King's College London

Environmental Research Group

PM_{10} Source apportionment at Hastings 1, A259 Bulverhythe

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1. Summary

This report provides a detailed analysis of air pollution measurements made at the Hastings 1 monitoring site. The Hastings 1 monitoring site was located on the north site of a residential section of the A259 at Bulverhythe. This report compared measured PM_{10} concentrations to the UK Air Quality Strategy Objectives / EU Limit Values and quantified the sources of PM_{10} that affected the monitoring site.

During 2006 the Hastings 1 monitoring site measured 44 days with mean PM_{10} concentration above 50 μgm^{-3} TEOM*1.3. This was a breach of the EU Limit Value and AQS Objective of 35 days. It was projected that the site would have measured 48 such days if pro rata allowance were made for missing measurements.

During 2003 the Hastings 1 site exceeded the EU Limit Value by a wide margin however the annual number of days with mean PM_{10} above 50 $\mu g\ m^{-3}$ TEOM*1.3 reduced during 2004 and the site achieved the Limit Value during 2004 and 2005. The annual number of days with mean concentrations above 50 $\mu g\ m^{-3}$ increased steadily during 2005 and 2006 to breach the EU Limit Value once again by the end of 2006.

To understand the sources of PM_{10} affecting the site a source apportionment technique was used. The source apportionment model 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. This included both regional sources and local sea salt PM_{10}.

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

- **Local primary** – PM_{10} estimated from the elevation in the 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 London and south east England, 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 μgm^{-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 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.

The uncertainty associated with the calculation of the concentration of local PM_{10} sources was assessed using the GUM (Guide to the Expression of Measurement Uncertainty in Measurement) approach (ISO, 1995). The lack of available background measurements of NO_X and PM_{10} in coastal areas of Sussex necessitated the use of a single background site in this study and did not therefore allow the inclusion of an uncertainty component arising from the spatial variation in the PM_{10} from background secondary and natural sources. It was therefore likely that uncertainty was underestimated.

Source apportionment showed that 7 (+/- 2, 2σ) μgm^{-3} TEOM *1.3 or 21 (+/- 6, 2σ) % of the 2006 annual mean PM_{10} measured at Hastings 1 came from local – other sources.

During the period April 2005 to the end of 2006 the maximum daily mean PM_{10} concentration measured at Hastings 1 was 93 μgm^{-3} TEOM*1.3. On those days where source apportionment was

possible, the maximum daily mean PM_{10} concentration at Hastings 1 was 85 μgm^{-3} TEOM*1.3. If the local – other PM_{10} source had not been present during 2006, the site would have experienced 7 (7 – 9, 2σ) days with mean PM_{10} above 50 μgm^{-3} TEOM*1.3 and therefore would have achieved the AQS Objective / EU Limit Value during 2006.

When averaged by day of week and hour of day, the local – other PM_{10} showed a clear diurnal pattern with the greatest concentrations being measured during the daytime. The mean concentration of local primary PM_{10} also showed a clear diurnal pattern that was similar to that of the local – other PM_{10}. The similar diurnal pattern suggested a link between these sources and it was found that 58% of the averaged hour of day and day of week changes in the concentration in local – other PM_{10} may be explained by the changes in the local primary PM_{10} concentration.

Local – other PM_{10} exhibited greatest concentrations when wind originated from directions between 120^{o} and 280^{o} with the maximum mean concentration being measured on wind directions perpendicular to the A259 from the south side of the road and along the A259 from the west. It appeared that greater concentrations of local – other PM_{10} arose from the A259 to the west of the monitoring site when compared to the concentration from the A259 to the east of the site. Relatively low concentrations for local – other PM_{10} arose on wind directions from the north of the monitoring site.

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} was a marker of road traffic emissions the similarities in the behaviour of the PM_{10} concentrations arising from the local primary and local – other sources further 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. During the site visit, silt was observed on the A259 beside Hastings 1 monitoring site, near the Hastings Municipal Services Depot, Bulverhythe Road and on the access road to Pebsham landfill and waste recycling sites. Silt may be carried from waste facilities onto the A259 by vehicles leaving these sites. All traffic on the A259 would have the potential to resuspend material deposited on the road which may account for concentrations of local – other PM_{10} outside the times when the waste facilities were open; Sundays for example. Analysis of local measured PM_{10} suggested that wind speed may also have been a factor in the resuspension of road silt, independent of traffic. This suggested that the mean local – other PM_{10} concentration of 7 (+/- 2, 2σ) μgm^{-3} TEOM *1.3 may be apportioned between a traffic induced component of 5 (+/- 2, 2σ) μgm^{-3} TEOM *1.3 and a wind blown component of 1.7 (+/- 0.6, 2σ) μgm^{-3} TEOM *1.3.

The mean concentration of local – other PM_{10} of 7 (+/- 2, 2σ) μgm^{-3} TEOM *1.3 during 2006 was consistent with a previous study of PM_{10} at the Hastings 1 monitoring site (Fuller and Hedley 2004). Fuller and Hedley (2004) used slightly different methodology but also found that a source of local – other PM_{10} was present at the monitoring site and attributed this to atypical resuspension of road dust. The local – other PM_{10} and a mean concentration of 10 μgm^{-3} TEOM *1.3 during 2003 and declined to 6 μgm^{-3} TEOM *1.3 during 2004.

Based on evidence from other studies, the concentration of local – other PM_{10} at Hastings 1 (7 (+/- 2, 2σ) μgm^{-3} TEOM*1.3) was consistent with the monitoring site being several hundred metres from a waste facility; the monitoring site was approximately 200m from the Hastings Municipal Services Depot on Bulverhythe Road and 1,100m from the entrance to Pebsham landfill and waste recycling sites. Each of these waste facilities lay to the west of the monitoring site. The greater concentrations of local – other PM_{10} from A259 to the west of the monitoring site when compared with A259 to the east of the monitoring site may be indicative of a emission gradient for local – other PM_{10} along the A259; greater emissions arising from the road to the west of the monitoring site which was closer to the waste facilities. Evidence for an emission gradient for local – other PM_{10} along the A259 was also found by Fuller and Hedley (2004). It is therefore very likely that higher concentrations of PM_{10} were present further west along the A259.

There was no evidence of PM_{10} emissions from the Pebsham landfill itself affecting the measured PM_{10} concentration at the monitoring site.

Given that the monitoring site achieved the AQS Objective during 2004 and 2005 but failed during 2003 and 2006, investigation of operational changes at the nearby waste facilities between 2003 and 2006 is key to the management of PM_{10} concentrations at Hastings 1 and on nearby sections of the A259.

It is recommended that:

- The findings of this report should be incorporated into the Council's Air Quality Action Plan.
- The Council should work together with the Environment Agency and operators of the Pebsham landfill and waste recycling sites and Hastings Municipal Services Depot to reduce the silt deposited on the A259 and adjacent roads.
    - A key objective is determine what changes took place at these waste facilities during the last 4 years to determine why the Hastings 1 monitoring site achieved the AQS Objective and EU Limit Value during 2004 and 2005 but failed to achieve the objective during 2003 and 2006.
    - Further analysis of measured PM_{10} concentrations at the Hastings 1 monitoring site should be undertaken in an attempt to determine the time of any significant changes in the measured PM_{10} concentrations. CUSUM techniques may be employed by for this analysis.
- 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 apparent seasonality exhibited in other studies (e.g. Fuller et al 2007a) may confound this assessment in the short – term. This source apportionment study should be repeated annually to quantify changes in local – other PM_{10}.
- Traffic counts should be undertaken on the access road to the Pebsham waste facility and on the A259 to inform future modelling exercises.
- Future source apportionment studies should include analysis of measurements from the Rother 2 monitoring site on the A259.

2. Introduction

This report is intended to assist Hastings Borough Council with its continuing Local Air Quality Management duties.

This report provides a detailed analysis of air pollution measurements made at the Hastings 1 monitoring site. The Hastings 1 monitoring site was located in a roadside location on a residential section of the A259 at Bulverhythe. The Pebsham landfill site lay to the north of monitoring site and a depot for refuse collection vehicles lay to the south.

This 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 the analysis of measurements made from 1st April 2005 to the end of 2006.

Previous Air Quality Assessments

The Council has undertaken the earlier stages of review and assessment of the Local Air Quality Management (LAQM) process within its area (see the individual Updating and Screening and Detailed Assessment reports prepared since 2003). 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 as to their relative importance to air quality within the Council's area.

The Detailed Assessment report assessed air quality along the A259 through Bulverhythe in accordance with DEFRA revised guidance (TG03). The findings of the Detailed Assessment report were that an area of relevant public exposure alongside the A259 was likely to exceed the UK Air Quality Strategy Objective for PM_{10}. As a consequence of these findings, the Council designated an Air Quality Management Area.

A Further Assessment was undertaken following the declaration of the Air Quality Management Area. The Further Assessment (Fuller and Hedley 2004) confirmed the likelihood of a breach of the AQS Objective for PM_{10} at residential locations on the A259. The Further Assessment also apportioned the sources of the PM_{10} measured at the Hastings 1 site and found that locally derived concentrations were dominated by a non – tailpipe transport source of PM_{10}. This source was thought to arise from atypical suspension of material deposited on the roadway. It was acknowledged that the Council could only affect local primary and atypical re-suspension sources and it was found that action on primary emissions alone could not lead to the daily mean objective being achieved.

The monitoring for both 2002 and 2003 indicated that the objective would be exceeded at the Council's monitoring site. At the time of the Further Assessment, the available PM_{10} measurements for 2004 indicated that concentrations were lower and that there was a likelihood that the site would meet the objective for the year.

The Further Assessment recommended that the Council:

- Investigate possible reasons for the marked reduction in concentrations during 2004.
- Amend the designated Air Quality Management Area as necessary in the light of the modelling in the Further Assessment.
- Undertake consultation on the Further Assessment findings with the statutory and other consultees as required.
- Continue its ongoing PM_{10} monitoring programme and extend this to include continuous NO_x measurements.

The Hastings 1 monitoring site achieved the AQS Objective for PM_{10} during 2004 and 2005. However, during 2006 PM_{10} concentrations at the site increased and the site exceeded the AQS Objective for the year. In response to the changes in PM_{10} concentrations during 2006, Hastings Borough Council commissioned King's College London to undertake a further PM_{10} source apportionment at the site to determine which sources were causing the AQS Objective to be breached once more.

3. The site

The Hastings 1 monitoring site was located on the north side of a residential section of the A259 in Bulverhythe. The site was installed in 2001 and originally measured PM_{10} by TEOM only. A NO_X analyser was added to the monitoring site in 2005. The monitoring site was approximately 5m from the kerb, around 2m closer to the road when compared with the façade of the adjacent housing. The sample inlets were approximately 1.5m from the ground. The monitoring site was located adjacent to a small access road to a playing field and open land. The area around the site was free of recent building works although local residents indicated that two new houses 10m east of the monitoring site. These houses were completed and occupied around two years previously.

Figure 1 The Hastings 1 monitoring site looking east along the A259. The PM_{10} and NO_X monitoring equipment was located the green cabinet. The white cabinet was formally used for gravimetric sampling.

Figure 2 The Hastings 1 monitoring site looking west along the A259.

Figure 3 The Hastings 1 monitoring site looking perpendicular to the A259, approximately south, towards housing opposite.

Figure 4 The Hastings monitoring site looking approximately north along the playing fields' access road.

Figure 5 Aerial view of Hastings 1 monitoring site and local area. The location of the monitoring site is marked with a red arrow. The entrance to the municipal services depot is marked with a white arrow.

Figure 5 shows an aerial view of the area around the Hasting 1 monitoring site. The A259 can be seen running approximately southwest / northeast. The access road to the Pebsham waste facility runs approximately north from the A259 on the left hand side of Figure 5. The area of the Pebsham landfill site lay directly to the north of the area shown in Figure 5.

4. Site visits

For the purpose of this study a site visit was undertaken on the afternoon of 29th May 2007. The site visit included a visit to the monitoring site, shown in Figure 1 to Figure 4. The weather during the site visit was dry but the preceding Bank Holiday weekend was very wet. Despite the recent wet weather a slight silt deposit was present in the roadway close to the monitoring site as shown in Figure 6.

Figure 6 Slight silt deposits seen on the A259 beside the Hastings monitoring site.

Two potential local sources of road silt were noted in the area. A trail of silt was seen leading from the Hastings Municipal Services Depot, operated by Veolia Environmental Services in Bulverhythe Road to the south of the A259. The silt trail was localised and did not extend beyond the immediate area around the site entrance as shown in Figure 7.

Figure 7 Slight silting around the entrance to the Hastings Municipal Services Depot, looking north along Bulverhythe Road towards the A259.

