Appendix J

Heathrow Airport Air Quality Modelling for 2008/9: Results and Model Evaluation. Report by AEA Energy & Environment on behalf of BAA, July 2010. AEAT/ENV/R/2948/Issue 1

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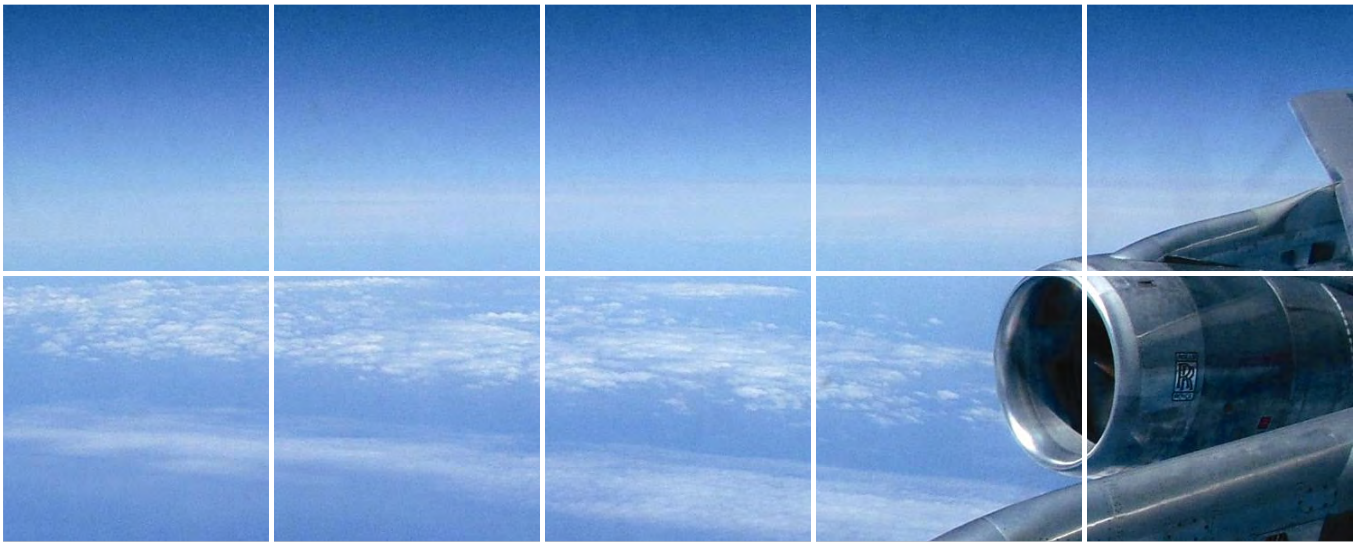

Heathrow Airport Air Quality Modelling for 2008/9: Results and Model Evaluation

Report to BAA

AEAT/ENV/R/2948/Issue 1
July 2010

Title	Heathrow Airport Air Quality Modelling for 2008/9: Results and Model Evaluation
Customer	BAA Ltd
Customer reference	PO3594787
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File reference	EPEO/ED45973
Reference number	AEAT/ENV/R/2948/Issue 1

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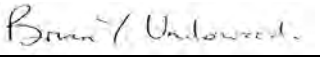
	Signature	
	Date	29th July 2010

Executive Summary

E.1 In 2009, BAA commissioned AEA to carry out an air quality study for Heathrow with three components:

(a) to compile an inventory of atmospheric emissions arising from airport operations for the 12-month period from 1st April 2008 to 31st March 2009, including the pollutants NO_x (oxides of nitrogen), PM_{10} (particulate matter with an aerodynamic diameter less than 10 microns) and $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5 microns);
(b) to carry out a dispersion-modelling study to quantify the contributions from airport sources and from road-vehicle emissions on the major road network around Heathrow to airborne concentrations in residential areas close to the airport; to combine these contributions with the estimated contribution from all other sources to give a view of total airborne concentrations around Heathrow in 2008/9;
(c) to evaluate the performance of the model using monitoring data collected around Heathrow in 2008/9.

E.2 This report presents the results of the model evaluation, then goes on to provide best estimates of the 2008/9 spatial distribution of concentrations of the designated pollutants around Heathrow. Separate reports are available on the compilation of the airport emission inventory and on the methodology used for the dispersion-modelling study.

E.3 The air quality around Heathrow is of continuing concern. The annual mean NO_2 concentration in some residential areas near the airport is close to or above the national objective, which should have been met by 2005. Thus, there is a vital interest in understanding how much airport operations contribute to pollutant concentrations in the vicinity of the airport. Although monitoring provides spot checks on the situation at specific locations, modelling is required to give a fuller appreciation of the spatial variation in airborne concentrations. It is also needed to allow the relative contributions to the concentration at key locations from various sources on the airport to be identified and to provide a basis for forecasting the air quality impact of operational changes on the airport.

E.4 This work updates the air quality modelling carried out to provide the evidence base for the last government's consultation on 'Adding Capacity at Heathrow', which followed the recommendations of the expert panels set up under the Project for the Sustainable Development of Heathrow (PSDH). The air quality work underpinning the consultation (referred to below as the PSDH work) was based on an airport emission inventory for 2002.

E.5 The PSDH work included an evaluation of the performance of the model, comparing modelled values for 2002 with measured values obtained for the same period from monitoring stations around the airport. This showed that annual-mean NO_x and NO_2 concentrations across the set of nine monitoring sites included in the comparisons were predicted with no significant average bias. Compilation of the 2008/9 emissions inventory and the associated dispersion modelling study have been carried out using a methodology very similar to that used for the PSDH work, so the conclusions drawn from the PSDH study are still relevant.

E.6 However, there are a few differences in the methodology for the 2008/9 study compared to that used for the PSDH work, including differences in the calculation of the contribution from sources beyond the airport and near-Heathrow major road network and a different approach to deriving NO_2 concentrations from NO_x concentrations. Moreover, the aircraft fleet operating at the airport and the distribution of engine technologies in the traffic on the roads around Heathrow are constantly evolving, and it is important to check that the modelling continues to give an unbiased view of concentrations around the airport as the relative contributions from various sources change. In addition, a number of monitoring sites around the airport have come into operation since 2002, including Sipson*, Harmondsworth,

* These are the short names of monitoring sites, introduced for convenience in the discussion – fulll site details are given in Section 2 of the report

Harlington, Oxford Avenue, Hatton Cross and Hayes. Except for Hayes, the sites are expected to have a significant airport contribution to annual-mean NO_x concentrations, and thus provide the opportunity for a more detailed test of the modelling of airport sources than possible with 2002 data.

E.7 Given the current situation around Heathrow in relation to national objectives and limits for NO_2, the evaluation places particular emphasis on this pollutant. However, NO_2 concentrations are derived from NO_x concentrations, so separate evaluations are made of the modelling for NO_x concentrations and the methodology for deriving NO_2 concentrations from NO_x concentrations. Evaluation of the modelling methodology for PM_{10} and $PM_{2.5}$ is limited by the characteristics of the available monitoring data.

E.8 The focus of attention in this study is to assess how well the model predicts concentrations in residential areas around the airport, in particular at locations strongly influenced by sources related directly to the operation of the airport. This includes receptors that are appreciably influenced by emissions arising within the airport perimeter itself but also receptors influenced strongly by road traffic emissions, where the traffic itself has a major airport-related component. Thus, concentrations are calculated within a 9 km square area, centred on the airport, with not only total concentrations presented in the area but also the separate contributions from key source categories. The area is very similar to that used in the PSDH work, which aids comparisons between the two studies. The 2008/9 model evaluation has been based on comparisons with continuous data obtained at 12 monitoring sites within the area, all having continuous NO_x/NO_2 analysers, 10 having continuous PM_{10} analysers and 3 with continuous $PM_{2.5}$ analysers.

E.9 A number of the data sets used have a data capture (fraction of hours in the 2008/9 period with valid data) less than 90% - usually taken as a lower limit when using data to test compliance with annual mean objectives - but nevertheless situated in important locations from a model evaluation perspective. For model evaluation purposes, however, the data-capture constraint can be loosened, given that the results of the dispersion modelling are available on an hourly basis. Thus, for model-monitoring comparisons at a particular site, the model results have been based on those hours of met data for which valid concentration measurements are available.

E.10 The results and conclusions of the study are summarised by pollutant below.

NO_x

E.11 Total period-mean NO_x concentrations are predicted with an average fractional discrepancy, defined as *(modelled value-measured value)/measured value*, of -5.2% (i.e. the model under-predicts on average by 5.2% across the sites), with a standard deviation of 12.2% (12 sites), where the latter is a measure of the site-to-site variability in the measured values that has not been captured by the model. Assuming the measurement uncertainty (one standard deviation) for long-period average NO_2 concentrations from continuous analysers to be around 5%, the observed bias is highly unlikely to be explained by statistical measurement fluctuations for a finite sample of 12 sites. Similarly, a large fraction of the unexplained site-to-site variability is unlikely to be attributable to measurement uncertainties. Thus, the model is slightly biased towards under-prediction of total period-mean NO_x concentrations.

E.12 The three sites with the largest contribution from emissions on the road network have significant negative values of the fractional discrepancy, suggesting that there is a systematic underestimation of this contribution, which is offset by an overestimation of other contributions across the sites leading to a quite small average fractional discrepancy.

Airport Sources

E.13 A comparison of measured and modelled NO_x concentration differences between sites north of the airport and Oaks Rd (south of the airport) for selected wind directions indicates that the model has no significant tendency either to overestimate or to underestimate the

contribution of airport sources* to the period-mean NO_x concentrations at receptors in the residential areas north of the airport, to the level of accuracy allowed by measurement uncertainties. In particular, it represents well the variation in the airport concentration contribution with distance from the principal sources on the airport and the variation with east-west location in relation to the ends of the northern runway.

E.14 This gives confidence that the model provides a good basis for investigating the potential impact on residential areas of operational changes on the airport that affect the magnitude and spatial distribution of NO_x emissions, for example the abandonment of the Cranford agreement (which would then allow departures on runway 09L) and the construction of a third runway north of the current runways. It also indicates that the model tendency to underestimate total period-mean NO_x concentrations is unlikely to arise from the modelling of airport sources.

E.15 A breakdown of the concentration differences across the airport by wind speed indicates a tendency for the model to overestimate at low wind speed and underestimate at high wind speed. Thus the remarkable level of agreement (for sites north of the airport) between modelled and measured values of the airport contribution to period-mean NO_x concentration is partly fortuitous, arising from a compensation between the two tendencies, and may not be maintained to the same extent if the met data in a given year exhibited a markedly different wind speed distribution to that in 2008/9. Nevertheless, given that the agreement is reasonably good in every wind-speed range, it would require a major shift in wind-speed frequency distribution to generate a significant discrepancy. The observed trend with wind speed could point to inaccuracies in the plume-rise modelling for aircraft sources, but the evidence from comparisons involving little influence from aircraft sources indicates that this cannot be the full explanation.

E.16 At Oaks Rd, close to the southern boundary of the airport, concentration-difference comparisons indicate that the modelling overestimates the contribution from airport sources by around 3 $\mu g/m^3$ (for a total airport contribution of 17 $\mu g/m^3$). The apparent greater overestimation of the airport contribution at Oaks Rd than at sites north of the airport may derive partly from the tendency noted above for the model to overestimate at low wind speeds, which has a greater effect south of the airport due to the greater probability of low wind speeds for northerly winds than for southerly winds. Nevertheless, the discrepancy at Oaks Rd is only of comparable size to the judged uncertainty in measured differences in period-mean concentrations.

