a poor surrogate for the health impact. There is mounting evidence that the toxic effects of PM_{10} are driven by the oxidation reactions. Determination of the oxidative potential of the PM_{10} from Manor Road would assist in understanding the possible toxic impacts of the local PM_{10} in the Manor Road area.

- It is likely that the local – other PM_{10} affects the overall PM_{10} composition at the site and may therefore introduce additional uncertainty in the 1.3 'correction' factor applied to the TEOM measurements for assessment of the EU Limit Value at the site. Gravimetric measurements of PM_{10} have been made at Manor Road and these should be processed into daily mean concentrations. These measurements would help to determine an appropriate 'correction' factor for the TEOM to gravimetric conversion at this site.

- We understand that Erith Haulage also have PM_{10} measurements. Analysis of these measurements in combination with those from Bexley 4 should be undertaken. This may allow triangulation on the local sources of PM_{10} in the area.

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