Further road silting was seen on the access road to Pebsham landfill and waste recycling sites. Clear silting was seen extending from the site entrance on the southbound carriageway to the A259 as shown in Figure 8. A landfill gas engine was also operating on the Pebsham landfill site.

Figure 8 Silting on the southbound carriageway of the access road from the Pebsham landfill and waste recycling sites.

5. Source apportionment method

Air pollution measurements

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. The NO_X measurement equipment was subject to fortnightly calibration using an NO cylinder with gas concentration certified by the cylinder supplier only. All measurements were logged by the instruments themselves and collected by KCL each 12 hours. Measurements from the monitoring site were validated by KCL using the most up to date calibration factors and disseminated daily on the SussexAir web page (www.sussex-air.net). The NO_X and PM_{10} instruments were serviced twice yearly in accordance with manufacturer's recommendations. Each service included flow checks and checks of other aspects of instrument performance including the TEOM microbalance K_0 factor.

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, service and daily manual validation were used to establish an operational and calibration history of the instruments and the pollution measurements were corrected for changes arising in service. Details of the monitoring site and the final dataset may be found at www.sussex-air.net

The source apportionment modelling also used measurements from other monitoring sites. Measurements at the nearby Eastbourne background monitoring site were carried out under the same quality regime as measurements at Hastings. Measurements from two other background sites in from the London Air Quality Network (Mole Valley 3 and Sevenoaks 2) were also used in the study. These two monitoring sites in had full traceablity to national metrological standards through UKAS accredited audits by the National Physical Laboratory, the use of traceable calibration sources and post measurement ratification by KCL.

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 were made using TEOMs. Allen et al., (1997); Smith et al., (1997); Green et al., (2001); Charron et al., (2004) and others 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 was recommended in the UK for comparison of TEOM PM_{10} measurements with the EU Directive (DETR, 1999). It was recognised that the 'correction' factor will depend on PM_{10} particle composition (Charron et al., 2004) and this was 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 was 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 did not vary across the London and the south east 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. However, as recognised in Fuller and Hedley (2004) the background secondary and natural PM_{10} at Hastings 1 included a local contribution from sea salt.

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 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 (e.g. Fuller and Baker 2001, Fuller et al 2007a, 2007b).

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 Hastings 1 the concentration of the regional secondary and natural components was derived from the Eastbourne background site. The selection of the Eastbourne site to derive the secondary and background PM_{10} at Hastings assumed that the sea salt PM_{10} contribution at Hastings could be represented by measurements at Eastbourne, as discussed in Fuller and Hedley (2004). Separate apportionment of sea salt PM_{10} contributions were determined by the difference in background secondary and natural PM_{10} at Eastbourne when compared with two inland background sites at Mole Valley (Dorking) and Sevenoaks.

Local events that were not associated with NO_X were not predicted by this model since it had 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. This approach was used to identify both local sources that were not sources of NO_X and local sources that were linked to NO_X that were not expected on the basis of NO_X and PM_{10} relationships derived from other sites in London and the south east.

Model Inputs and Outputs

The model was applied separately to measurements of NO_X and PM_{10} that were averaged in three ways to look at possible characteristics of the local PM_{10} sources at Hastings 1. 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 local 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 Hastings monitoring site. The selection of appropriate wind direction measurements for Hastings monitoring site is discussed below. Care should be taken when interpreting the results of this analysis since equal weighting was given to the 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.

There were less background NO_X and TEOM monitoring sites in the costal areas of Sussex compared with the availability of local background monitoring sites in previous studies (Fuller and Baker; 2001, Fuller and Hedley 2006, Fuller et al 2007a, 2007b). The local PM_{10} contribution from sea salt further constrained the selection of suitable background monitoring sites. In this study a single background site (Eastbourne) was therefore used. The Eastbourne background is a similar distance from the coast to Hastings 1 and also measured both NO_X and PM_{10} by TEOM during the study period.

For each analysis appropriately averaged measurements from the Eastbourne background site 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 Eastbourne from

regression gradients as described in Fuller et al (2002) and Fuller and Green (2006). The modelled total PM_{10} at the Hastings monitoring site was then calculated by adding the mean non-primary PM_{10} from Eastbourne to the primary PM_{10} calculated from NO_X measurements at Hastings. The PM_{10} concentration at Eastbourne (and Hastings) due to sea salt was determined by considering the difference in the concentration of PM_{10} from secondary and natural sources at Eastbourne and the two inland sites; Mole Valley 3 (Dorking) and Sevenoaks 2.

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. This included both regional sources and local sea salt PM_{10}.

- **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 London and south east England, 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 south east England, 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, 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 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 minutes wind direction measurements were used along with contemporaneous pollution measurements.

Wind direction measurements were not available at the Hastings 1 monitoring site. Wind direction measurements were therefore taken from the nearest coastal monitoring site; Chichester roadside. The Chichester site was located in a fairly open position adjacent to the A27 and had a wind vane located on a mast approximately 5 m above ground level. The ability of the wind direction measurements at Chichester to represent those over a wider area were tested by comparing the Chichester measurements to those made at Reigate and Banstead 1 (Horley) and at Sevenoaks 2. Good agreement was found between the wind direction measurements at the two sites however it appeared that the Chichester wind vane might have experienced some sheltering from winds between 0^o and 90^o.

Uncertainty Estimates

The method of calculating the local – other PM_{10} relied on the difference between measured and modelled PM_{10}. However this difference might have also be due to artefacts arising from uncertainty in the measurement and modelling process.

The uncertainty associated with the calculation of the concentration of PM_{10} from local sources 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 in 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

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.

The use of a single background site in this study did not allow the inclusion of an uncertainty component arising from the spatial variation in the PM_{10} from background secondary and natural sources and hence uncertainty was likely to be underestimated.

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.

6. Results and discussion

Air pollution measurements 2006

Air pollution measurements from the Hastings 1 monitoring site are shown in Table 2 along with measurements at nearby sites in Sussex and Surrey. For additional comparison measurements from three industrial roadside sites (type 'I' in Table 2) close to waste transfer facilities are also shown along with measurements from the Marylebone Road kerbside site. Measurements from all sites are shown for 2006. The measurements from the Sussex sites were fully ratified. Measurements from other sites were partially ratified.

Measurements from each monitoring site were compared to the UK Air Quality Strategy 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 μgm^{-3} (gravimetric). 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 μgm^{-3} (gravimetric) on more than 35 days per year. As shown in Table 2, the Hastings monitoring site met the annual mean Limit Value during 2006. However, on the basis of the available measurements the site exceeded the daily mean Limit Value. As discussed in Section 5 TEOM measurements should be multiplied by 1.3 for comparison to the EU Limit Value.

Table 2 is ordered by PM_{10} concentration and clearly indicates the concerns regarding the PM_{10} concentrations at the sites close to waste facilities (type I). Each of these sites exceeded the daily mean 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. The source apportionment scheme in Fuller et al. (2002), suggested that primary PM_{10} emissions were linked to NO_X and thus high levels of PM_{10} would be expected at Marylebone Road due to local primary sources. Such an explanation did not account for the PM_{10} concentrations measured at Brent 5 and Bexley 4 thus a non tail pipe source of PM_{10} was obviously affecting these sites. The Sutton 5 site was classified as roadside but it situated around 800m from two waste facilities and was affected by an additional non-tail pipe PM_{10} source.

The Hastings 1 site was the only site in Sussex to exceed the EU Limit Value for PM_{10} during 2006. The elevated PM_{10} at the Hastings site above background could not be explained by tailpipe emissions alone; the Chichester 1 site measured greater mean NO_X concentrations than Hastings but achieved the EU Limit Value for PM_{10}. Measurements from Eastbourne and Mole Valley 3 were included to provide an indication of urban background concentrations in towns in Sussex and Surrey.

Site	Type	PM_{10} µgm^{-3} TEOM*1.3				NO_X
		PM_{10} Capture %	Mean	Daily mean > 50	Full year projected daily mean >50	Annual mean µgm^{-3}
Ealing 8	I	99	74	224	226	
Brent 5	R	99	70	191	193	124
Marylebone Road	K	97	47	151	156	308
Bexley 4	I	94	43	106	113	70
Sutton 5	R / I	95	35	50	53	79
Hastings 1	**R**	**93**	**35**	**44**	**46**	**54**
Tower Hamlets 1	U	95	30	20	21	60
Ealing 2	R	97	26	18	19	140
Kens & Chelsea 1	U	99	26	16	16	60
Lewes 1	R	93	29	14	14	43
Chichester 1	R	98	29	7	7	79
Eastbourne	U	98	25	6	6	29
Mole Valley 3	U	99	23	4	4	39

Table 2 Measurements of air pollution at the Hastings 1 roadside site and other nearby sites during 2006. Measurements are ordered by the number of days with mean PM_{10} above 50 µgm^{-3} TEOM*1.3.

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

Figure 9 shows the annual mean PM_{10} concentration at sites across Sussex. Measurements from the long term inner London background site Tower Hamlets 1 are also shown to provide a longer-term perspective. Looking at PM_{10} concentrations at Tower Hamlets 1 a considerable improvement in annual mean PM_{10} concentrations was evident; annual mean concentrations of around 30 – 35 µgm^{-3} TEOM*1.3 in 1995 reduced to around 25 µgm^{-3} TEOM*1.3 in 2007. This site measured a steady decrease in mean concentrations during the late 1990s but concentrations have been relatively stable since. Two large PM_{10} pollution incidents can also be seen in Figure 9 in 1996 and 2003, that were both due to an influx of long-range transport of PM_{10} from continental sources. PM_{10} concentrations from the Hastings 1 are also shown in Figure 9. Analysis of changes in the PM_{10} concentrations at the Hastings site were confounded by the elevated PM_{10} concentrations during 2003, however when compared with other sites across Sussex it appears that the PM_{10} concentration at Hastings showed a substantial decrease during 2004 then increased during 2005, 2006 and the first part of 2007.

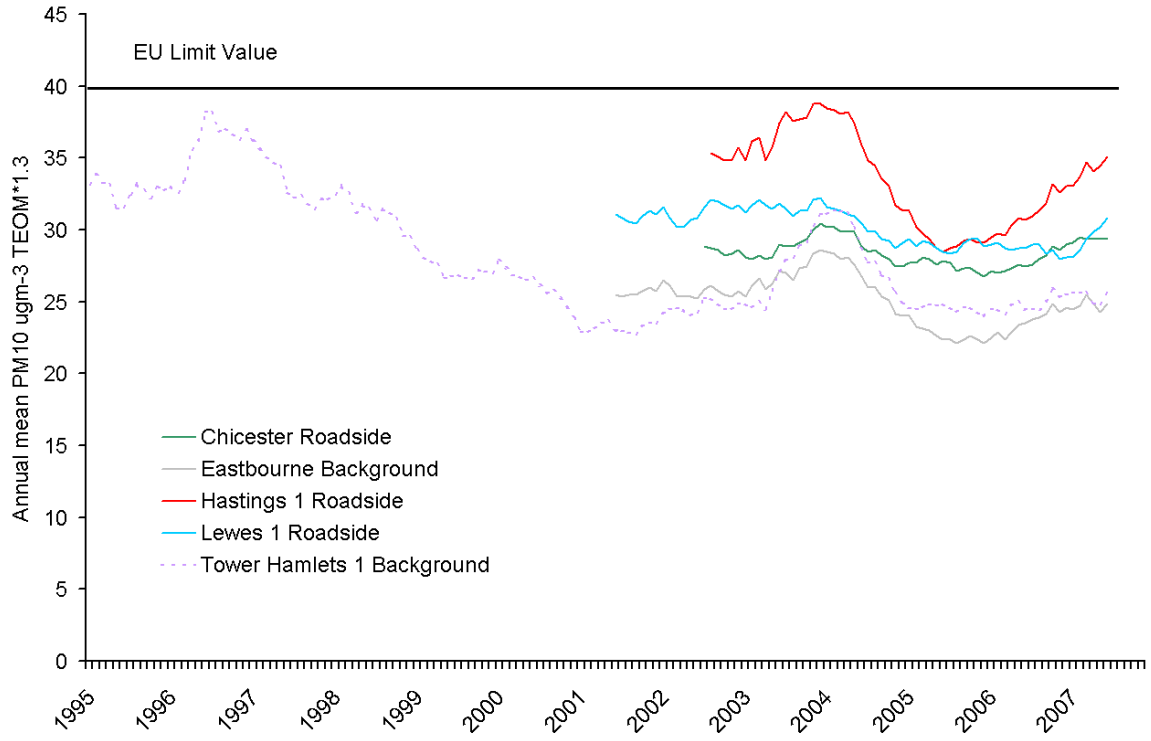

Figure 9 Annual mean PM_{10} concentrations at sites in Sussex. Measurements from the inner London urban background site Tower Hamlets 1 are shown to provide a longer term perspective.