E.17 Given the evidence that the modelling is a reliable basis for predicting the spatial variation of the contribution from airport sources to period-mean NO_x concentrations around the airport, contours of this contribution have been derived from model results on a spatial grid of receptor points. These indicate that NO_x contributions from airport sources above 30 $\mu g/m^3$ in 2008/9 were confined to areas within the airport boundary, with the contribution in the nearest residential areas in the range 10-20 $\mu g/m^3$. The modelled contribution from airport sources falls to at most 6.3 $\mu g/m^3$ at the M4 motorway, but varies in an east-west direction along the motorway as a result of the contour shape, which is governed by the prevalence of south-westerly winds coupled with the spatial distribution of sources on the airport. Contour shapes show some differences from those calculated for 2002 in the PSDH work, partly as a result of the opening of T5 and partly due to a greater frequency of westerly winds in 2008/9 than in 2002.

E.18 A detailed comparison of the 2008/9 modelled values of the airport contribution at 13 representative sites with corresponding values from the PSDH work shows that the 2008/9 values are broadly comparable to those for the PSDH 2002 and 2010SM cases, which is in line with the magnitude of the estimated airport emissions for the three cases. There are some detailed differences from the PSDH results not related to emission differences that principally reflect differences in the wind rose between 2008/9 and 2002.

* Defined to include all sources within the airport perimeter plus elevated (LTO) aircraft sources, although the latter make a small contribution to ground-level concentrations once they are above a few hundred metres in height.

Road Network Sources

E.19 Comparison of concentration differences for pairs of sites with one of the sites (Hillingdon, LHR2, Hayes, Oxford Avenue) strongly affected by a nearby road indicates that the modelling underestimates the contribution to period-mean NO_x concentrations from emissions on the major road network around Heathrow; this reinforces the evidence provided by an examination of the discrepancies in total period-mean concentrations. The extent of the underestimation is significantly greater than can be attributed solely to measurement errors.

E.20 It would be premature to view this as evidence for a systematic under-prediction of road vehicle NO_x emissions using the current emissions methodology, given that the basic traffic data used in the emissions quantification have not been fully evaluated. There is evidence that modelled total traffic flow on the M4 motorway adjacent to the Hillingdon site is well represented by the traffic model, but there is no information on how realistic are the predictions of Heavy Duty Vehicles (bus/coach and Heavy Goods Vehicle) fraction and vehicle speed, parameters that are particularly important from an emissions perspective. For the M25, it appears that, in addition, total flows are underestimated.

E.21 There is some evidence from the concentration-difference comparisons that a key contributor to the discrepancies at near-road receptors relates to network intersections or other areas of flow disturbance, which lead to traffic queues, flow breakdown or changes in speed. It is possible to account for queues in the emissions methodology if they are explicitly recognised in the traffic data, but in the set of data available for the 2008/9 inventory any link delays were absorbed into effective link speeds, thereby not allowing the spatial distribution of queuing emissions to be represented. It is recommended that this deficiency is removed in future traffic data sets generated for air quality assessment purposes. With reference to speed data, it may not be enough to provide hourly-averaged speed if this speed is the net effect of periods of smooth flow interspersed with periods of flow breakdown.

E.22 There appears to be an additional discrepancy between modelling and measurements at Green Gates, not attributable to airport sources and not readily explained in terms of under-prediction of the contribution from the major road network around Heathrow. This may point to a local source not included in the modelling, although measurement uncertainties for concentration differences may also have played a part. Although large point sources have been modelled individually, it cannot be ruled out that the 1-km spatial resolution of emissions from medium-sized point sources in the LAEI may be having an influence on the accuracy of modelled concentrations close to Green Gates.

E.23 There are also additional discrepancies in NO_x concentrations at Hayes that cannot be explained in terms of under-prediction of the road network contribution. Hayes has a particularly large contribution from area sources representing emissions from the London Atmospheric Emissions Inventory (LAEI) and the National Atmospheric Emissions Inventory (NAEI), including a substantial contribution from the Great Western railway line. However, there is not enough information to determine if the discrepancy arises from sources local to the site or is more widespread in Hayes.

E.24 The observed discrepancies point to the need for a more detailed evaluation of traffic model outputs and how these are used to calculate emissions. It may be advantageous to defer that work until a traffic model is available that has been calibrated and validated with particular reference to those traffic characteristics that are key to the quantification of road traffic emissions and to the estimation of the road-network contribution to airborne pollutant concentrations.

E.25 In the interim, in order to generate a 'best-estimate' modelled NO_x concentration field around the airport, the road-network NO_x contribution was scaled everywhere by a constant factor (1.21), chosen so that the average discrepancy between modelled and measured period-mean NO_x concentrations across the 12 monitoring sites is reduced to zero. This simple procedure has the merit of increasing the concentrations more in absolute terms in areas where the road network makes a large contribution, reflecting the evidence from the monitoring data, but is unlikely to remove all the discrepancy relating to the road network at

sites such as Hayes and LHR2 (although at least some of the discrepancy at these sites may be due to features specific to the site and not necessarily generalisable to other receptors). Also, the scaled NO_x concentration field may still underestimate concentrations at near-road receptors that are strongly influenced by traffic queuing at junctions or are situated close to areas of the network subject to other types of flow disruption.

E.26 Although the average discrepancy across the sites has been reduced to zero, it is likely that there is a residual tendency towards overestimation at receptors immediately south of the airport because of an over-prediction of the contribution from airport sources in northerly winds. Similarly, for receptors to the (north) west of the airport there may be a systematic residual underestimation because of the under-prediction of the contribution from the M25.

E.27 The contour plot of period-mean NO_x concentration based on the set of 2008/9 results that include the road-network scaling factor is much closer in appearance to the equivalent plot for the PSDH 2002 case than for the PSDH 2010SM case. However, the NO_x 75 $\mu g/m^3$ contour in the 2008/9 results (approximately equivalent to the NO_2 40 $\mu g/m^3$ contour) does not extend as far from the airport boundary into Harlington as in the 2002 results; also, a smaller area of Hayes between the railway line and the M4 is above the 75 $\mu g/m^3$ level.

E.28 A more detailed comparison of results for 13 representative sites shows that the average total NO_x concentration from the 2008/9 study is much closer to the equivalent PSDH average for 2002 case than for the forecast 2010SM case, with the average 3.8% lower than for the 2002 PSDH case and 29.3% higher than for the 2010SM case.

NO_2

E.29 The availability of ozone measurements at three of the monitoring sites included in the analysis allows a separate test of the component of the methodology for deriving NO_2 concentrations from NO_x concentrations that predicts the total oxidant (sum of O_3 and NO_2) concentration from the background oxidant and the local NO_x concentrations. The modelled values agreed with measured values within the level of accuracy of the measurements, with an average fractional discrepancy between modelled and measured values of 6% (overestimation).

E.30 A comparison of modelled and measured period-mean NO_2 concentrations at the 13 monitoring sites included in the study – using the modelled NO_2 concentrations derived from NO_x concentrations that include the road-network scaling factor – gives an average fractional discrepancy of 1.6% (i.e. the model overestimates by on average 1.6%), with a standard deviation of 9.7%. For comparison, using NO_x concentrations that do not include the road-network scaling factor, the average fractional discrepancy in period-mean NO_2 concentrations is -1.8% (i.e. an underestimation of 1.8%), with a standard deviation of 9.7%. Neither of the two values of average fractional discrepancy can be interpreted as a significant model bias.

E.31 The performance of the Jenkin approach for deriving period-mean NO_2 concentrations from period-mean NO_x concentrations can be separated from the performance of the modelling for NO_x concentrations to some extent (though not fully) by comparing NO_2/NO_x ratios. Using the NO_x results that include the road-network scaling, the average fractional discrepancy in the NO_2/NO_x ratios is 2.1% (i.e. the model on average overestimates the ratio by 2.1%) with a standard deviation of 5.5%. For comparison, without the road-network scaling factor, the average fractional discrepancy is 4.1% with a standard deviation of 6.0%. This level of agreement is within what is expected from the semi-empirical (Jenkin) methodology used for this study, judging from the scatter on the data points used to derive the underlying $[NO_2]/[OX]$ relationship. Thus, the results indicate that the Jenkin methodology does not introduce any significant bias into the model results, so that once the bias in NO_x concentrations has been removed no further model adjustment is necessary.

E.32 The NO_2 concentration results on a grid of receptors have been used to generate contours of period-mean NO_2 concentration in 2008/9. Areas of exceedence of the annual-mean limit (40 $\mu g/m^3$) extend out into residential areas from the airport boundary, from the motorways and

from the Great Western railway line, in accord with the areas of highest emission density. The grid results may not have the spatial resolution to determine if individual receptors close to the contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis. It should be borne in mind that the NO_2 contours presented should be viewed as 'interim' on the grounds that they have been derived from NO_x values based on the interim traffic model results, adjusted using the simple road-network scaling factor.

E.33 Comparing the 2008/9 NO_2 contour plot with the equivalent 2002 PSDH plot shows that the exceedence areas extend further out from the motorway and railway line into residential areas in 2008/9, despite the NO_x concentrations in 2008/9 being on average similar to or slightly lower than in the 2002 PSDH results at a given location, implying that the NO_2/NO_x ratios are higher in 2008/9. On the other hand, the exceedence area in 2008/9 does not extend as far north into Harlington from the airport boundary as in the 2002 PSDH case, reflecting the lower modelled NO_x concentrations in this area in 2008/9. The increase in NO_2/NO_x ratios can be traced primarily to the higher average primary NO_2 fraction* in 2008/9 compared to that in the 2002 analysis, principally resulting from the higher fractions now associated with road-traffic NO_x emissions.

E.34 Examining the changes from the PSDH results in more detail at 13 representative receptors shows that the average modelled NO_2 concentration across these sites for 2008/9 is 4.7% higher than for the 2002 PSDH case, whereas the average NO_x concentration is 3.8% lower. Thus, the modelled NO_2/NO_x ratios for 2008/9 are on average 7.9% higher than for the 2002 PSDH case, whereas they are lower than for the PSDH 2010SM case by on average 11.6%.

PM_{10}

E.35 Based on the data from the ten continuous PM_{10} analysers in the study area, the average fractional discrepancy between modelled to measured total period-mean PM_{10} concentration is -0.4 %, with a standard deviation of 17.5%. The measured value at Harmondsworth is an outlier, suggesting either an instrumental problem or the influence of a local source not included in the modelling. It is worth noting that the instrument at Harmondsworth is a BAM (Beta Attenuation Monitor), whereas the instruments at the other sites (except Hayes) are of the TEOM (Tapered Element Oscillating Micro-balance) type.

E.36 Excluding Harmondsworth, the average fractional discrepancy is 4.3% (i.e. the model overestimates by 4.3% on average), with a standard deviation of 9.5%. The average fractional discrepancy both with and without Harmondsworth is lower than the accuracy of the measurement technique, so the comparison is able to demonstrate only that any model bias for total period-mean concentrations is less than the uncertainty in the measurements.

E.37 The modelled contribution from the designated road network and airport sources is on average only 2.3 $\mu g/m^3$ (maximum 5.2 $\mu g/m^3$, at LHR2) compared to a modelled background contribution of 17.2 $\mu g/m^3$, so the model-monitoring comparisons of total period-mean concentration mainly assess the background contribution. Furthermore, the smallness of the modelled contribution from airport and road-network sources highlights the difficulty of evaluating the performance of the modelling for these sources even using difference analysis, given that the expected differences are only comparable to 'natural' variation in the background (i.e. site-to-site variations in the background that are not captured by the modelling) and less than measurement uncertainties.

Airport Sources

E.38 Comparison of modelled and measured PM_{10} concentration differences between LHR2 and Oaks Rd and between Harlington and Oaks Rd indicates that the underestimation or overestimation of the contribution from airport sources to period-mean PM_{10} concentrations, if any, is less than estimated measurement uncertainties.