Figure 10 shows the annual number of days when PM_{10} concentrations exceeded 50 µg m^{-3} TEOM*1.3 at the same sites as shown in Figure 9. This is a measure of the number of PM_{10} pollution incidents during the year and can be a very sensitive measure of changes in PM_{10} concentration for those sites with a large population of daily mean concentrations around 50 µg m^{-3} TEOM*1.3; typical roadside sites for example. The measurements from Tower Hamlets 1 clearly showed a reduction in the annual number of days with mean PM_{10} above 50 µg m^{-3} TEOM*1.3 between 1995 and 2006. The regional pollution incidents during 1996 and 2003 can be clearly seen. During 2003 the Hastings 1 site exceeded the EU Limit Value by a wide margin however the annual number of days with mean PM_{10} above 50 µg m^{-3} TEOM*1.3 reduced during 2004 and the site achieved the Limit Value during 2004 and 2005. The annual number of days with mean concentrations above 50 µg m^{-3} TEOM*1.3 reached a minimum during 2005 and increased steadily during 2005 and 2006 to breach the EU Limit Value once again by the end of 2006. Provisional measurements during 2007 show that the annual number of days with mean PM_{10} concentrations above 50 µg m^{-3} TEOM*1.3 continued to increase and have already exceed the Limit Value for the year. During late 2006 and 2007 the annual number of days with mean PM_{10} concentrations above 50 µg m^{-3} TEOM*1.3 also increased at Chichester Roadside and at the Tower Hamlets 1 and Eastbourne background sites, however the increases seen at these sites were far less than those measured at Hastings 1. A sharp rise in the annual number of days with mean PM_{10} concentrations above 50 µg m^{-3} TEOM*1.3 was measured at Lewes 1 from the start of 2007. At the time of writing the cause of the increase at Lewes 1 was being investigated by the local site operator but it is thought to be a local effect caused by construction works close to the monitoring site.

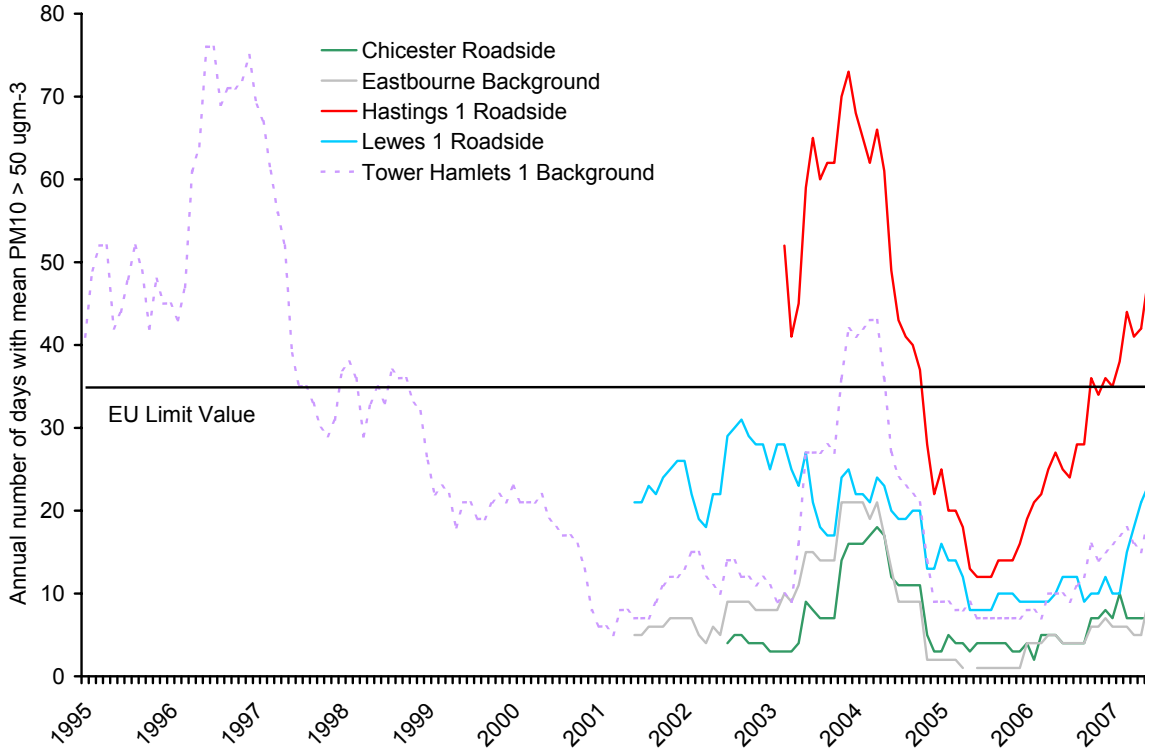

Figure 10 Annual number of days when PM_{10} concentrations exceeded 50 µg m^{-3} TEOM*1.3 at sites in Sussex. Measurements from the inner London urban background site Tower Hamlets 1 are shown to provide a longer term perspective.

Measured PM_{10} concentration by wind direction

The origins of air pollution affecting a monitoring site can be initially investigated by the use of pollution roses. These display the mean air pollution concentration from each wind direction. As discussed in section 5 wind direction measurements from Chichester were used to represent conditions at Hastings. Wind direction measurements from Chichester were grouped according to 10° sectors. A PM_{10} pollution rose for the Hastings 1 monitoring site for 2006 is shown in Figure 11.

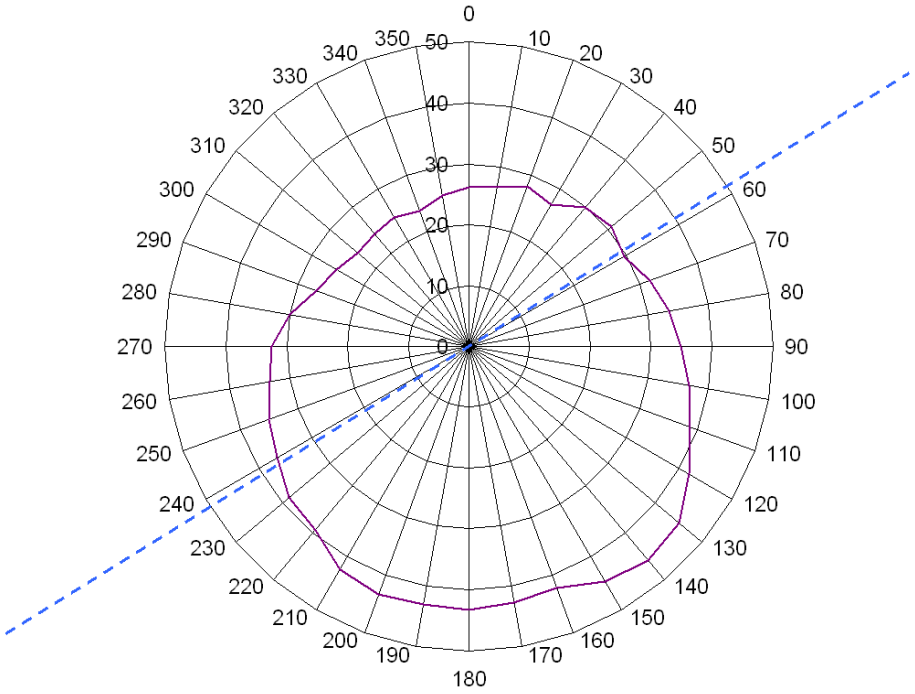

Figure 11 Mean PM_{10} concentration at Hastings 1 during 2006. PM_{10} concentrations were averaged in 10° wind sectors. Mean concentrations are shown in µg m^{-3} TEOM*1.3. The blue dotted line shows the approximate orientation of the A259 with respect to the monitoring site.

Figure 11 shows that the mean PM_{10} concentration by wind direction varied between 23 µg m^{-3} TEOM*1.3 from a wind direction of 340° to a maximum mean concentration of 46 µg m^{-3} TEOM*1.3 from a wind direction of 140°. Overall the greatest mean PM_{10} affected the monitoring site when wind arose from a direction perpendicular to the orientation of the A259, from the south side. The pollution rose in Figure 11 shows that the PM_{10} concentrations at the site were not affected by a nearby point source. However PM_{10} concentrations can arise from range of sources (APEG 1999) and it would be premature to conclude that the road was the main source of PM_{10} at this site on the basis of this analysis alone.

To begin to look at the locally derived PM_{10}, as distinct from background sources, it was useful to consider the difference in PM_{10} concentration between Hastings 1 and the nearby background site at Eastbourne as shown in Figure 12. The mean concentration of the locally derived PM_{10} shown in Figure 12 was least for wind directions from the north and also for wind directions from the east. The mean concentration of the locally derived PM_{10} was greatest for wind directions perpendicular to the A259 from the south side and also along the A259 from approximately a southwest direction.

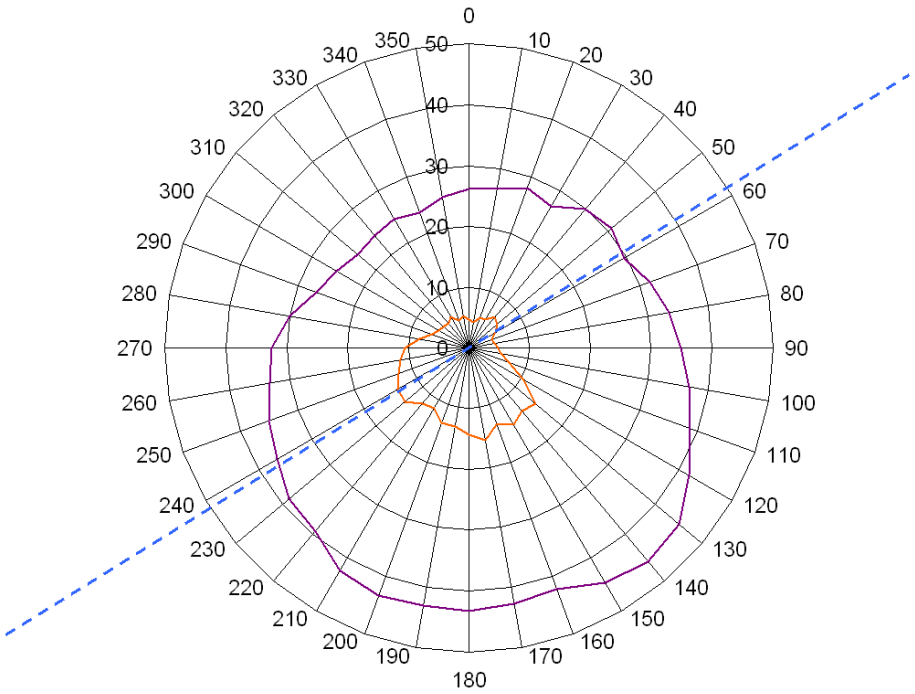

Figure 12 Mean PM_{10} concentration at Hastings 1 during 2006 (purple line) and the mean increment in PM_{10} concentration at Hastings 1 above the background site at Eastbourne is shown in orange. PM_{10} concentrations were averaged in 10° wind sectors. Mean concentrations are shown in µg m^{-3} TEOM*1.3. The blue dotted line shows the approximate orientation of the A259 with respect to the monitoring site.

It is possible extend pollution rose analysis by including wind speed as an additional factor. Such analysis was used very effectively by Carslaw et al (2006) to determine the impact of Heathrow Airport on local NO_X concentrations. The method of analysis used by Carslaw et al (2006) built upon analysis carried out by Yu et al (2004) around airports in the USA.

Bivariate polar plots can be used to illustrate and identify the relative contributions of surrounding pollution sources upon mean concentrations recorded at a point. Pollutant concentrations, at 15 minutes mean resolution, were separated into individual wind direction bins, in this case 10 degree bins. For example, all measurements made during wind directions between 0 and 10 degrees from north were separated, then 10 and 20 degrees etc. These subsets were then subdivided again according to wind speed, in this case 1 ms^{-1} bins. This produced a polar coordinate grid of mean concentrations for each wind direction and speed that were applied to a surface contour model to produce surface contour maps. The method also gave equal weighting to all wind speed / wind direction bins regardless of the number of measurements in each bin which ranged from total time periods of a few hours to several days.

Figure 13 shows the mean PM_{10} concentration at the Hastings 1 monitoring site during 2006. It can be seen from Figure 13 that the lowest mean concentrations at the monitoring site arose on northerly winds and the mean concentration from this direction reduced with higher wind speeds. The highest mean concentration measured at the site arose on winds from a broadly southerly direction and in these directions the mean PM_{10} concentration increased with increasing wind speed.

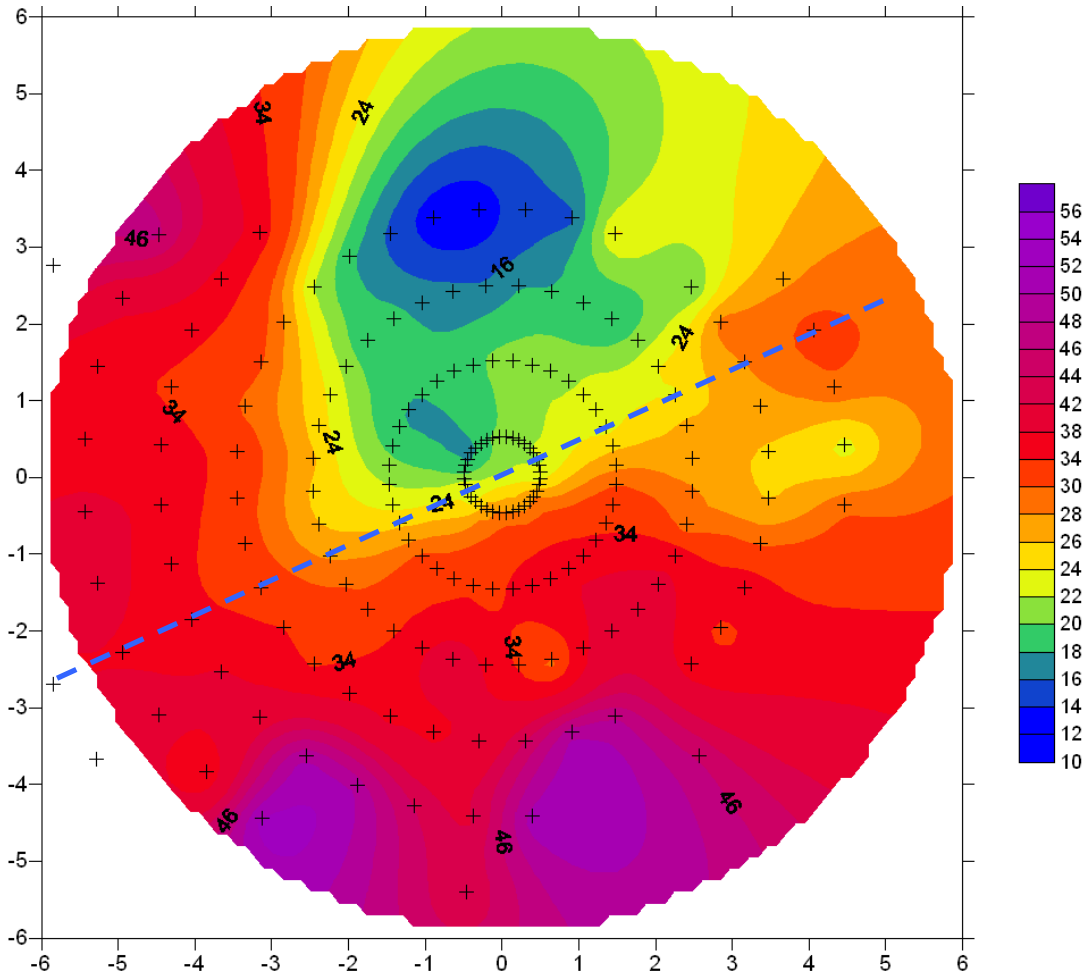

Figure 13 Bivariate polar plot of mean PM_{10} concentration (ugm^{-3} TEOM*1.0) at Hastings 1 during 2006 with respect to wind direction and wind speed (ms^{-1}). Crosses denote wind direction and speed bins for which measurements were available. The blue dotted line shows the approximate orientation of the A259 with respect to the monitoring site.

Figure 14 focuses specifically on the local sources of PM_{10} and shows the concentration difference between Hastings 1 and the Eastbourne background site with respect to wind direction and speed. Figure 14 shows that the local PM_{10} sources made little contribution to the total PM_{10} concentration at Hastings 1 for wind directions between approximately north and east. Comparing the mean concentrations shown in Figure 13 and Figure 14 it is evident that the majority of the overall PM_{10} concentration measured during high wind speeds from approximately southerly wind directions could be accounted for by PM_{10} that was also measured at Eastbourne. It is likely that a component of this local PM_{10} was sea salt. However, the local PM_{10} sources had the greatest concentrations on wind directions perpendicular to the road from the south. The local PM_{10} from this direction increased with increasing wind speed. It was also possible that the gap between housing on the south side of the A259, opposite the monitoring site, also affected the measured concentration. Figure 14 also shows a local PM_{10} source to the west and northwest associated with high wind speeds.

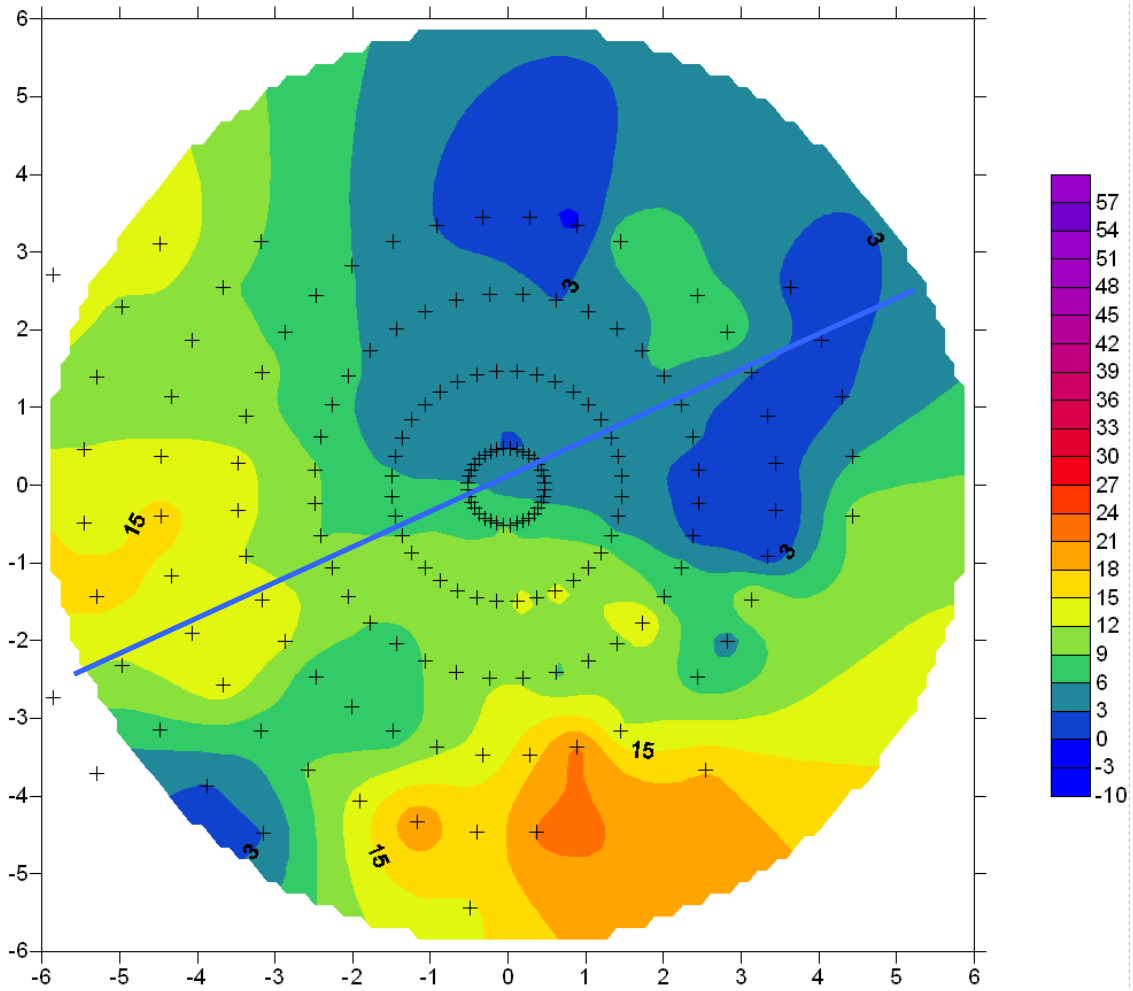

Figure 14 Bivariate polar plot of increment in mean PM_{10} concentration (ugm-3 TEOM*1.0) at Hastings 1 above Eastbourne during 2006 with respect to wind direction and wind speed (ms^{-1}). Crosses denote wind direction and speed bins for which measurements were available. The blue dotted line shows the approximate orientation of the A259 with respect to the monitoring site.

Comparison of measured and modelled concentrations

Measured and modelled annual mean PM_{10} concentrations at the Hastings 1 monitoring site are shown in Figure 15. Overall the model performed well. The measured annual mean concentrations at Hastings exceeded the modelled concentrations by 7 µg m^{-3} TEOM*1.3. The difference between the modelled and measured annual mean concentrations exceeded the uncertainty estimate of 2 µg m^{-3} TEOM*1.3 and could not therefore be explained by model artefacts.

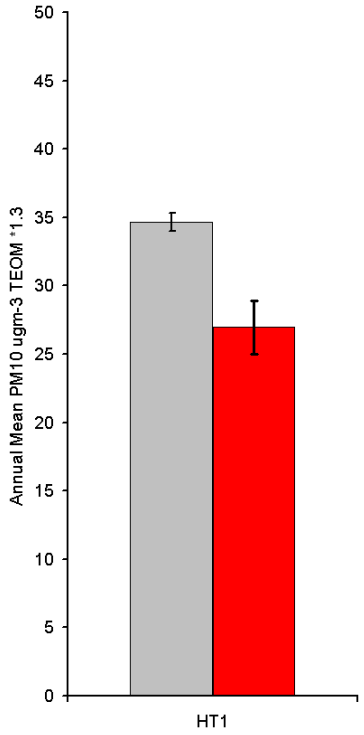

Figure 15 Measured and modelled 2006 annual mean PM_{10} concentrations at the Hastings monitoring site . Uncertainty estimates are shown at 2σ. Measured concentrations are shown grey and modelled concentrations are shown in red.

Source apportionment of mean PM_{10} concentration

Results of the source apportionment of the mean PM_{10} concentration at the Hastings 1 monitoring site are shown in Figure 16 and Table 3. PM_{10} from background and natural sources made the largest contribution to the mean concentration at the site. The local – other source made the second largest contribution to the mean concentration at the site; 7 (+/- 2, 2σ) µgm^{-3} TEOM *1.3 or 21 (+/- 6, 2σ) %.

All background sources accounted for 61 % and the TEOM offset accounted for a further 11% of the annual mean concentration. The vast majority of the 28% of PM_{10} arising locally was from the local – other source which exceeded the local primary by a factor of 3.

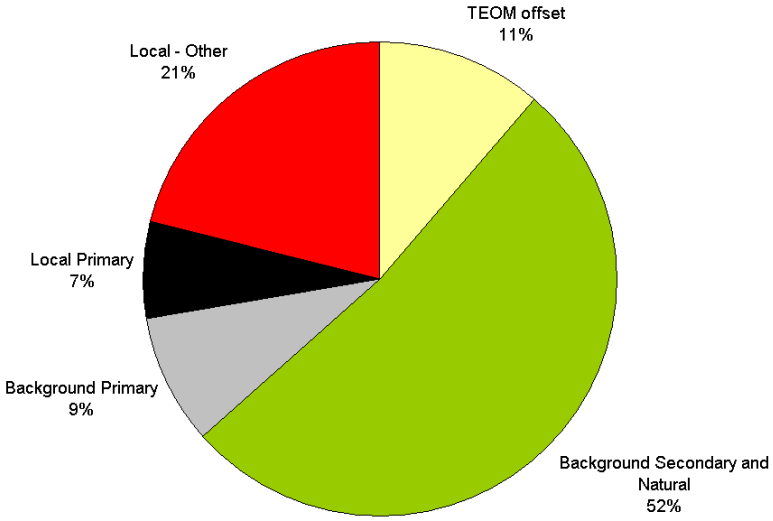

Figure 16 Source apportionment of mean PM_{10} concentration at the Hastings 1 monitoring site during 2006.

Source	Mean concentration μgm^{-3} TEOM *1.3 2006
TEOM offset	4
Background Secondary and Natural	18
Background Primary	3
Local Primary	2
Local - Other	7
Total	**34**

Table 3 Source apportionment of mean PM_{10} concentration at the Hastings monitoring site during 2006.