* The fraction of NO_x that is released in the form of NO_2 (prior to the further generation of NO_2 by gas-phase reactions)

E.39 For LHR2, the model appears to overestimate the contribution from emissions on the runway (principally from brake and tyre wear), which could result from inaccuracies in the spatial distribution of the emissions rather than in the magnitude of the total emissions. At Harlington, there is good agreement between the modelled and measured concentration difference in a wind direction range giving a dominant contribution from airport sources. However, the absolute differences are less than 1 $\mu g/m^3$, which is less than the estimated measurement uncertainties.

E.40 The measured PM_{10} concentration difference between Green Gates and Oaks Rd for wind directions giving an an airport contribution at Green Gates is negative whereas the modelled difference is positive, although small in magnitude in both cases. This emphasises the difficulty in interpreting such small concentration differences.

E.41 Thus, there is no significant evidence that the contribution from airport sources is either overestimated or underestimated within the limits set by measurement uncertainties. Based on the model results, the contribution from airport sources to total period-mean PM_{10} concentration in 2008/9 was between 0.1 and 1.0 $\mu g/m^3$ in the residential areas just north of the airport (out of a total of around 20 $\mu g/m^3$), reaching around 2 $\mu g/m^3$ at the airport perimeter.

E.42 Comparing the 2008/9 model results for the contribution from airport sources (to period-mean PM_{10} concentrations) with equivalent results from the PSDH for the 2002 and 2010SM cases shows that at a given location the contributions are broadly comparable, as expected from the magnitude of airport emissions for the three cases. The principal differences in the 2008/9 results can be related to differences in meteorology.

Road-Network Sources

E.43 The three sites with the largest modelled road-network contribution to period-mean PM_{10} concentration are LHR2, Oxford Avenue and Hayes. None of these sites is close to a motorway. Comparison of modelled and measured concentration differences for LHR2-Harlington shows a missing modelled contribution to period-mean PM_{10} concentrations at LHR2 deriving from a narrow range of north-easterly wind directions, similar to that found for NO_x at LHR2. In the NO_x case, the peak was judged most likely to arise from traffic perturbations at the junction of the Northern Perimeter Road with Neptune Rd, and this is judged also the most likely origin of the peak for PM_{10}. The total contribution to the period-mean concentration represented by the missing peak, however, is less than 1 $\mu g/m^3$.

E.44 The comparisons chosen to highlight the road-network contribution suggest that it may be under-predicted (with a compensating over-prediction of the background or LAEI/NAEI contributions). However, the evidence is not strong, given the small magnitude of concentration differences compared to measurement uncertainties and the potential for un-modelled site-to-site variability in the background contribution. In addition, there is a question of how generalisable are the results for these three sites to the network as a whole, particularly to near-motorway receptors, given that the fidelity of the traffic data close to the sites has not been evaluated. Furthermore, discrepancies at LHR2 and Hayes may relate to localised flow perturbations at junctions. Thus, the information provided by the PM_{10} evaluation is an inadequate basis for making a whole-network adjustment to modelled concentrations, so no adjustment factors have been applied to the model results on the grid of receptors used for generating contour plots. However, the potential for model underestimation close to junctions and to other regions of flow disturbance should be noted.

E.45 Contour plots based on the modelling results show that off-airport values above the 40 $\mu g/m^3$ limit value for annual mean PM_{10} concentration within the study area in 2008/9 were confined to areas within the road margins of the M4 and other major roads and within about 30 m of the centre of the M25 (with concentration values east of the M25 road centre higher than those west). Off-airport values above the surrogate annual mean value of 31.5 $\mu g/m^3$, used to test the limit on 24-hour mean concentrations, were principally confined to areas within about 30 m from the centre of the M4 and about 50 m from the centre of the M25, although also extended 10-20 m from the centre of a few non-motorway road links. These areas

should be taken as indicative of areas vulnerable to exceedence of the relevant limit, but the grid results may not have the spatial resolution to determine if individual receptors close to the relevant contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis.

E.46 The data used in the evaluation for PM_{10} does not provide a good test of the model at distances of a few tens of metres from a major motorway, so the predicted areas of exceedence close to the margins of the M4 and M25 should be treated with caution. There is some tentative evidence that the modelled 2008/9 PM_{10} concentrations close to the margins of these motorways are overestimates.

E.47 A comparison of the 2008/9 values for total PM_{10} concentration with equivalent values for the PSDH 2002 and 2010SM cases, using 13 representative receptor locations, shows that the 2008/9 values are on average closer to the PSDH results for the 2010SM case than to the results for the 2002 PSDH case, principally reflecting the fall in the background contribution since 2002.

$PM_{2.5}$

E.48 There were only three $PM_{2.5}$ monitoring sites operating in the study area in 2008/9 (Oaks Rd, Green Gates and Harmondsworth). In the modelling, the background component is the dominant contributor (9.6 $\mu g/m^3$) at these sites, with the airport and road network sources together contributing at most 1.2 $\mu g/m^3$.

E.49 The agreement between measured and modelled values is within the expected measurement uncertainty for Oaks Rd and Green Gates but there is significant over-prediction at Harmondsworth, by 41% (3.4 $\mu g/m^3$)[*]. The average fractional discrepancy between modelled and measured values is 17% and the average absolute discrepancy is 1.5 $\mu g/m^3$.

E.50 Even leaving aside measurement uncertainties, the comparison between modelled and measured total period-mean $PM_{2.5}$ values is unable to provide any detailed information on the performance of the modelling for airport and road network sources, given that their combined contribution is smaller than the uncertainty in the modelled contribution from all other sources (principally the background contribution).

E.51 Similarly, comparisons of $PM_{2.5}$ concentration differences are unable to provide any detailed information on the contribution from airport and road network sources, given that the modelled differences are smaller than the site-to-site variability in the contribution from other sources that is not captured by the model (and smaller than expected measurement uncertainties on concentration differences). The different measurement technique used at Harmondsworth further complicates the interpretation of differences involving that site. Thus, no source-specific model evaluation is possible for $PM_{2.5}$, and the comparisons of total period-mean concentrations are able only to confirm that the predicted total concentrations are within the range expected based on the monitoring data and its uncertainties.

E.52 Contour plots of total period-mean $PM_{2.5}$ concentration indicate that, according to the modelling, the values above 25 $\mu g/m^3$ limit/objective (coming into force in 2020/2015 respectively) were confined largely to areas within about 30 m of the M25. The caveats placed earlier on modelled PM_{10} concentrations at such close proximity to the M4 and M25 motorways apply to $PM_{2.5}$ also.

[*] It is worth noting that the instrument at Harmondsworth is of the light-scattering type, whereas the other two sites have TEOM instruments

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Tables and Figures

Abbreviations

ADMS	Atmospheric Dispersion Modelling System
AEA	A business name of AEA Technology plc
APU	Auxiliary Power Unit
AQEG	Air Quality Expert Group
AQMA	Air Quality Management Area
AQS	Air Quality Strategy for England, Scotland, Wales and Northern Ireland
AQSR	Air Quality Standards Regulations
ATWP	Air Transport White Paper
AURN	Automatic Urban and Rural Network
BAM	Beta Attenuation Monitor
CERC	Cambridge Environmental Research Consultants
CTA	Central Terminal Area
DC	Data Capture
EU	European Union
FDMS	Filter Dynamic Measurement System
HGV	Heavy Goods Vehicle
IQR	Inter-Quartile Ratio
LAQN	London Air Quality Network
LDV	Light Duty Vehicle
LHR	London Heathrow Airport
LTO	Landing and Take-Off
NAEI	National Atmospheric Emission Inventory
NO_x	Nitrogen Oxides ($NO+NO_2$)
NPR	Northern Perimeter Road
OS	Ordnance Survey
OSIRIS	Optical Scattering Instantaneous Respirable Dust Indication System
OX	Oxidant (sum of O_3 and NO_2)
PCM	Pollution Climate Mapping
PM_{10}	Particulate Matter with aerodynamic diameter less than 10μm*
$PM_{2.5}$	Particulate Matter with aerodynamic diameter less than 2.5μm
PSDH	Project for the Sustainable Development of Heathrow
QA/QC	Quality Assurance/Quality Control
SD	Standard Deviation
SM	Segregated Mode
T5	Terminal 5
TEOM	Tapering Element Oscillating Microbalance
(US)EPA	(US) Environmental Protection Agency
VCM	Volatile Correction Model

* To be precise, particles that pass through the selective size inlet of a specified measuring instrument with 50% efficiency at 10μm (2.5 μm for $PM_{2.5}$) aerodynamic diameter, where the 'aerodynamic diameter' of a particle is the diameter of a spherical particle of unit relative density that would have the same gravitational settling velocity as the particle of interest.

1 Introduction

Background

1.1 London Heathrow Airport (Heathrow) is the world's busiest international airport, serving around 65 million passengers in 2008, and is a key component of the UK's transport infrastructure. The airport lies close to residential areas, however, and the off-site air quality impacts of its operations are kept under review by both the airport operator, BAA, and by the local authorities in the administrative areas surrounding the airport. This review process draws on measurements made at a number of automatic monitoring sites around the airport, and also includes the periodic updating of an airport emission inventory accompanied by a dispersion modelling study. These aim to inform airport stakeholders of the evolving contribution of the airport to local airborne pollutant concentrations.

1.2 In 2009, BAA commissioned AEA to carry out an air quality study for Heathrow with three components:

(a) to compile an inventory of atmospheric emissions arising from airport operations for the 12-month period from 1st April 2008 to 31st March 2009, including the pollutants NO_x (oxides of nitrogen), PM_{10} (particulate matter with an aerodynamic diameter less than 10 microns) and $PM_{2.5}$ (particulate matter with an aerodynamic diameter less than 2.5 microns);
(b) to carry out a dispersion-modelling study to quantify the contributions from airport sources and from road-vehicle emissions on the major road network around Heathrow to airborne concentrations in residential areas close to the airport; to combine these contributions with the estimated contribution from all other sources to give a view of total airborne concentrations around Heathrow in 2008/9;
(c) to evaluate the performance of the model using monitoring data collected around Heathrow in 2008/9.

1.3 This report presents the results of the model evaluation, then goes on to provide best estimates of the 2008/9 spatial distribution of concentrations of the designated pollutants around Heathrow. Separate reports are available covering the compilation of the airport emission inventory[1] and the methodology used for the dispersion-modelling study (including the estimation of the contribution from sources not included explicitly via dispersion modelling)[2]. The former will be referred to as 'the 2008/9 inventory report' and the latter as the '2008/9 modelling methodology report'.

1.4 The Heathrow inventory feeds into the London Atmospheric Emission Inventory (LAEI)[3] and the National Atmospheric Emission Inventory (NAEI)[4] via the normal updating cycle for these inventories, although there may be a delay due to a phasing mismatch*. The inventory and modelling study also provide information to the local authorities in administrative areas around Heathrow to assist them in discharging their responsibilities under Part IV of the Environment Act 1995, whereby they are required to review periodically the concentrations of designated pollutants within their areas against air quality objectives set at the national level in the Air Quality Strategy for England, Scotland, Wales and Northern Ireland (AQS)[5]. Where it is expected that an objective cannot be met by the required date, the local authority is required to declare an Air Quality Management Area (AQMA) and to bring forward an Air Quality Action Plan to reduce concentrations, to the extent that the sources responsible for the failure to meet objectives are within its control.