The ratios of NO_X : primary PM_{10} emissions from the London Atmospheric Emissions Inventory were examined to determine a worst case ratio as a sensitivity test. The worst case emitter was found to be a pre-Euro rigid HGV with a NO_X : primary PM_{10} ratio of 0.21 μgm^{-3} ppb^{-1} (including an estimate for non-exhaust emissions such as tyre and brake wear) which exceeded the ratio of 0.15 μgm^{-3} ppb^{-1} determined from the NO_X : primary PM_{10} concentration ratio at sites across London and southeast England. Use of the worst case ratio in the model reduced the local – other PM_{10} to 18% of the total measured mean concentration, a change of 1 μgm^{-3} TEOM *1.3, within the uncertainty estimate of 2 μgm^{-3} TEOM *1.3. Local primary PM_{10} increased to 10%, background primary increased to 13% and PM_{10} from background secondary and natural sources reduced to 48%.

Source apportionment of daily mean PM_{10} concentration

The daily mean time series of source apportioned PM_{10} concentration at the Hastings 1 monitoring site is shown in Figure 17. Source apportionment was undertaken on 253 days during 2006. Source apportionment was not possible on the remaining days due to the absence of NO_X and / or PM_{10} measurements at either or both the Hastings and Eastbourne monitoring sites. Source apportionment was also undertaken for 234 days during 2005.

It is evident from Figure 17 that the daily mean PM_{10} concentration measured at the site was not constant but varied from day to day. Three different types of pollution episode can be seen in Figure 17.

> A – the combination of background secondary and natural sources and primary sources caused the daily mean PM_{10} concentration to exceed 50 μgm^{-3} TEOM*1.3.
>
> B – the daily mean PM_{10} concentration exceeded 50 μgm^{-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.
>
> C – background secondary and natural sources alone caused the daily mean PM_{10} concentration to exceed 50 μgm^{-3} TEOM*1.3.

During the study period the maximum daily mean PM_{10} concentration measured at Hastings 1 was 93 μgm^{-3} TEOM*1.3. On those days where source apportionment was possible, the maximum daily mean PM_{10} concentration at Hastings 1 was 85 μgm^{-3} TEOM*1.3 during episode B.

Daily mean PM_{10} at the site exceeded 50 μgm^{-3} TEOM*1.3 on 44 (42 - 47, 2σ) of the 340 days in 2006 when PM_{10} measurements were available which equated to a full year estimate of 48 (45 - 50 2σ) days. The daily mean PM_{10} at the site exceeded 50 μgm^{-3} TEOM*1.3 on 32 of the 253 days in 2006 when PM_{10} source apportionment was possible available, equating to a full year estimate of 46 (42 - 48, 2σ) days, which closely matched the full year estimate derived from the full measured data set.

If the local other source was removed from the site, the daily mean PM_{10} concentrations was projected to have exceeded 50 μgm^{-3} TEOM*1.3 on just 7 days 7 (7 – 9, 2σ) days during 2006. If the local – other source was not present the site would have achieved the EU Limit Value / AQS Objective in 2006.

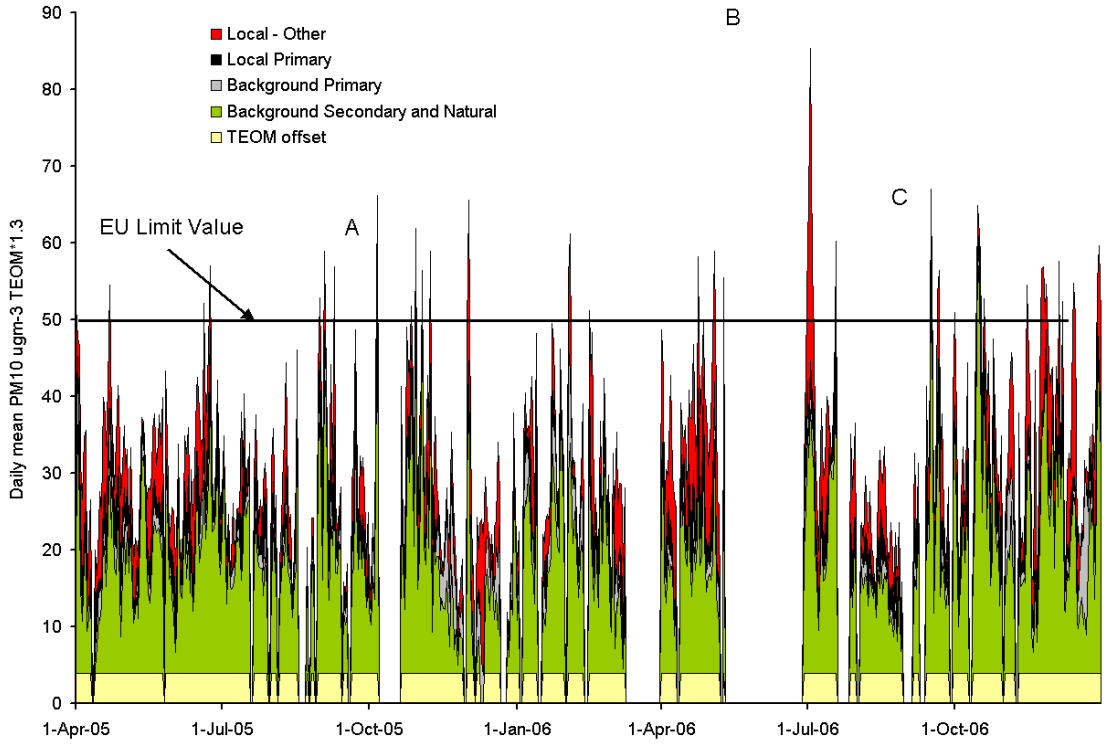

Figure 17 Time series of daily mean PM_{10} concentrations. Different types of pollution episodes are marked A to C and are discussed in the text.

Quantification and characterisation of the local – other PM_{10} was a key objective of the study. Figure 18 shows the daily mean concentration of the local – other PM_{10} with uncertainty shown at 2σ. The maximum daily mean concentration of local – other PM_{10} during the study period was 41 +/- 2 μgm^{-3} TEOM*1.3. The local – other PM_{10} alone did not exceed the EU Limit Value concentration. The source apportionment model produced negative concentrations for the local – other PM_{10} on 51 days during the study period. The negative concentration on 40 of these days was within the expected model uncertainty and these apparent negative concentrations were therefore not significant. On the remaining 11 days the negative concentration of the local – other PM_{10} was not accounted for within the uncertainty estimates which suggested either a negative basis in the predicted concentration of the local – other PM_{10}, an under estimation of the uncertainty associated with this component, or a combination of both. An underestimation of the uncertainty associated with the local – other PM_{10} may have arisen from an inability to account for the uncertainty in the geographical variation of the background PM_{10} due to the use of a single base site in the model as discussed in section 5.

Figure 19 shows the daily mean concentration of local primary PM_{10}. The mean concentration of PM_{10} from the local primary source is less than the local - other PM_{10}. On 52 days the mean concentration of primary PM_{10} was negative and several such days were not accounted for by the model uncertainty. On these days the mean concentration of NO_X at the background site in Eastbourne were greater than the NO_X concentration at the Hastings 1 roadside site. Greater concentrations at the Eastbourne background site when compared with the Hastings 1 roadside site were expected during primary pollution episodes during wintertime when elevated background concentrations can occur in build-up areas – the Eastbourne background site was surrounded by the busy urban centre of Eastbourne whereas the Hastings site was bounded by open land to the north. The difficulties that the uncertainty model experienced in the detection all of negative artefacts was due to the use of a single base site as discussed in section 5.

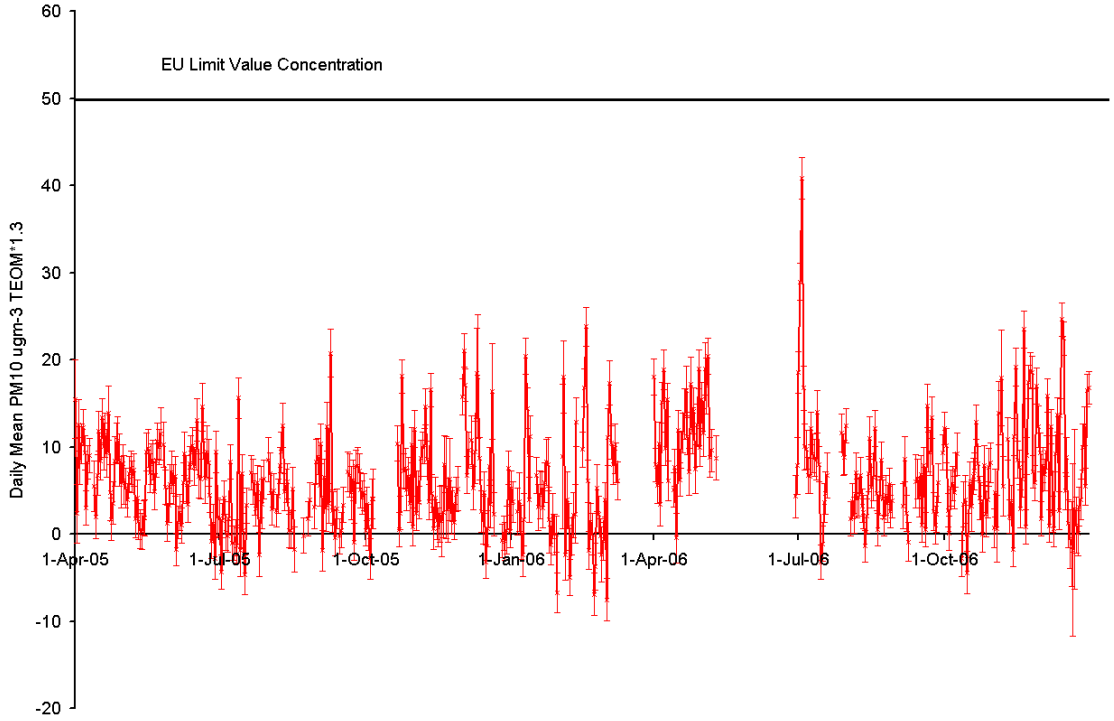

Figure 18 Time series of the modelled daily mean PM_{10} concentration from the local - other source. Uncertainty is shown at 2σ.

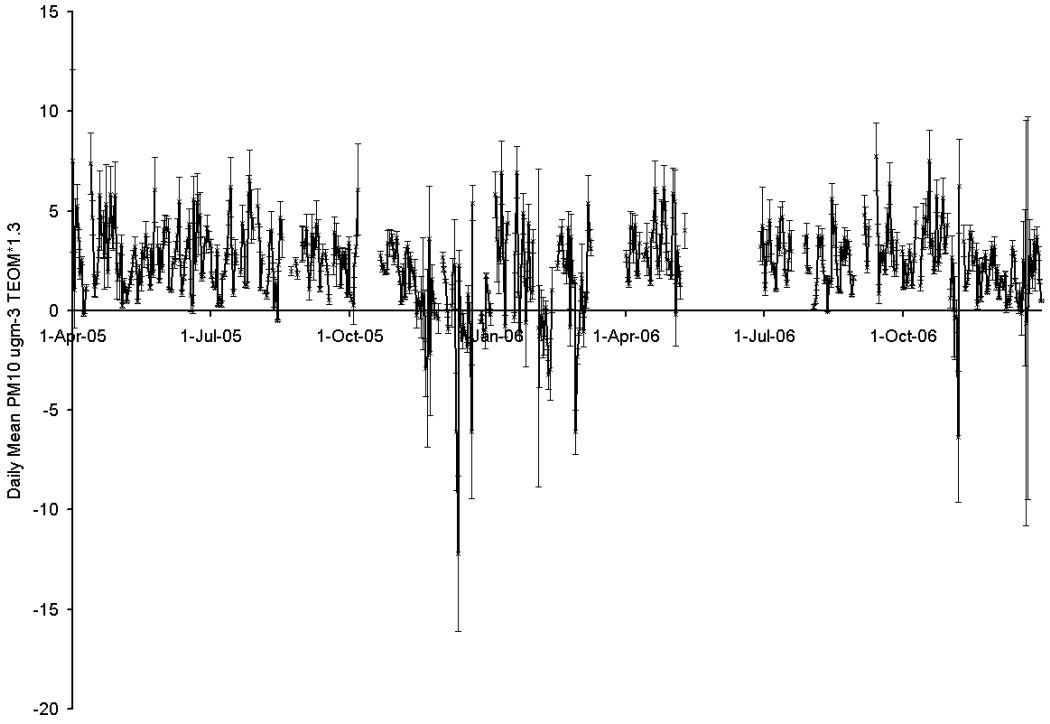

Figure 19 Time series of the modelled daily mean PM_{10} concentration from the local primary source. Uncertainty is shown at 2σ.