1.5 The air quality around Heathrow is of continuing concern. The annual mean NO_2 concentration in some residential areas near the airport is close to or above the AQS objective (40 µg/m^3), which should have been met by 2005. The air quality modelling work underpinning the government consultation 'Adding Capacity at Heathrow' forecast that there would be exceedences of the EU limit value (40 µg/m^3) in 2010 (the date when compliance with the limit becomes mandatory). Although there are forecast to be widespread exceedences of the limit value in London in 2010[6] – for which the government is likely to

* The 2008/9 Heathrow inventory was not finished in time to be included in the 2008 version of the London Atmospheric Emissions Inventory.

seek a time extension from the European Commission – the Mayor's draft air quality[6] strategy notes that the limit has been met consistently since 1999 at non-roadside monitoring locations in outer London, except around Heathrow airport. The boroughs around Heathrow* have all declared an AQMA for NO_2.

1.6 Similarly, in its *'Future of Air Transport'* White Paper (ATWP)[7] the last government's support of a third runway at Heathrow was provisional on it being confident that the air quality limits (as well as a noise condition) could be met, which led to the setting up of the Project for the Sustainable Development of Heathrow to examine the technical basis for developing the required confidence. After consulting on the evidence base relating to the environmental conditions[8], the (then) Secretary of State announced his support for a third runway[9], again emphasising in the decision document the need to meet air quality limits. In the responses to the consultation[10], a majority did not believe that the air quality criterion could be met if a third runway was built.

1.7 In light of the above, there is a vital interest in understanding how much airport operations contribute to pollutant concentrations in the vicinity of the airport. Although monitoring provides spot checks on the situation at specific locations, modelling is required to give a fuller appreciation of the spatial variation in airborne concentrations. It is also needed to identify the relative contributions from various sources on the airport to the concentration at key locations and to provide a basis for forecasting the air quality impact of operational changes on the airport.

1.8 Prior to the current programme of work, the last published Heathrow inventory based on actual airport activity data was for the calendar year 2002. An inventory for that year was first compiled in 2004[11] in the context of the periodic updating process noted above. The long gap between that inventory and the 2008/9 inventory can be traced partly to the decision to await the final recommendations of the Project for the Sustainable Development of Heathrow (PSDH)[12] before the next inventory update. However, as part of the air quality work underpinning the government consultation on 'Adding Capacity at Heathrow', the 2002 inventory was revised[13] using a methodology that implemented the PSDH recommendations. Air quality modelling was then carried out by Cambridge Environmental Research Consultants (CERC) using this 2002 inventory and a number of forecast airport inventories. The results of this modelling provided the evidence base relating to the air quality test for Heathrow expansion set by the ATWP, which was a key component of the 'Adding Capacity at Heathrow' consultation. As a shorthand in the remainder of this report, the air quality work underpinning the consultation will be referred to as the 'PSDH work'.

1.9 The PSDH work included an evaluation of the performance of the model by CERC, comparing modelled values for 2002 with measured values obtained for the same period from monitoring stations around the airport[14]. This established that the model gave a good estimate (within 10%) of the airport contribution to total NO_x concentrations at the monitoring site close to the northern runway (LHR2) and a good account of how this contribution changes as the distance from from the centre of gravity of airport sources increases. It also showed that annual-mean NO_x and NO_2 concentrations across the set of 9 monitoring sites were predicted with no significant average bias, and allowed quantification of the site-to-site variability in concentrations not accounted for by the model. The 2008/9 emissions inventory was compiled using a methodology very similar to that used for the 2002 inventory, and the 2008/9 dispersion modelling used the ADMS-Airport[15] code, developed by CERC for the PSDH work and licensed to AEA for use in the 2008/9 work. Thus, the modelling methodology for the 2008/9 work has, to an extent, been already evaluated.

1.10 However, there are a few differences in the methodology for the 2008/9 study compared to that used for the PSDH work, including differences in the calculation of the contribution from sources beyond the airport and near-Heathrow major road network and a different approach to deriving NO_2 concentrations from NO_x concentrations. Besides, the aircraft fleet operating at the airport and the distribution of engine technologies in the traffic on the roads around Heathrow are constantly evolving, and it is important to check that the modelling continues to give an unbiased view of concentrations around the airport as the relative contributions from

* London Borough of Harlington, London Borough of Hounslow, Spelthorne Borough Council, Slough Borough Council

various sources change.

1.11 In addition, a number of monitoring sites around the airport have come into operation since 2002, including Sipson*, Harmondsworth, Harlington, Oxford Avenue, Hatton Cross and Hayes. Except for Hayes, the sites are expected to have a significant airport contribution to annual-mean NO_x concentrations, and thus provide the opportunity for a more detailed test of the modelling of airport sources than possible with 2002 data.

1.12 Finally, it is anticipated that the 2008/9 inventory and modelling will form the baseline for an investigation of the response of concentrations around the airport to potential operational changes on the airport, and it is common practice to 'verify' the model using current data before moving on to forecast potential future changes.

Scope

1.13 As noted above, ambient air quality in the UK is managed by reference to the Air Quality Strategy (AQS) for England, Scotland, Wales and Northern Ireland[5], which sets objectives for airborne concentrations of specified pollutants†, together with target dates for their achievement. In addition, air quality limit values and associated introduction dates set by EU Directives have been taken into English law‡ through the Air Quality Standards Regulations[16](AQSR). Although there is considerable overlap between the AQS and AQSR, there are some differences in detail, particularly in relation to dates of applicability.

1.14 Of the key pollutants of interest from a human health standpoint, this study focuses on NO_2, PM_{10} and $PM_{2.5}$. The justification for this choice is given in the 2008/9 inventory report and will not be repeated here. In view of the current situation around Heathrow in relation to the annual mean NO_2 objective and limit value, the evaluation places particular emphasis on this pollutant. However, given that NO_2 concentrations are derived from NO_x concentrations, there is separate, detailed evaluation of the modelling for NO_x concentrations and the methodology for deriving NO_2 concentrations from NO_x concentrations. The objectives and limit values for the pollutants of interest are shown in Table 1.1.

1.15 The 2008/9 modelling methodology report defines a 'study area' 9 km square, centred on the airport (shown in Fig 2.1), within which detailed concentrations are predicted. The choice of this area is explained in the latter report and will not be repeated here. The model evaluation is carried out using monitoring data obtained at sites operating continuous analysers within this area, as explained in Section 2. Comparisons with NO_2 diffusion-tube measurements in the area is not included within the scope of the current study.

1.16 It is not sufficient in the model evaluation to show that total concentrations are predicted with reasonable accuracy at the set of monitoring sites. A large contribution to total concentration within the study area derives from sources outside the area, including sources a long way from it, which generate a concentration field only slowly varying across the study area. Thus systematic errors in modelling the contribution from local sources could be compensated by an error in the longer-range component, with such a compensation not necessarily persisting into the future as the balance between sources changes. For this reason, it is important to be able to isolate – or at least enhance – the contribution from particular local source groups, to allow separate evaluation of the modelling for those sources. The strategy used to achieve this enhancement is explained in Section 3, but relies on having hourly concentration averages from continuous analysers.

1.17 It is important to bear in mind that, even when the concentration contribution from particular source groups can be isolated, comparison with monitoring data tests jointly the emissions methodology and dispersion modelling. Generally, there is no independent check on emissions other than via their influence on concentrations. This raises the possibility of fortuitous cancellation of errors in emissions quantification and dispersion modelling, which may not persist into the future as meteorology and the spatial distribution of emissions

* These are the short names of monitoring sites, introduced for convenience in the discussion – fulll site details are given in Section 2 of the report
† Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter (PM_{10} and $PM_{2.5}$), benzene, 1,3-butadiene, ozone, carbon monoxide (CO), lead and polycyclic aromatic hydrocarbons (PAHs)
‡ The $PM_{2.5}$ limit value has not yet been taken into UK law.

changes. Thus, the evidence on model performance is cumulative, as the modelling is tested in a variety of source configurations and meteorology. The air quality methodology used to calculate concentrations for the PSDH model evaluation was very similar to that used here, but for a different aircraft fleet mix and for different meteorology, gave good agreement in the airport contribution at LHR2 derived from modelling and measurement. Together, the studies increase confidence that good agreement between model and measurements has not resulted from cancellation of major errors.

1.18 It is worth noting that the emissions on the near-Heathrow major road network for 2008/9 were derived from an 'interim' traffic model, for which only limited tests of the model outputs had been reported. As discussed in Section 3, it is likely that some of the discrepancy between measured and modelled concentrations close to roads derives from inaccuracies in characterising the traffic data, rather than from emission-factor or dispersion-modelling inaccuracies, but it was outside the scope of the present study to investigate how much of the discrepancy might be attributable to the traffic data.

Report Structure

1.19 Section 2 of the report describes the monitoring data used in the comparisons; Section 3 discusses the comparison between model results and monitoring data; and Section 4 draws conclusions.

2 Monitoring Data

2.1 Site Selection

2.1.1 The focus of attention in this study is to assess how well the model predicts concentrations in residential areas around the airport, in particular at locations strongly influenced by sources related directly to the operation of the airport. This includes receptors that are appreciably influenced by emissions from within the airport perimeter itself but also receptors influenced strongly by road traffic emissions, where the traffic itself has a major airport-related component. Of course, there is no sharp boundary to this region, but the modelling methodology report defines a 9 km square 'study area', centred on the airport, within which concentrations are calculated in detail - not only total concentrations but also the separate contributions from key source categories*. This study area is very similar to that used in the PSDH work to present predicted concentrations around Heathrow, which helps in comparing results from the two studies.

2.1.2 Within the study area, 12 sites with continuous monitoring data for the 2008/9 period were identified, with all the sites having continuous NO_x/NO_2 analysers, 10 having continuous PM_{10} analysers and 3 with continuous $PM_{2.5}$ analysers: the model evaluation was based on comparison with monitoring data at this set of sites. The M25 site at Staines lies just outside the area so, arguably, could have been included in the evaluation, but this site was rejected in the PSDH model evaluation: it is situated much closer to the carriageway than is relevant to outdoor public exposure and the interpretation of its data proved problematic. Thus, the site has not been included in the current study (although its PM_{10} concentrations are mentioned in Section 3). The extent of the study area and the set of sites used in the evaluation are shown in Fig 2.1.

2.1.3 There are a large number NO_2 diffusion tube sites in the area, some belonging to the national network of diffusion tube sites and others belonging to local authority networks. NO_2 diffusion tubes have lower-precision than continuous NO_x/NO_2 analysers, although they play a valuable role in mapping spatial variations in NO_2 concentrations in areas with few (or no) continuous analysers. The present study has focused on a detailed assessment of the model predictions for separate source contributions, which is the principal driver of spatial variations in total concentrations. A comparison of the modelling results with NO_2 diffusion tube measurements in the period, although potentially interesting, was outside the scope of the study.

2.1.4 Table 2.1 presents relevant characteristics of the monitoring sites, including a short name that will be used in the discussions in the remainder of the report, the site OS co-ordinates and the range of pollutants monitored at the site. It also gives a brief description of the environment local to the site, and these descriptions are supplemented by Google satellite images in Figs 2.2 (a)-(l), at a spatial resolution chosen to show the principal local features. It is common for monitoring sites to be given a classification (rural, urban background, roadside etc) relating to the type of environment that the site can be taken to represent. For sites potentially affected significantly by airport sources, this classification scheme is less useful. From a model-evaluation perspective, the key distinguishing feature amongst sites is the extent to which they are influenced by various sources of emissions. The monitoring sites included in this evaluation span a useful range from this perspective, from sites where the sources on the airport have a major influence (such as LHR2), sites where emissions from a nearby road have a dominant influence (such as Hillingdon and Hayes) and sites located within residential areas with an appreciable (but not dominant) airport contribution and/or nearby road contribution (for example, Sipson, Harlington, Harmondsworth, Oxford Avenue, Cranford and Hatton Cross).