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 20 shows the source-apportioned concentration of PM_{10} at Hastings 1 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 can be seen between weekdays and weekends with the total mean concentration being greater on weekdays than on Saturday and Sunday. During the weekdays the maximum total mean PM_{10} concentration increased from Monday to Friday. From concentration minima around hour 2 to 3 GMT (hour 3 - 4 BST), mean PM_{10} concentrations rose rapidly during hours 3 and 4 GMT (hour 4 and 5 BST) each weekday morning. The timing of the peak concentration was always during normal working hours before concentrations fell rapidly each afternoon. A relative plateau in total mean PM_{10} concentration was evident between hour 8 and hour 15 GMT (hours 9 and hour 16 BST) on Saturdays albeit a lower concentration compared with that experienced on weekdays. The total mean PM_{10} on Sundays was similar to Saturday however a narrow peak in mean concentration was evident during hour 7 GMT (hour 8 BST), the cause of which was unclear.

The mean concentration of the local – other PM_{10}, averaged by day of week and hour of day is shown in Figure 21. The local – other PM_{10} was below the detection limit of the model overnight however the concentration rose rapidly during hours 4 to 7 GMT (5 or 8 BST) each day to peak during working hours.

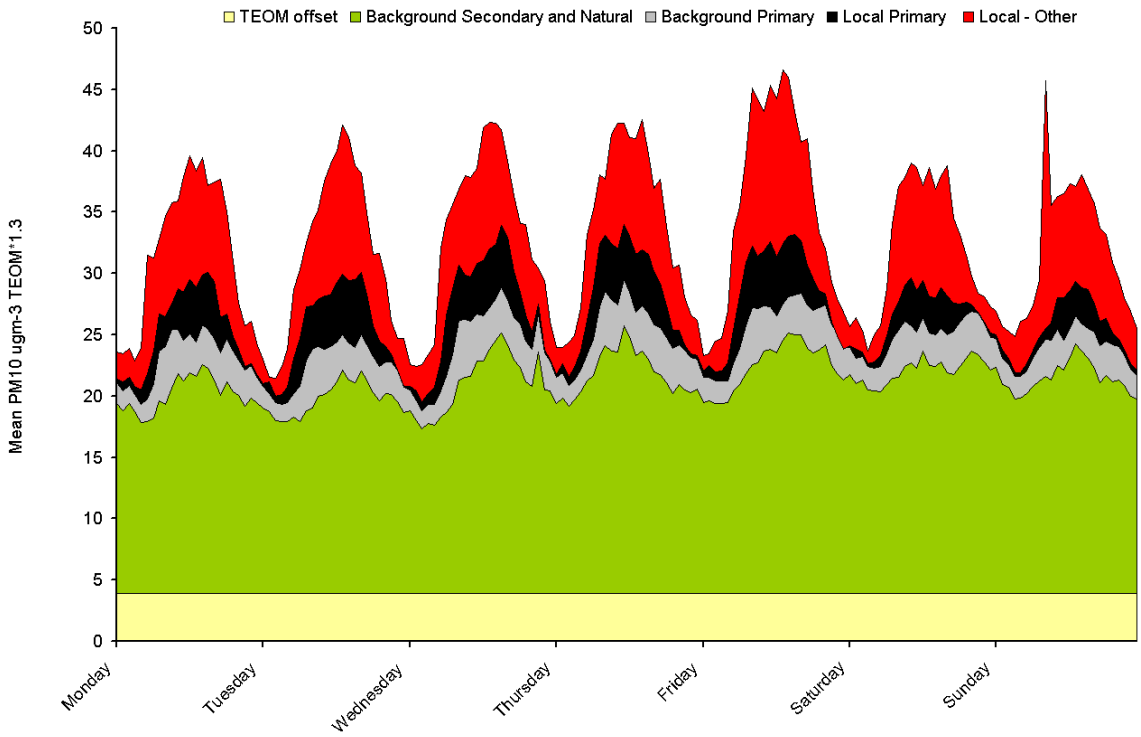

Figure 20 Source apportioned concentrations of PM_{10} at Hastings 1 averaged by day of week and hour of day. Times were based on GMT.

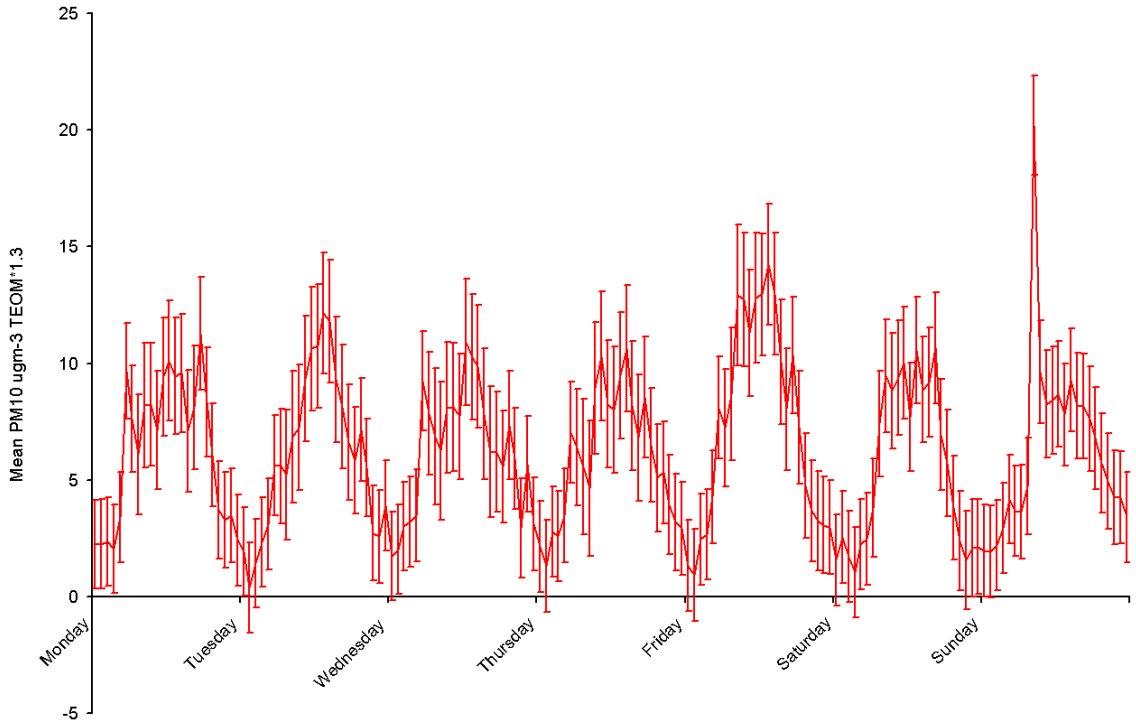

Figure 21 Concentrations of PM_{10} from local - other sources at Hastings 1 averaged by day of week and hour of day. Times are shown in GMT and uncertainty estimates are shown at 2 σ.

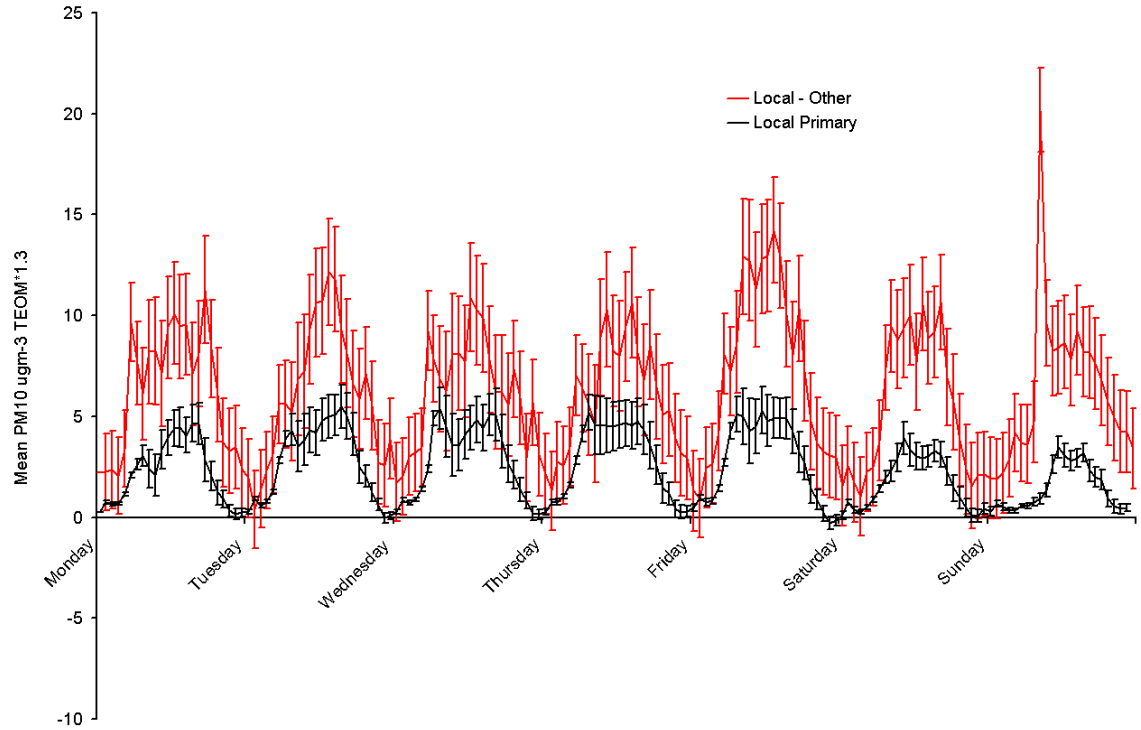

Figure 22 Concentrations of PM_{10} from local sources at Hastings 1 averaged by day of week and hour of day. Times are shown in GMT and uncertainty estimates are shown at 2 σ.

Figure 22 shows the mean concentration from the local – other and local primary sources. The mean concentration of local primary PM_{10} showed a clear diurnal pattern that was similar to that of the local – other PM_{10}. However, the local primary PM_{10} was greater on weekdays than weekends, a behaviour

that was not as evident in the local – other PM_{10}. The similar diurnal pattern suggested a link between these sources. The extent to which the local primary PM_{10} explained the variance in the local – other PM_{10} concentration is explored in Figure 23 which shows a scatter plot of the mean concentration of the two sources averaged by hour of day and day of week. Figure 23 suggests a relationship between the two PM_{10} sources. The correlation coefficient (r^2) of 0.58 suggested that 58% 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. Reduced major axis linear regression (see Ayres 2001) of local – other on local primary PM_{10} indicated a relationship with slope of 1.9 (+/- 0.2, 2σ) and an intercept of 1.7 (+/- 0.6, 2σ) μgm^{-3} TEOM*1.3 with r = 0.76.

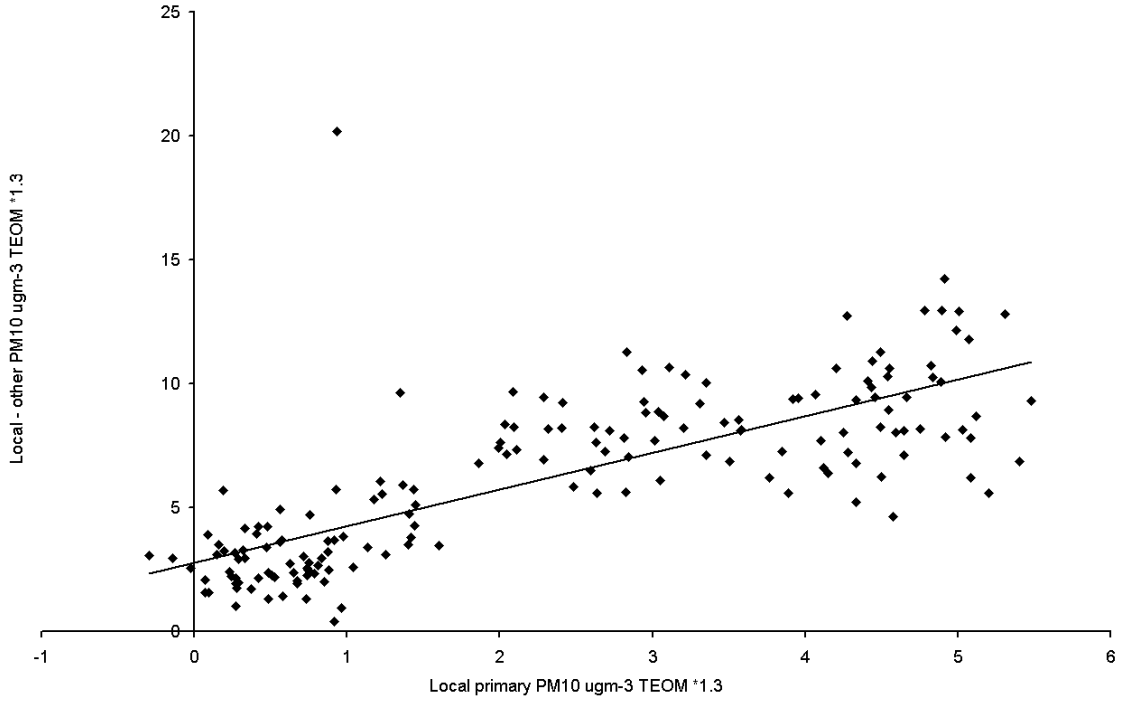

Figure 23 Scatter plot of local – other PM_{10} vs local primary PM_{10}. Both sources have been averaged by hour of day and day of week.