2.1.5 The changing pattern of source contributions across the sites is used to advantage in the analysis by taking concentration differences between sites, which highlight the contribution

* This breakdown is not given for NO_2 because of the non-linear relationship between NO_x and NO_2 concentrations

from specific sources. In this context, Oaks Rd serves a particular function in the evaluation, given that for a range of southerly wind directions it receives no contribution from the airport sources and little contribution from the major road network around the airport, so acts as a 'background' site when taking concentration differences for selected ranges of wind direction (see Section 3).

2.1.6 For the sites that are close enough to the nearest links of the road network to receive a significant contribution from them (for example, LHR2, Hillingdon, Hayes and Oxford Avenue), the co-ordinates of the site have been adjusted in the dispersion modelling to ensure that the site sits the correct distance from the modelled road (which may not perfectly coincide with the actual road, given the finite tolerance of the spatial representation of the road network in the dispersion modelling).

2.1.7 Table 2.1 also specifies if the site belongs to either the LAQN[17] (London Air Quality Network) or AURN[18] (Automatic Urban and Rural Network). This identification is included mainly in relation to the QA/QC (Quality Assurance/Quality Control) provisions under which the site operates. Sites not affiliated to either network may nevertheless be operated to a QA/QC standard equivalent to that of one of these networks. Oaks Rd, Green Gates, Colnbrook and Sipson are operated to the AURN QA/QC standards. The Hillingdon sites not not explicitly part of the LAQN network are nevertheless operated to LAQN QA/QC standards. The essential features of the QA/QC procedures for both networks have been summarised by Laxen *et al*[19].

2.2 Data Characterisation

NO_x and NO_2

2.1.8 Table 2.2 (a) and (b) give some characteristics of the NO_x and NO_2 data sets used in the analysis, with the first column identifying the website from which the data were downloaded. All the analysers included are of the chemiluminescence type, which is the EU reference method for NO_2. The EU sets an accuracy objective of ±15% at the 95% confidence level for NO_x/NO_2 continuous analysers[20], and the AQEG report on nitrogen dioxide in the UK[21] states that it is likely that the great majority of UK national network measurements meet this uncertainty requirement. For sites operated to LAQN standards, a working uncertainty of 10% (at 2 standard deviations) has been suggested[22], based on observation and analysis. Technical guidance for air quality review and assessment[23] suggests that the overall uncertainty of the measurements (considering both accuracy and precision) from a continuous analyser is expected to be about ±10% (2 standard deviations) for long-period averages that are well above the instrument detection limit, provided that appropriate QA/QC methods are applied.

2.1.9 The tables give the ratification status of the data at the time of the analysis reported here. Most of the data sets were fully ratified at the time, but with a few exceptions, as detailed in the table. Provisional data is subject to adjustment on ratification, but it is not expected that the changes (if any) will have an appreciable effect on the analyses reported in Section 3.

2.1.10 Table 2.2 also gives the data capture (DC), the fraction of hours in the twelve-month period with valid data. It is normal to set a lower limit of 90% on DC when monitoring data are being used to check compliance with air quality objectives and limit values for annual mean values[23]. Clearly, for 2008/9 there are a number of sites with DC less than 90% but nevertheless situated in important locations from a model evaluation perspective. In the context of a model evaluation exercise, however, the constraints on DC may be loosened. Given that the results of the dispersion modelling are available on an hourly basis, it is possible to include in the dispersion modelling for a particular site only those hours of met data for which valid concentration measurements are available, thereby allowing like-for-like comparison of modelled and measured values.

2.1.11 Of course, there is still a requirement that the range of meteorological conditions in the hours with valid data be reasonably representative of the full range experienced over twelve months, but this perspective does allow sites with DC less than 90% to be used in the

evaluation, whereas they might be rejected in testing for compliance with limits. The lowest DC for NO_x/NO_2 is 81.5% (Hatton Cross). Table 2.2 also gives the longest continuous run of missing data, showing that in the case of Green Gates most of the missing hours occurred in a single period (Aug/Sep 2008), whereas they were distributed amongst several gaps for the other sites with low DC. However, even Green Gates was judged to have a sufficient representation of combinations of meteorological variables to be used in an evaluation of model performance for long-period average concentrations. Thus, all sites have been included in the analysis, albeit taking account explicitly of the data gaps as explained above.

2.1.12 Table 2.2 (a) and (b) give, respectively, the period-mean NO_x and NO_2 concentrations, defined as the simple arithmetic average of concentrations in all hours with valid data. In this report, the term 'period mean' will be used for averages over the 2008/9 twelve-month period. This reserves the term 'annual mean' to refer to average over a calendar year, which is the metric used for air quality objectives and limits. Also given in the Table 2.2 is the maximum hourly value, to give some idea of the dynamic range of the hourly measurements. The highest hourly NO_x value at Sipson (3719 $\mu g/m^3$) looks anomalous: in fact there were two consecutive hours with high values (3719 $\mu g/m^3$ and 2815 $\mu g/m^3$), with the next highest value in the period only 724 $\mu g/m^3$. The Sipson data set, however, was fully ratified, so no data values were rejected. The two high values contribute 0.75 $\mu g/m^3$ to the total period-mean NO_x concentration.

2.1.13 The period-mean NO_x concentrations over the 12 sites span an appreciable dynamic range, from 56.1 $\mu g/m^3$ to 124.8 $\mu g/m^3$, indicating the potential for testing the influence of local sources on NO_x concentrations. The values for period-mean NO_2 concentration span a smaller range (from 32.0 $\mu g/m^3$ to 54.9 $\mu g/m^3$), reflecting the non-linear relationship between NO_2 and NO_x concentrations. Nevertheless, NO_2 range is still substantial from a model-evaluation perspective.

2.1.14 Table 2.2 (a) for NO_x also presents the 25^{th} and 75^{th} percentile of the hourly concentration values, together with their ratio (the inter-quartile ratio, IQR). This ratio has significance in the methodology for deriving period-mean NO_2 concentrations from period-mean NO_x concentrations, as described in the modelling methodology report. Generally, other purely statistical parameters of the distribution of hourly values do not provide much additional insight, although they may be useful for data consistency checking. On the other hand, averages taken for particular wind directions and wind speeds give more information on the key sources influencing the concentrations, and are the principal metrics used in the analysis in Section 3.

2.1.15 For NO_2, Table 2.2 (b) also gives the number of hours in the period with hourly-average concentration above 200 $\mu g/m^3$, which is relevant to the short-period NO_2 objective/limit that there should be fewer than 18 values above 200 $\mu g/m^3$ in a (calendar) year. In the present context, the values in the table can be used to test the methodology in which a surrogate annual mean NO_2 concentration of 60 $\mu g/m^3$ is used to test for compliance with the short-period limit (see the 2008/9 modelling methodology report). Clearly the data in Table 2.2 (b) are consistent with the assumption that if the annual mean is less than 60 $\mu g/m^3$ it is unlikely that the short-period limit will be exceeded. However, given that the period-mean values are well below 60 $\mu g/m^3$, the data do not provide a sensitive test of the assumption.

2.1.16 Bearing in mind missing data, an alternative way of expressing the short-period criterion is that the 99.79^{th} percentile of hourly concentrations should be less than 200 $\mu g/m^3$. Table 2.2 (b) gives the relevant values, again showing that the short-period limit was satisfied at all the sites in 2008/9.

2.1.17 From Table 2.2 (b) it can be seen that the 2008/9 period-mean NO_2 concentration was above 40 $\mu g/m^3$ for 5 of the sites. However, for sites with data capture below 90%, such as Green Gates, the value can only be taken as indicative of the 12-month mean concentration, given the potential influence of missing data.

PM_{10}

2.1.18 Tables 2.2 (c) provides characteristics of the data sets used for the PM_{10} analysis in Section 3, in a similar manner to those provided for NO_x and NO_2, although some data columns are specific to PM_{10}.

2.1.19 It is noteworthy that the data capture for Hatton Cross is particularly low (70.1%), with most of the missing hours confined to a single period from October 2008 to February 2009. Given that most of the winter period is therefore missing, this raises the concern that low temperatures and low values of surface heat flux will be under-represented in the meteorological data set relevant to the hours with valid concentration measurements, so additional caution may be warranted in using the Hatton Cross PM_{10} data.

2.1.20 Eight of the ten PM_{10} sites have TEOM (Tapering Element Oscillating Microbalance) analysers, as noted in Table 2.1. It is standard practice to adjust concentration measurements from this type of instrument for the loss of volatile components (for example ammonium nitrate) resulting from the heated inlet. Tests reported in the AQEG report on particles[24] have shown that there is variability in the relationship between concentrations measured by co-located TEOM and reference instruments, but an interim adjustment factor of 1.3 was proposed for the UK. Recently, however, a more accurate method of correcting TEOM measurements (using the Volatile Correction Model[25]) has been devised for use with UK TEOM data. The model relies on data from the network of FDMS* (Filter Dynamics Measurement System) instruments established in the last few years; in general data from 2007 onwards can be corrected in this way. Equivalence to the EU reference method for PM_{10} can be demonstrated for the FDMS instrument[23].

2.1.21 For the TEOM sites, Table 2.2 (c) gives both the uncorrected period-mean concentration and the VCM-corrected period mean. For sites belonging to the LAQN the data was already available in VCM-corrected form (with uncorrected data also available); for the remaining sites, the VCM correction was carried out for the present study, using the VCM web portal[25]. The process of VCM correction has the potential to further lower the data capture if the FDMS sites themselves have missing data; the additional data loss, however, was less than 1%. Data capture values shown in the table relate to the final VCM-corrected data.

2.1.22 Uncertainties relating to the correction of TEOM data to to gravimetric-equivalent values add to the measurement uncertainty for these instruments: the results cited in the AQEG report suggest than an accuracy of better than 15% (at the 95% confidence level) should not be expected.

2.1.23 For the remaining two sites (Harmondsworth and Hayes) the instrument is a BAM (Beta Attenuation Monitor). For specific versions of the BAM (with unheated inlet) it is possible to demonstrate equivalence to the EU reference method[23], with raw data corrected to gravimetric equivalent by dividing by 1.21. As downloaded from the Hillingdon website, the data for Harmondsworth and Hayes were already corrected to gravimetric equivalent.

2.1.24 It will be noted later that measured period-mean given by the Harmondsworth BAM data is an outlier compared to other measured values in the area and compared to model results. This may signal an instrument problem, but the data were not discarded before the stage of comparing measurements with modelling results. The data for Harmondsworth were not ratified for the Jan-Mar 2009 period, but the values were consistently high throughout the 12-month period.

2.1.25 Harmondsworth also has an OSIRIS (Optical Scattering Instantaneous Respirable Dust Indication System) analyser, which operates on the principle of light scattering. Equivalence between this type of analyser and the EU reference method has not been shown. Technical guidance[23] suggests that this type of instrument, suitably calibrated, may be useful for indicative or screening purposes but not for detailed air quality assessments. The 2008/9 period-mean PM_{10} value from the Harmondsworth OSIRIS instrument is shown in Table

* The FDMS TEOM is a modified version of the TEOM designed to tackle the problem of loss of volatile components.

2.2(c) for information, but is not used further in the evaluation exercise.

2.1.26 The objective/limit on shorter-period PM_{10} concentrations – that there be less than 35 exceedences per year of a 24-hour mean value of 50 $\mu g/m^3$ - is recognised to be more onerous generally than the annual-mean objective. As discussed in the 2008/9 modelling methodology report, compliance with this objective is judged using a surrogate annual-mean concentration, as recommended in technical guidance for local authority air quality review and assessment[23], which gives

No. 24-hour mean exceedences = -18.5 + 0.00145 x annual mean^3 + (206/annual mean)

2.1.27 According to this, there will not be more than 35 exceedences of a 24-hour mean value of 50 $\mu g/m^3$ if the annual mean is less than 31.5 $\mu g/m^3$, so it has become common practice in air quality review and assessment to use the latter as a surrogate for the short-period limit when testing compliance using modelling results, on the grounds that model results for long-period averages are less uncertain than for short-period averages. The use of this surrogate annual-mean value can be subjected to a local test using the PM_{10} monitoring data around Heathrow for the 2008/9 period, and Table 2.2 (c) gives the number of daily exceedences at each of the monitoring sites. For all the sites with period-mean less than 31.5 $\mu g/m^3$, the number of daily exceedences is less than 35. For Harmondsworth (BAM), with a period-mean of 34.7 $\mu g/m^3$, the number is greater than 35 (45). Although these results are consistent with the use a limit of 31.5 $\mu g/m^3$ on the annual mean as a surrogate for the short-period limit, they do not provide a sensitive test, given that all except one of the period-mean values are well below 31.5 $\mu g/m^3$.

2.1.28 Table 2.3 shows the number of daily exceedences predicted by the above relationship compared to the measured value. This shows agreement between measurement and prediction within the associated level of uncertainty in the relationship (estimated from the scatter on the data used to develop the relationship), bearing in mind possible deviations for sites with low data capture. This adds confidence in the use of the use of an annual-mean surrogate.

2.1.29 An alternative way of testing the short-period limit for measurements with missing data is to test that the 90.41th percentile of daily means throughout the period is less than 50 $\mu g/m^3$. This metric is also shown for the monitoring sites in Table 2.2 (c), confirming that the value was indeed less than 50 $\mu g/m^3$ at all sites except Harmondsworth, as expected.

$PM_{2.5}$

2.1.30 Table 2.2 (d) give some characteristics of the data for the 2008/9 period from the three $PM_{2.5}$ analysers included in the evaluation. The Green Gates and Oaks Rd instruments are of the TEOM type, with appropriate size-selecting inlet. Standard correction methods for TEOM annual-mean $PM_{2.5}$ measurements, based on comparisons with UK gravimetric measurements, have not yet been proposed, but the instruments are conventionally set up with an (US) EPA default adjustment protocol (TEOM reading*1.03 + 3 $\mu g/m^3$). Equivalence with the EU reference method for $PM_{2.5}$ has not been shown for the standard TEOM instrument.

2.1.31 The Harmondsworth measurements are from the OSIRIS instrument at the site, and similar comments apply for $PM_{2.5}$ as those made above for PM_{10}.

2.1.32 The data capture of the two TEOM analysers was high for the period (>95%). Although lower at Harmondsworth (87%), it is still adequate for model evaluation purposes, as explained earlier in the discussion for NO_x.

Ozone

2.1.33 As explained in Section 3 (NO2), local ozone measurements can be used to check the calculation of total oxidant concentrations (sum of O_3 and NO_2 concentrations) that form part of the methodology for deriving NO_2 concentrations from NO_x concentrations. Ozone is

measured (by ultraviolet absorption) at three of the sites in the study area (Harlington, Hillingdon and Cranford) and some data characteristics of the ozone data for the 2008/9 period are shown in Table 2.2 (e).

2.1.34 The data capture is high at Harlington and Hillingdon (around 99%), but low at Cranford, which will be borne in mind when the data are put to use in Section 3.

3 Results and Discussion

3.1 NO_x

Total Period Mean

3.1.1 The key aim in the model evaluation exercise is to assess how well the combined emission quantification and dispersion modelling methodologies are able to predict annual mean NO_x and NO_2 concentrations. In the context of the present 2008/9 study, therefore, the focus of attention is on concentrations averaged over the twelve-month period, termed the period-mean concentration, as explained in Section 2.

3.1.2 In a detailed comparison between model predictions and measured values at monitoring sites, it is important to consider the impact of missing data. If the modelling is to be carried out using a full year of hourly meteorological (met) data, there is usually a requirement that the data capture (fraction of hours with valid data) in the measurements be at least 90%; even then it would be preferable if the data gaps were distributed over the year rather than focused in one period, to avoid bias. In the 2008/9 case, there are a number of sites with data capture (DC) less than 90% (see Section 2) but nevertheless situated in important locations from a model evaluation perspective.

3.1.3 Given that the results of the dispersion modelling are available on an hourly basis, it is possible to include in the dispersion modelling for a particular site only those hours of met data for which valid concentration measurements are available, thereby allowing like-for-like comparison when the DC falls below 90%. Of course, there is still a requirement that the range of meteorological conditions in the hours with valid data be reasonably representative of the full range experienced over the twelve months, but this perspective does allow sites with DC less than 90% to be used in the evaluation, whereas they might be rejected in testing for compliance with limits.

3.1.4 The lowest DC for NO_x amongst the sites used in the assessment was 81.4% (Hatton Cross). Having set up the procedure to make like-for-like comparisons for sites with DC<90%, it was extended to sites even with DC>90%, to put all sites on an equal footing in the analysis. Of course, the concentration contour plots and results at specific receptors generated after the model evaluation will be based on model results that include all hours of the period. For convenience in the discussion below, concentrations averaged over the hours with valid measurements will be termed 'period-mean' concentrations and those averaged over all hours of the period will be termed 'all-hours period-mean' concentrations.

3.1.5 Table 3.1 compares the modelled total period-mean NO_x concentrations at the continuous NO_x/NO_2 analysers with the measured values, and gives the breakdown of the model total by source category. It is worth noting that the rural background contribution varies from site to site in this table only because a different selection of hours (with valid measurements) is being taken in each case, not because there is any spatial variation in the model contribution over the study area. The average of the modelled values is 73.1 $\mu g/m^3$, whereas the average over the measurements is 78.9 $\mu g/m^3$.

3.1.6 It is judged more appropriate to discuss model-monitoring differences in terms of fractional discrepancies (*(modelled-measured)/measured*) rather than absolute discrepancies (*modelled-measured*), and the corresponding values are shown in Table 3.1. Thus the average fractional discrepancy (also referred to below as the bias) is -5.2%, i.e. the model underestimates on average by 5.2% across the set of sites, with a standard deviation of 12.2% (12 sites), where the latter is a measure of the site-to-site variability in the measured values that has not been captured by the model. Taking the measurement uncertainty (one standard deviation) for long-period averages to be around 5% (Section 2) indicates that the observed bias is highly unlikely to be explained by statistical measurement fluctuations for a finite sample of 12 sites. Similarly, a large fraction of the site-to-site variability not explained

by the model is unlikely to be attributable to measurement uncertainties.

3.1.7 There are alternative ways of presenting the comparison between the two data sets. For example, the model 'explains' 76% of the variance in the measured values about their mean, i.e. the reduction in the variance (mean square absolute discrepancy) when the measurements are referred to the model values compared to the variance when they are referred to their arithmetic average is 76%. Fig 3.1 presents a scatter plot of modelled versus measured period-mean values. The correlation coefficient for the two data sets (which measures the extent to which they are linearly related) is 0.89.

3.1.8 For interest, Table 3.2 shows the difference between the period-mean concentrations and the all-hours period-mean concentrations, to indicate the influence of missing hours. The differences range from -0.45 to 2.4 $\mu g/m^3$ at the period-mean level, with the largest difference at Green Gates; differences may be larger in particular wind-direction ranges.

3.1.9 For convenience, the following terminology for source groups will be used in the discussions below:

(a) 'airport' emissions refers to sources on the airport* and does not include airport-related road-vehicles on the landside road network; the term is a little loose in that it includes all aircraft emissions in the LTO cycle, including elevated emissions that may arise beyond the airport perimeter (although the contribution from emissions above a few hundred metres in height is small at the receptors of interest);
(b) 'runway' emissions, which includes aircraft emissions from take-off roll, initial climb, final approach and landing roll;
(c) 'apron emissions', which includes APU emissions and airside vehicle/plant emissions; these may be lumped together sometimes because their modelled spatial distributions overlap, making it difficult to separate out their individual contributions by the directional analysis of monitoring data.

3.1.10 For the three sites with the highest total contribution from airport sources, LHR2, Hatton Cross and Oaks Rd. the fractional discrepancy is –4.8%, 16.3% and 13.1% respectively. For the three sites with the largest road network contribution, Hillingdon, LHR2 and Hayes, the fractional discrepancy is -10.8%, -4.8% and -27.4% respectively, suggesting that there is a systematic underestimation of the road contribution. This highlights the importance of evaluating the model separately for the various source contributions, given that the balance between contributions may change in the future. This is the objective of the more detailed analysis described below.

3.1.11 For comparison, in the model evaluation carried out by CERC (for 2002) in the PSDH work, the modelled annual-mean concentration averaged across 8 monitoring sites† was 76.2 $\mu g/m^3$ compared to a average of 77.6 $\mu g/m^3$, a fractional discrepancy of only -1.8%. It should be noted that the set of 8 sites used in the PSDH comparison did not include as many sites close to the airport as in the set available for the 2008/9 evaluation.

3.1.12 Excluding the three 'road' sites mentioned above, the average of the modelled concentrations is 64.8 $\mu g/m^3$ whereas the average of the measured values is 66.6 $\mu g/m^3$. Even these nine sites have an appreciable contribution from the modelled road network, typically 14 $\mu g/m^3$, so would be subject to some underestimation if there was a systematic underestimation of the road-vehicle contribution that persisted beyond the immediate vicinity of the road (as would be the case if emissions are being underestimated).

3.1.13 Table 3.1 shows that all sites have a major combined contribution from the LAEI/NAEI area sources and the rural background, which is fairly constant across the set of sites (except at Hayes), so inaccuracies in this contribution could act to partly offset inaccuracy in the contributions from airport and road-network sources. Again, this emphasises the importance of evaluating the performance of the modelling of airport and road vehicle sources separately

* Aircraft (including main engines, APUs and engine testing), airside vehicles/plant, car parks and taxi queues, heating plant and the fire-training ground.
† Excluding LHR10, the Staines near-M25 site, which was considered an outlier.

from that of the LAEI/NAEI/background contributions.

3.1.14 The availability of monitoring results from the Oaks Rd site, upwind of the airport along the principal south-westerly wind direction, presents the opportunity to isolate the contribution from airport sources by taking concentration differences between a monitor north of the airport and Oaks Rd, focusing on wind directions that point to and from the two sites. A similar type of analysis was carried out (for Heathrow) by CERC for the PSDH work[14]. In taking concentration differences, the assumption is made that the rural background contribution does not have a significant concentration gradient between the two monitors. Similar difference analyses can enhance the evaluation of the road network contribution at near-road sites.

3.1.15 As described in the 2008/9 modelling methodology report, the dispersion modelling results were obtained separately for each hour of the period, allowing average concentration differences to be calculated for selected wind direction (and wind speed) ranges. It is important to bear in mind when comparing concentration *differences* that the under/overestimation of the difference may have a contribution from the over/underestimation of the concentration being subtracted. Thus, there is benefit in using 'clear' differences, i.e. in situations where the sources of interest have a much larger contribution at one site than at the other.

3.1.16 The 1 km spatial resolution of the area sources (LAEI and NAEI) in the study area restricts the angular resolution of model results from these sources, which is a limitation (compared to the 10° angular resolution set by the meteorological data) for the squares within a few km of any given receptor. However, the source categories represented in the area emissions (such as domestic and commercial combustion) are not highly focused spatially (and the emission densities are not large), so the limited spatial resolution is not likely to be a significant limitation (but it should be borne in mind in the angular comparisons presented below).

3.1.17 The measurement errors associated with concentration differences cannot be ignored. If the measurement biases of the analysers are uncorrelated, then the error in the (absolute) difference is greater than the error in the value at each site (taken to be around 5%). However, if the sites belong to the same network or are operated to the same QA/QC procedures it is expected that there will be some correlation between the systematic errors at each site. It is judged unlikely that the uncertainty in period-mean differences for the sites around Heathrow will be less than 2 $\mu g/m^3$ or higher than 5 $\mu g/m^3$ (at 1 standard deviation), although these estimates have not been based on any specific data or analysis.