Mean source apportioned PM_{10} concentration by wind direction

Figure 24 shows the source apportioned mean concentration of PM_{10} at Hastings 1, averaged by wind direction. This analysis can provide important insight into the location of PM_{10} sources affecting a monitoring site in addition to the analysis of the total measured PM_{10} concentration. In addition to the source apportionment schemes used for daily mean concentration and mean concentration average by day of week and hour of day reported earlier, the background secondary and natural PM_{10} was further split to specifically identify a local sea salt contribution. The local sea salt PM_{10} was derived from the mean concentration difference between the secondary and background PM_{10} sources at Eastbourne and Sevenoaks. Measurements undertaken by KCL and the NPL on behalf of DEFRA have separately quantified the inland concentration of PM_{10} due to sea salt and it must be remembered that the sea salt contribution shown here was the local increment only.

The greatest overall mean concentration of PM_{10} arose during broadly southerly winds (120^o to 220^o). This increased mean concentration was caused by an elevation in the local – other, local primary and sea salt PM_{10} from these wind directions. The concentration of PM_{10} from background secondary and natural sources was elevated during easterly winds (with a peak concentration around 120^o). This was indicative of long range transport of PM_{10} from continental sources and was consistent the expected behaviour of secondary PM_{10} sources as highlighted by APEG (1999) and Smith (1997).

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.

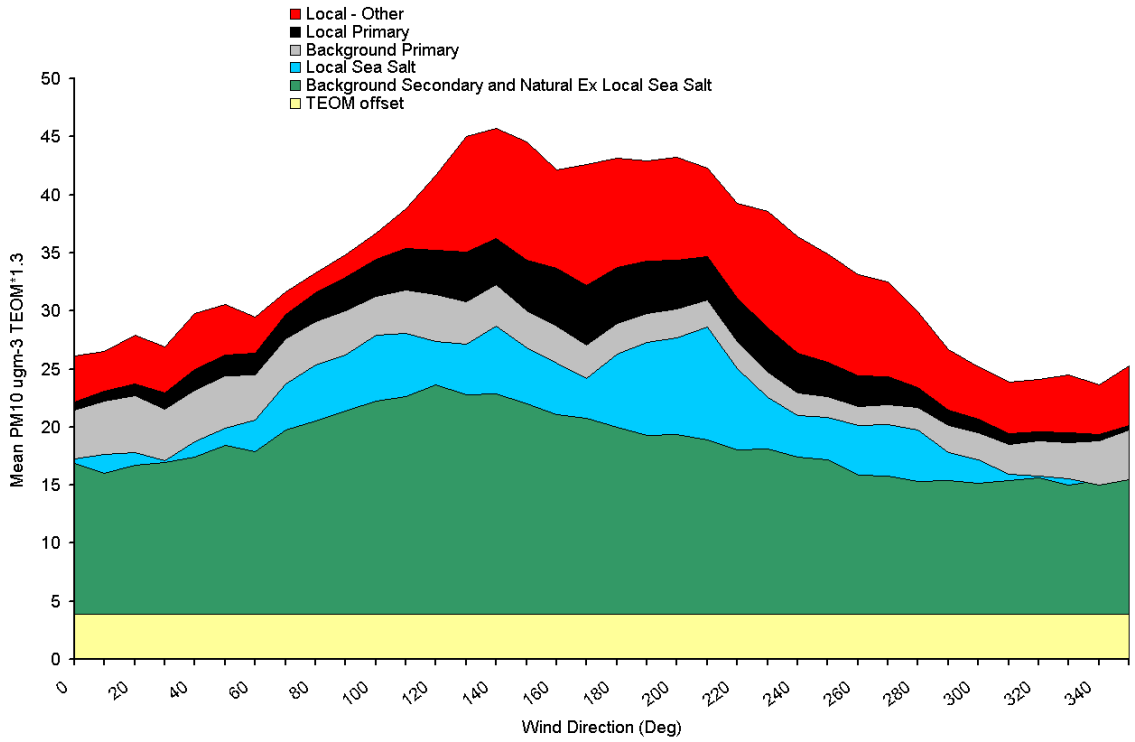

Figure 24 Source apportioned PM_{10} averaged by wind 10^{o} direction sectors.

Figure 25 shows the mean concentration of local – other PM_{10} sources averaged by 10^{o} wind sectors. The mean concentration of the local – other PM_{10} was greater than the uncertainty of the model for all wind directions winds apart from the 350^{o} sector and winds from sectors between 70^{o} and 100^{o}.

The local – other PM_{10} exhibited greatest mean concentrations when wind originated from directions between 120^{o} and 280^{o} with the maximum mean concentration being measured on wind directions perpendicular to the A259 from the south side and along the A259 from the west. It appeared that greater concentrations of local – other PM_{10} arose from the A259 to the west of the monitoring site when compared to the concentration from the A259 to the east of the site. Relatively low concentrations of local – other PM_{10} arose on wind directions from the north of the monitoring site.

Figure 26 shows both local primary and the local – other PM_{10}. 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 the A259 and other nearby roads. The mean concentration of local primary PM_{10} was clearly determined by the orientation of the A259 relative to the monitoring site. The greatest mean concentration of primary PM_{10} originated from wind directions perpendicular to the A259 from the south side with relatively little primary PM_{10} arising from the north side of the road. The mean concentration of primary PM_{10} did not exhibit the west – east bias shown by the local – other source.

Figure 27 shows the relative mean concentration of local PM_{10} that arose from each wind direction. The radial distribution of the local – other PM_{10} was close to that of the local primary PM_{10} however, the distribution of mean concentrations in Figure 27 emphasised the difference in the relative mean concentrations of the local sources arising from the A259 to the west and the east of the monitoring site; a higher mean concentration of local – other PM_{10} was measured from the west of the monitoring site when compared with that from the east.

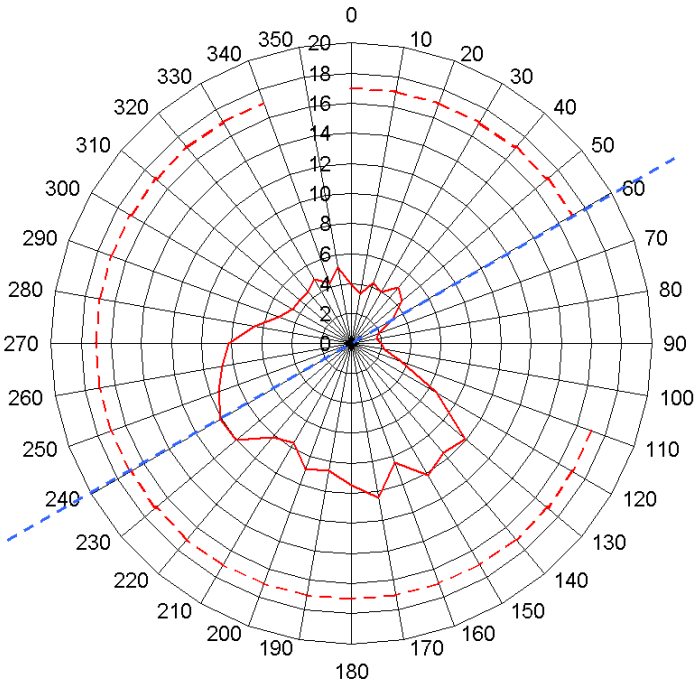

Figure 25 Source apportioned mean concentrations of local - other PM_{10} at Hastings 1 averaged by 10° wind sector. The blue dotted line denotes the approximate orientation of the A259 with respect to the monitoring site. The red dotted line shows the wind sectors where the modelled mean concentration of local – other PM_{10} exceeded the modelled uncertainty estimates. Mean concentrations are shown in μgm^{-3} TEOM*1.3.

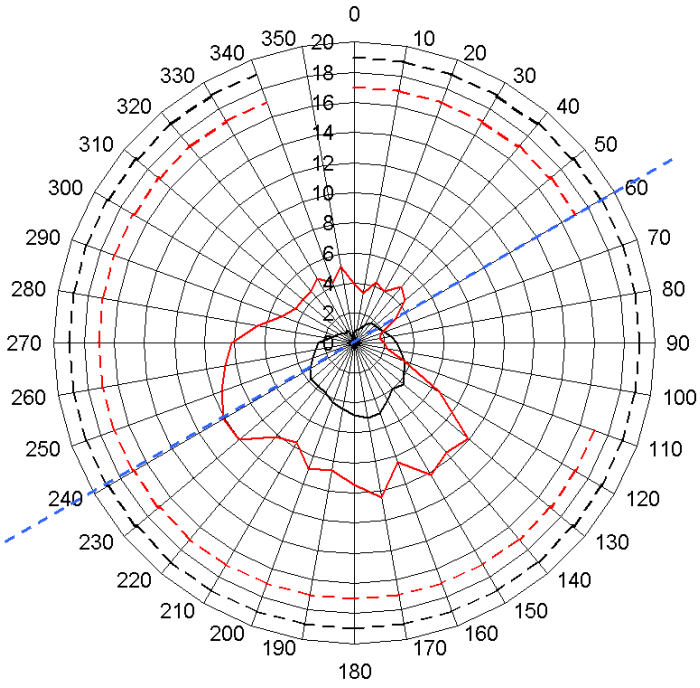

Figure 26 Source apportioned mean concentrations of PM_{10} from local sources at Hastings 1 averaged by 10° wind sector. The mean concentration of local – other PM_{10} is shown in red and local primary PM_{10} is shown in black. The blue dotted line denotes the approximate orientation of the A259 with 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 μgm^{-3} TEOM*1.3.

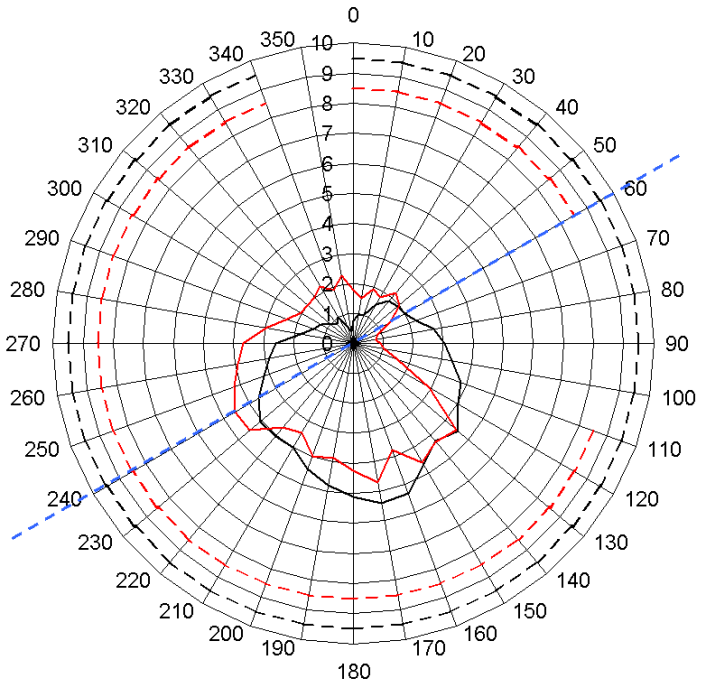

Figure 27 Source apportioned mean concentrations of PM_{10} from local sources at Hastings 1 (2006) averaged by 10° wind sector. Concentrations are expressed relative to the annual mean. Insignificant negative concentrations are not shown. The mean concentration of local – other PM_{10} is shown in red and local primary PM_{10} is shown in black. The blue dotted line denotes the approximate orientation of the A259 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.

Reduction of Local – Other PM_{10} Required to Meet the Air Quality Strategy Objective

The measured concentration of PM_{10} at the Hastings 1 monitoring site exceeded the daily mean EU Limit Value during 2006. Source apportionment of daily mean concentrations allows the assessment of PM_{10} reduction scenarios. Here the reduction in the concentration of the mean local – other PM_{10} required to achieve the daily mean AQS was determined.

Figure 28 shows the annual number of days with mean concentration of PM_{10} above 50 μgm^{-3} TEOM*1.3 for progressive reductions in the mean concentration of local – other PM_{10}, based on measurements made during 2006. Pro-rata allowance was made for days lost due to incomplete measurement data. It was clear from Figure 28 that the annual number of days with mean PM_{10} above 50 μgm^{-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 Hastings 1 needed to be reduced by around 20 % (15 – 25%, 2σ) for the site to have met the AQS Objective during 2006.

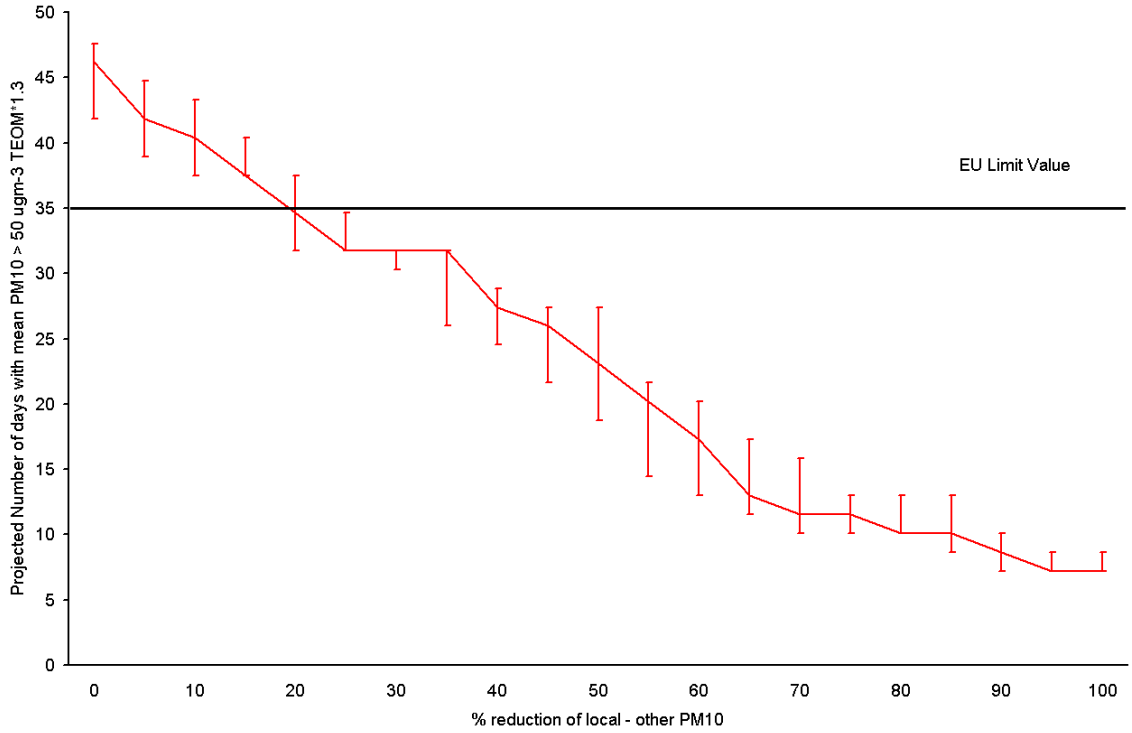

Figure 28 Reduction scenarios for the concentration of local - other PM_{10}, compared to the daily mean EU Limit Value. Analysis was based on 2006 measurements and pro-rata adjustment was made for measurement availability.

Comparison with PM_{10} Source Apportionment Studies Close to Waste Facilities

Further insight into the PM_{10} concentrations at Hastings 1 may be obtained from considering other studies of PM_{10} on haulage routes from waste facilities. Source apportionment studies at two sites close to the entrance to waste transfer sites (Brent 5 and Bexley 4) found concentrations of local – other PM_{10} of up to 33 (+/- 3, 2σ) μgm^{-3} TEOM*1.3. Lower concentrations of local – other PM_{10} were found at two other sites (Hammersmith & Fulham 3 and Sutton 5) that were several hundred metres from waste facilities. The Hastings 1 monitoring site was approximately 200m from the Hastings Municipal Services Depot on Bulverhythe Road and 1,100m from the entrance to Pebsham landfill and waste recycling sites. Each of these waste facilities lay to the west of the monitoring site along the A259.

Site	Distance from waste site along haul route	Mean local – other PM_{10} μgm^{-3} TEOM*1.3	Reference
Brent 5	~ 15m	33 (+/- 3, 2σ)	Fuller, Hedley and Baker 2007a
Bexley 4	< 30 m	$14^{(1)}$ – $31^{(2)}$	(1) Fuller and Baker 1999 (2) Fuller and Hedley 2006
H'smith & Fulham 3	450 m	6 (10 – 4, 2σ)	Fuller and Hedley 2006
Sutton 5	~ 800 m	8 (+/- 6, 2σ)	Fuller, Hedley and Baker 2007b

Table 4 Concentrations of local - other PM_{10} from previous studies of PM_{10} near waste facilities.

7. Conclusions

During 2006 the Hastings 1 monitoring site measured 44 days with mean PM_{10} concentration above 50 μgm^{-3} TEOM*1.3. This was a breach of the EU Limit Value and AQS Objective of 35 days.

Source apportionment of the measured PM_{10} concentration was required to understand the sources of PM_{10} at the site. A model was created to apportion measured concentrations of PM_{10} at Hastings 1 averaged as daily means, by day of week and hour of day and by wind direction. To judge model performance and to provide estimates of uncertainty associated with the model outputs, the ISO GUM approach was used to create an uncertainty model that was 'run' in parallel to the main model. The lack of background measurements of NO_X and PM_{10} in coastal areas of Sussex necessitated the use of a single background site in this study and did not therefore allow the inclusion of an uncertainty component arising from the spatial variation in the PM_{10} from background secondary and natural sources. It was therefore likely that uncertainty was underestimated.

The source apportionment model performed well, however it did not agree with measured concentrations at Hastings 1 indicating the presence of an additional source of PM_{10} that was not included in the model. This source was termed local – other PM_{10}. Source apportionment showed that 7 (+/- 2, 2σ) μgm^{-3} TEOM *1.3 or 21 (+/- 6, 2σ) % of the annual mean PM_{10} measured at the site came from local – other sources.

The mean concentration of PM_{10} at Hastings 1 showed considerable day-to-day fluctuation. During the study period the maximum daily mean PM_{10} concentration measured at Hastings 1 was 93 μgm^{-3} TEOM*1.3. On those days where source apportionment was possible, the maximum daily mean PM_{10} concentration at Hastings 1 was 85 μgm^{-3} TEOM*1.3. If the local – other PM_{10} source had not been present during 2006, the site would have experienced 7 (7 – 9, 2σ) days with mean PM_{10} above 50 μgm^{-3} TEOM*1.3 and therefore would have achieved the AQS Objective / EU Limit Value for the year.

When averaged by day of week and hour of day, the local – other PM_{10} showed a clear diurnal variation and peaked during working hours. The mean concentration of local primary PM_{10} also showed a clear diurnal pattern that was similar to that of the local – other PM_{10}. The similar diurnal pattern suggested a link between these sources and it was found that 58% of the averaged hour of day and day of week changes in the concentration in local – other PM_{10} may have been explained by the changes in the local primary PM_{10} concentration. Regression analysis suggested that the local – other PM_{10} had a component that was related to the primary PM_{10} and a further component that was independent of primary sources that had a mean concentration of 1.7 (+/- 0.6, 2σ) μgm^{-3} TEOM*1.3.

The local – other PM_{10} exhibited greatest concentrations when wind originated from directions between 120^o and 280^o with the maximum mean concentration being measured on wind directions perpendicular to the A259 from the south side of the road and along the A259 from the west. It appeared that greater concentrations of local – other PM_{10} arose from the A259 to the west of the monitoring site when compared to the concentration from the A259 to the east of the site, indicating that the construction of two houses to the east of the site was not an important PM_{10} source during the study period. Relatively low concentrations for local – other PM_{10} arose on wind directions from the north of the monitoring site.

Within the source apportionment scheme the local primary PM_{10} was related to the NO_X concentration measured at the site and therefore good agreement with this source and the orientation of the road would be expected. Given that the local primary PM_{10} was a marker of road traffic emissions the similarities in the behaviour local primary and local – other sources further 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. During the site visit, silt was observed on the A259 beside Hastings 1 monitoring site, near the Hastings Municipal Services Depot, Bulverhythe Road and on the access road to Pebsham landfill and waste recycling sites. The silt may have been carried from waste facilities onto the A259 by vehicles leaving these sites. All traffic on the A259

would have the potential to resuspend material deposited on the road which may account for concentrations of local – other PM_{10} outside the times when the waste facilities were open; Sundays for example. Analysis of local measured PM_{10} suggested that wind speed may also have been a factor in the resuspension of road silt, independent of traffic. This suggested that the mean local – other PM_{10} concentration of 7 (+/- 2, 2σ) μgm^{-3} TEOM *1.3 consisted of a traffic induced component of 5 (+/- 2, 2σ) μgm^{-3} TEOM *1.3 and a wind blown component of 1.7 (+/- 0.6, 2σ) μgm^{-3} TEOM *1.3.

The mean concentration of local – other PM_{10} of 7 (+/- 2, 2σ) μgm^{-3} TEOM *1.3 during 2006 was consistent with a previous study of PM_{10} at the Hastings 1 monitoring site (Fuller and Hedley 2004). Fuller and Hedley 2004 used slightly different methodology but also found that a source of local – other PM_{10} was present at the monitoring site and attributed this to atypical resuspension of road dust. The local – other PM_{10} had a mean concentration of 10 μgm^{-3} TEOM *1.3 during 2003 and declined to 6 μgm^{-3} TEOM *1.3 during 2004.

During 2003 the Hastings 1 site exceeded the EU Limit Value by a wide margin however the annual number of days with mean PM_{10} above 50 $\mu g\ m^{-3}$ TEOM*1.3 reduced during 2004 and the site achieved the Limit Value during 2004 and 2005. The annual number of days with mean concentrations above 50 $\mu g\ m^{-3}$ increased steadily during 2005 and 2006 to breach the EU Limit Value once again by the end of 2006. Clearly the investigation of these changes in the local – other PM_{10} concentration at Hastings 1 is key to the management of pollution concentrations at this site and on nearby sections of the A259.

The concentration of local – other PM_{10} at Hastings 1 (7 (+/- 2, 2σ) μgm^{-3} TEOM*1.3) was consistent with the monitoring site being several hundred metres from a waste facility; the monitoring site was approximately 200m from the Hastings Municipal Services Depot on Bulverhythe Road and 1,100m from the entrance to the Pebsham landfill and waste recycling sites. Each of these waste facilities lay to the west of the monitoring site however visual evidence from the site visit suggested that the contribution of the Hastings Municipal Services Depot to the silt load on the A259 was minor when compared with that from the Pebsham landfill and waste recycling sites The greater concentrations of local – other PM_{10} from A259 to the west of the monitoring site when compared with A259 to the east of the monitoring site may have been indicative of a emission gradient for local – other PM_{10} along the A259; greater emissions arising from the road to the west of the monitoring site which was closer to the waste facilities. Evidence for an emission gradient for local – other PM_{10} along the A259 was also found by Fuller and Hedley (2004). It is therefore very likely that higher concentrations of PM_{10} were present further west along the A259.

There was no evidence of PM_{10} emissions from the Pebsham landfill itself affecting the measured PM_{10} concentration at the monitoring site.

8. Recommendations

It is recommended that:

- The findings of this report should be incorporated into the Council's Air Quality Action Plan.
- The Council should work together with the Environment Agency and operators of the Pebsham landfill and waste recycling sites and Hastings Municipal Services Depot to reduce the silt deposited on the A259 and adjacent roads.
    - A key objective is determine what changes took place at these waste facilities during the last 4 years to determine why the Hastings 1 monitoring site achieved the AQS Objective and EU Limit Value during 2004 and 2005 but failed to achieve the objective during 2003 and 2006.
    - Further analysis of measured PM_{10} concentrations at the Hastings 1 monitoring site should be undertaken in an attempt to determine the time of any significant changes in the measured PM_{10} concentrations. CUSUM techniques may be employed by for this analysis.
- 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 apparent seasonality exhibited in other studies (e.g. Fuller et al 2007a) may confound this assessment in the short – term. This source apportionment study should be repeated annually to quantify changes in local – other PM_{10}.
- To inform future modelling exercises traffic counts should be undertaken on the access road to the Pebsham waste facility, on Bulverhythe Road and on the A259.
- Future source apportionment studies should include analysis of measurements from the Rother 2 monitoring site on the A259.

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