Evaluation of the Modelling for Airport Sources

LHR2-Oaks Rd

3.1.18 The LHR2-Oaks Rd concentration difference was given particular attention in the model evaluation undertaken by the PSDH[14]. LHR2 is only 180 m from the centre-line of the northern runway (27R), so receives a major contribution from runway sources, offering the potential for a good test of the 'moving-jet' module in ADMS-Airport (see the 2008/9 modelling methodology report). In addition, there are no major sources immediately upwind of Oaks Rd for the range of angles over which the wind blows airport sources towards LHR2, so the difference is 'clear'.

3.1.19 A form of presentation of the concentration differences that has proved useful in other similar analyses is to plot the mean concentration as a function of wind direction (i.e. with all hours of the period sorted by wind sector* and the concentration then averaged over the hours for a given sector), which will be termed a 'concentration difference rose'. This is displayed as a 'radar' plot in Fig 3.2, in which the angle in the plot corresponds to wind sector and the radial distance is the mean concentration for the sector†. This figure shows remarkably good

* Wind direction in the met data is already digitised into 10° sectors, which are labelled by the mid-angle of the sector

† It is important to note that in this form of presentation the concentration for a given wind sector has not been weighted by the relative probability that the wind blows in that sector. This avoids making the comparisons for sectors with low frequency difficult to read. However, it is important to recognise that discrepancies in some angular ranges have much less impact on the period-mean than in others. Table 3.3, on the other hand, includes the frequency weighting, as do the figures showing contribution as a function of wind speed.

agreement in the modelled and measured differences in the angular range 120° to 270°, when the wind blows from the airport towards LHR2 – the present focus of attention - although the model underestimates the concentration difference when the wind blows from some northerly directions.

3.1.20 For angles above about 180°, LHR2 'sees' emissions from a major part of the take-off roll on the nearby runway 27R (westerly operation) and also from other parts of the airfield including the CTA (Central Terminal Area), T5 (Terminal 5) aprons and runway 27L (although the contribution from these sources is significantly smaller than that from 27R). Thus, the good agreement persists over a major part of the spatial distribution of airport sources.

3.1.21 A particular feature of Fig 3.2 is the peak in the monitoring difference for NE winds that is not reflected in the model difference, but discussion of this feature will be deferred to the section below on the analysis for road-network emissions.

3.1.22 The comparison for LHR2-Oaks Rd differences can now be made quantitative, by evaluating the contribution to the total period-mean concentration difference from wind directions that give a significant airport contribution at LHR2, choosing sectors 170° to 270° inclusive; this range of angles is marked on Fig 3.3. Although sectors 120° to 160° also point from the runway to LHR2, aircraft generally depart on the southern runway (09R) for this range of angles, so the contribution to period-mean concentrations is small. The LHR2-Oaks Rd entry in Table 3.3 gives the modelled and measured contributions from the selected sectors to the period-mean concentration difference, showing a discrepancy of only 2.9% (model overestimation) on a contribution of around 35 $\mu g/m^3$.

3.1.23 Table 3.4 shows the breakdown by source category of the modelled contribution to the period-mean NO_x concentration difference in the 170° to 270° range. The airport accounts for 88% of the model difference. Clearly, aircraft sources dominate the airport contribution, and ancillary model results show that take-off roll accounts for around 65% of the aircraft contribution.

3.1.24 A further level of evaluation can be carried out by investigating how the concentration contribution from the selected angular range is distributed as a function of wind speed. For this purpose, the hours for which the wind direction lies in the chosen range are partitioned amongst a set of wind speed categories separated by around 0.5 m/s[*], with averages then taken for each category; the mean concentration for a given category is multiplied by the fraction of all hours in the year for which the wind lies in the given speed category (and angle range) to generate the contribution to the total period-mean concentration difference from the category.

3.1.25 The resulting set of values are shown in Fig 3.4, which will be termed a 'contribution/wind speed' plot. The figure demonstrates a good level of agreement across the major part of the wind speed range, but does indicate a tendency for the model to overestimate at low wind speeds and underestimate at high wind speeds, which was also found in the PSDH model evaluation[14]. Thus the remarkable level of agreement in the total contribution from this angle range is partly fortuitous, arising from a compensation between these two tendencies, and may not be maintained to the same extent if the met data in a given year showed a markedly different wind speed distribution. Nevertheless, given that the agreement is reasonably good in every wind-speed category, it would require a major shift in wind-speed frequency distribution to generate a significant overall discrepancy.

Filtering by Westerly Departure Runway

3.1.26 One of the indicators of model performance devised for the PSDH model evaluation involved determining the difference in average concentrations at LHR2 between hours when 27R (close to LHR2) was used for departures and hours when 27L (far from LHR2) was used for

[*] Wind speed in the met data is given in terms of a discrete set of values, which are the m/s equivalent of a whole number of knots. In the analysis, hours with reported wind speed of zero or 0.5 m/s were assigned to a single bin with representative speed 0.75 m/s in line with the procedure in ADMS-Airport in which wind speeds of less than 0.75 m/s are set to 0.75 m/s, with the wind direction set to that in the previous hour (or the latest preceding hour with speed above 0.75 m/s).

departures. This was one way of testing the ability of the model to predict the fall-off in the concentration contribution from aircraft on the runway as a function of distance from the 'centre-of-gravity' of airport sources (critical to predicting the aircraft contribution in residential areas north of the airport). In fact, the test is made more stringent by comparing average concentrations separately for each hour of the day. The resulting comparison is displayed in Fig 3.5, which shows the mean LHR2-Oaks Rd NO_x concentration difference (for wind direction within the range 170° to 270° inclusive) by hour of day, separately for hours with departures on 27R and 27L.

3.1.27 Clearly, the average change in concentration between hours when aircraft take off on 27R and hours when they take off on 27L is well reproduced by the model, giving confidence that the model is representing the behaviour of the aircraft contribution as a function of distance from the key airport sources. In addition, during the daytime, the hour-of-day concentration profile when aircraft take off on 27R is fairly well reproduced by the model. The dip in concentration around 15:00 hours (local time) reflects the fact that departures switch between runways at this time (in westerly operation), but complete change-over may not occur at precisely 15:00 every day, so hours near the change-over time may have departures on both 27R and 27L. In the analysis for Fig 3.5, hours were assigned to either the 27R or the 27L categories depending on the which runway had the maximum number of departures in the hour. The comparison in the night hours is not very useful since many hours have departures on neither 27R or 27L, so the concentration is an average for only a few hours and the natural variability in concentration is therefore greater.

3.1.28 Integrating over all hours and normalising appropriately gives the total contribution to the period-mean NO_x concentration difference from the selected sector range for each of the operating modes. Table 3.5 gives the comparison between modelled and measured values for this contribution, showing a remarkable level of agreement, with a fractional discrepancy of less than 4% for departure on 27R (overestimation) and a fractional discrepancy of around 5% (underestimation) for departure on 27L.

3.1.29 Since the PSDH (2002) analysis, additional continuous NO_x/NO_2 sites have become operational in residential areas north of the airport (Harlington, Hillingdon Harmondsworth and Sipson), offering the potential to examine directly the model performance for on-airport sources at receptors further than LHR2 from the runway. However, it should be borne in mind that the wind angles that bring pollutant from sources on the airport to these sites also bring pollutant from the A4 and Northern Perimeter Road, potentially complicating the interpretation, so the 27R/27L comparison remains a valuable additional model test on variation with distance from airport sources.

Bi-Polar Plot

3.1.30 The PSDH model evaluation demonstrated a visually appealing way of presenting concentration differences jointly as a function of wind direction and speed, as a bi-variate polar plot (bi-polar plot for short). Figs 3.6 (a) and 3.6(b) show the LHR2-Oaks Rd NO_x concentration differences presented in this way, with Fig 3.6(a) showing modelling results and Fig 3.6(b) showing monitoring data. The plots are generated by assigning the hourly concentration differences to the set of joint wind sector and speed categories, then taking the average over the set of hours within each joint category.

3.1.31 The set of average LHR2-Oaks Rd concentration differences for the joint categories are then represented on a polar plot in which the radial distance represents wind speed[*], the angle clockwise from the *y* (up-down) direction on the page represents wind angle (the direction from which the wind blows, clockwise from north) and the colour represents a concentration range. The plots have been smoothed to make the visual comparisons easier[†]. Although the plots give a good visual impression of major features of the concentration distribution, it is important not to over-interpret them. Some of the joint categories contain few hours and the concentrations from them are therefore subject to greater sampling fluctuations. Under the

[*] It is important to keep in mind when interpreting the plots that radial distance represents wind speed not spatial distance. All concentrations on a given plot relate to the specific locations of the monitoring sites.
[†] The smoothing is applied only for presentational purposes in this type of figure. All numerical analyses are carried out with un-smoothed data.

action of the smoothing algorithm, concentration outliers may generate localised spatial features which, although visually striking, may simply reflect a sampling fluctuation. However, broad features of the plot reflect the results from many hours and are thus more reliable.

3.1.32 A key feature of both plots is that the concentration difference is large and positive for winds blowing from the SW quadrant, which point from airport sources towards LHR2. Difference concentrations are above 50 $\mu g/m^3$ across most of the quadrant, both in the measurement and the model results. The plots again demonstrate the model overestimation at low wind speeds and underestimation at high wind speeds noted earlier. Although the colour coding focuses the eye on these systematic differences, it is important to recognise that the difference in concentration is generally much less than a factor of two across the whole speed range.

3.1.33 The relatively high concentration at high wind speeds is considered diagnostic of an elevated source, so in this instance reflects the influence of plume rise for hot engine exhaust plumes. However, the comparison in Fig 3.6 cannot be interpreted as showing that the plumes are elevated according to measurement but at ground-level according to modelling. Ground-level plumes generally lead to a rapid decline in concentration with increasing wind speed, whereas both monitoring and modelling plots show concentration remaining high up to the highest wind speeds. A contribution to the difference in the plots, nevertheless, may arise from inaccuracies in the modelling of plume rise, with an indication that the model gives too little plume rise at low wind speed and too much at high wind speed. Generally, the heights of rise are of order tens of metres, and even quite small differences in plume height can have a significant impact on ground-level concentrations.

3.1.34 Furthermore, there is a need for caution in interpreting the variation of concentration with wind speed as simply related to plume elevation: other factors may be at work. For example, emissions may not arise equally in all wind speeds (because of a difference in average wind speed for hours of the day with quite different emission rates) and the distribution of atmospheric 'stability' conditions (which affect the rate of dispersion) may not be the same at each wind speed. In addition, the influence of sampling fluctuations needs to be borne in mind for the highest wind speeds, which are relatively infrequent.

3.1.35 It is worth bearing in mind that the concentrations in the bi-polar plot are not weighted by the relative number of hours in the bin, whereas high wind speeds are relatively infrequent. Thus, the contribution to period-mean concentrations from the highest wind speeds is relatively small, as shown in the difference/wind speed plot (Fig 3.5).

3.1.36 The discrepancy in the difference concentration for wind directions in the NE quadrant is clearly visible in the bi-polar plot, and will be discussed in the section below relating to the road network contribution.

Sipson-Oaks Rd

3.1.37 As noted earlier, additional continuous NO_x/NO_2 sites have become operational in residential areas north of the airport (London Harlington, Hillingdon Harmondsworth and Hillingdon Sipson) since the PSDH 2002 analysis, offering the potential to examine directly the model performance for airport sources at receptors further than LHR2 from the runway.

3.1.38 Fig 3.7 shows the difference rose for Sipson-Oaks Rd. Focusing first on wind directions pointing from airport sources to the Sipson monitoring site (with sectors 120° to 240° inclusive accounting for most of the airport contribution), the figure shows good agreement between model results and monitoring data across the range of sectors. The relevant entry in Table 3.3 compares the modelled and measured contribution to the period-mean concentration difference from this range of angles, confirming the good level of agreement, with the model value only 9% lower than the measured value (i.e. a difference of 1.2 $\mu g/m^3$). Table 3.6 gives the breakdown by source category of the contribution from this angle range to the period-mean concentration difference, showing that the airport accounts for 80% of the

concentration difference according to the model.

3.1.39 In contrast to the situation for LHR2-Oaks Rd, the modelled contribution from apron emissions is comparable to that from the runway emissions because at the wind angles for which Sipson 'sees' take-off roll emissions from departures on 27R (generally greater than 180°) the emission density on the runway is already low (with many aircraft already airborne by the time they pass Sipson)*. Thus the comparison at Sipson tests a quite different airport source mix than that at LHR2.

3.1.40 For angles greater than 230°, where there is a relatively small contribution from the runway, there is a hint of model underestimation. At these angles, there is a contribution at Sipson from the road complex (including the M25 west of the airport): the road network contribution will be further discussed in the section on road-network sources.

3.1.41 Figure 3.8 gives the contribution/wind speed plot for the sector range 120° to 240°, again showing that the good agreement in the total contribution has resulted from a cancellation of the model overestimation at low wind speeds and underestimation at high wind speeds, but the discrepancy over the middle speed range (which contributes most to the total contribution) is generally better than 20%. The influence of the 'outlier' high measured concentrations (for 2 hours only), discussed in Section 2, can be seen in the comparison for wind-speed categories around 8 m/s.

3.1.42 The bi-polar plots in Fig 3.9 are an alternative way of displaying the features discussed above. Focusing first on the areas of green, which represent a positive difference between Sipson and Oaks Rd for winds blowing from the S-SW (i.e. from the airport). The model reproduces well the measured concentration-difference magnitude, angular range and distribution as a function of wind speed. Again, the influence of the 'outlier' values can be seen for angles around 210° (and wind speed around 8 m/s), with the 'smoothing' routine used for this particular form of presentation spreading the peak to neighbouring joint angle/speed categories.

Harlington–Oaks Rd

3.1.43 Monitoring data from the Harlington site were not available for the PSDH 2002 model evaluation. The Harlington-Oaks Rd difference rose is displayed in Fig 3.10, with airport sources contributing principally over the sectors 160° to 240° inclusive. Although wind angles a little greater than this point from western end of the northern runway, the concentration contribution is small because departures will be on 27R (the eastern end of the northern runway) for these angles and there will be little emission density at the western end.

3.1.44 The wind directions pointing from the airport to the Harlington site will also carry pollutants from road vehicles on the Northern Perimeter Road and on the A4, but the breakdown of the difference by source contribution (Table 3.7) shows that the road network contributes only 11% of the total difference in period-mean concentrations, whereas airport sources contribute 87%, according to the modelling, with runway emissions accounting for a large fraction (around 70%) of this. Thus the Harlington-Oaks Rd difference provides a good test of the modelling for the airport contribution to NO_x concentrations in the residential areas of Harlington.

3.1.45 In contrast to the situation for Sipson, some wind angles that correspond to departures on 27R point to Harlington from parts of the runway that still have significant NO_x emission density from take-off roll, so the airport contribution in Harlington is comparatively large despite the site being further from the runway.

3.1.46 The Harlington-Oaks Rd entry in Table 3.3 shows that the model overestimates the contribution from sectors 160° to 240° by 20%, which is equivalent to 1.6 $\mu g/m^3$, which is less that the expected uncertainty in concentration differences. The contribution/wind speed plot for this range of angles is displayed in Fig 3.11, showing overestimation in a medium range of wind speeds and generally good agreement above 4 m/s. The five wind speed bins

* In fact, Sipson receives a larger contribution from initial climb than from take-off roll.

from 1.5 m/s to 4.1 m/s contribute 4.2 μg/m^3 (out of 9.5 μg/m^3) to the period-mean concentration difference according to the modelling whereas they contribute 2.8 μg/m^3 (out of a total of 7.9) according to the measurements, which represents a model overestimation by 50%. The contribution from the remaining wind speed bins is much the same in the modelling and monitoring data (5.3 μg/m^3 modelled versus 5.1 μg/m^3 measured).

Harmondsworth-Oaks Rd

3.1.47 The Harmondsworth-Oaks Rd difference rose is displayed in Fig 3.12, with airport sources contributing principally over the sectors 110° to 190° inclusive. Harmondsworth, being further west than Sipson or Harlington, has a relatively small airport contribution despite being closer than Harlington to the runway. Wind directions that lead to departures on 27R - which generate the highest emission density on the northern runway – do not point from the runway to the Harmondsworth site: for the range of angles pointing from airport sources to the site, aircraft currently depart from the southern runway (09R). In addition, wind directions that do point from the major part of the northern runway towards Harmondsworth are relatively infrequent. These features are reflected in the source breakdown of the contribution from the 110° to 190° sector range to the period mean concentration, as given in Table 3.8, which shows that the contribution from apron emissions is larger than the contribution from runway emissions. The comparison of modelled and measured contributions to the period-mean from this range of sectors is shown in Table 3.3, with the model underestimating in this case by 24%, equivalent to 1.0 μg/m^3. Monitoring data from the Harmondsworth site were not available for the PSDH 2002 model evaluation.

3.1.48 In Fig 3.12 the agreement between model and measurement is good over the range 110° to 150°, which includes most of the runway and CTA sources. Between 150° and 190°, airport sources are still a major contributor, with about 40% deriving from runway sources and 60% from apron (T5) sources, but here the model under-predicts the difference, which may indicate an under-prediction of the contribution from the T5 aprons. However, the absolute difference in the contribution to the total period-mean concentration difference is only around 1 μg/m^3. For angles greater than 190°, the road network gives the largest contribution from local sources, and the model underestimates the difference by around a factor of two.

Green Gates-Oaks Rd

3.1.49 There is particular interest in the Green Gates site because annual-mean NO_2 concentrations there have been not far below the limit value for a number of years, raising concerns that the opening of T5 may have a significant impact in the Longford area.

3.1.50 The Green Gates-Oaks Rd difference rose is shown in Fig 3.13, with airport sources mainly contributing for wind sectors 100° to 180°. The total NO_x contribution to period-mean concentrations from airport sources is relatively small, for similar reasons to those given above for Harmondsworth, with aircraft mainly taking off on the southern runway when the wind blows from airport sources to the site. The breakdown by source of the contribution to the period-mean concentration difference from these sectors is given in Table 3.9, with airport sources accounting for 95% of the total difference; aircraft (main engines), APUs and airside vehicles contribute comparable amounts to the relatively small airport total.

3.1.51 The modelled difference shows a peak in concentration in the 120° sector, for which the wind points to Green Gates from apron sources in the CTA, and here the model value is a little higher than the measured value, whereas for angles around 160°, which point from T5 aprons to Green Gates, the model value is a little less than the measured value.

Oxford Avenue-Oaks Rd

3.1.52 The Oxford Avenue site receives a substantial contribution to period-mean NO_x concentrations from airport sources, being downwind of major airport sources along the dominant wind direction. In addition, it lies quite close to the A4.

3.1.53 Fig 3.14 shows the Oxford Avenue-Oaks Rd difference rose, with airport sources mainly contributing over the 210° to 260° sector range. Elevated concentration differences are shown over this sector range in both the modelling and monitoring results, with the model difference a little less than the measured difference. Table 3.10 gives the breakdown by source of the contribution to the period-mean concentration difference from these sectors, showing that airport sources account for 69.5% of the total, with the road network accounting for 30.3%. The Oxford Avenue-Oaks Rd entry in Table 3.3 shows a larger absolute discrepancy between modelled and measured values (4.2 $\mu g/m^3$) than for the other sites selected for their airport contribution. This can be attributed to the larger road-network contribution, given the evidence (discussed later) of systematic under-prediction of the road network contribution across the study area. Nevertheless, the fractional discrepancy between the two values is still less than 20%.

Oaks Rd-Harlington (Sipson, Harmondsworth)

3.1.54 It is also possible to test the modelling for airport sources by taking differences between Oaks Rd and a site north of the airport for northerly wind sectors. The model-monitoring comparison is more difficult to interpret in this case because the concentrations include a substantial contribution from the road network at both sites, but they provide useful additional information.

3.1.55 An appropriate range of sectors to capture the airport contribution at Oaks Rd is 330° to 90° and the differences between Oaks Rd and three northerly sites, Harlington, Harmondsworth and Sipson, are examined over this range. Table 3.3 shows the relevant comparison of modelled and measured differences, indicating that the model overestimates the difference, on average by 3.4 $\mu g/m^3$. From Table 3.1, it can be seen that the modelling over-predicts the total period-mean concentration at Oaks Rd (by 6.4 $\mu g/m^3$), for which the overestimation of the airport contribution therefore provides a partial explanation.

3.1.56 The general features of the comparisons are similar for all three northerly sites, so only the Oaks Rd-Harlington differences will be examined in more detail. In a sense, the difference rose can deduced by reversing the signs of the concentrations in Fig 3.10, but because of the nature of the polar plot this is difficult to read for northerly quadrants, so is re-plotted with signs reversed in Fig 3.15.

3.1.57 This reveals a significant over-prediction for wind angles around 320° to 350°: these sectors point to Oaks Rd from the T5 aprons, which are the principal airport contributors in this range. The runway gives little contribution for these sectors since, in principle, aircraft should be taking off from 27L/27R for these wind directions (although the correlation between wind direction and change of runway operation is not exact). The over-prediction of the difference in the 320° to 350° range might indicate an overestimation of the T5 contribution at Oaks Rd, but caution is needed, given that the modelled contribution at Harlington from these directions (which has a significant road network contribution) may be underestimated. Evidence will be presented below that there is a general under-prediction of the contribution from the road network across the study area. There is a smaller model overestimation of the concentration difference (by 14%) for the sector range 10° to 60°, which includes contributions from take-off roll on the southern runway and from CTA apron emissions.

3.1.58 Fig 3.16 gives the contribution/wind speed comparison for the whole 330° to 90° range, showing even more strongly than in the differences for southerly winds (e.g. Fig 3.4) that model overestimation at low wind speed is partly offset by an underestimation at higher wind speeds. In this instance, the overestimation at low wind speeds has a greater effect on period-mean concentrations because the probability of low wind speeds is higher for northerly winds than it is for southerly winds, as illustrated in Fig 3.17. In the discussion of the LHR2-Oaks Rd differences, it was speculated that underestimation of plume rise at low wind speed for main engine exhaust emissions (and overestimation at high wind speed) may be contributing to the discrepancy. In a similar vein, the lack of plume rise modelling for APU emissions on the aprons may also be playing a part. It is worth noting that the frequency of northerly winds is relatively low and quite strongly angle-dependent (see wind rose in the 2008/9 modelling methodology report). Thus, uncertainties in the met data for wind direction

may contribute to modelling-monitoring differences.

3.1.59 From the three comparisons for Oaks Rd in Table 3.3, the modelling overestimates the contribution to the concentration difference by around 3 $\mu g/m^3$. If this is attributed solely to overestimation of the airport contribution at Oaks Rd, it would account for about one half of the total overestimation of the the period-mean NO_x contribution at Oaks Rd (6.4 $\mu g/m^3$).

Summary for Airport Sources

3.1.60 It is useful to summarise the position for airport sources before moving on to comparisons for the road-network contribution.

3.1.61 Referring to Table 3.3, the values of the contribution to period-mean concentration difference for sectors dominated by airport sources range over an order of magnitude across six sites north of the airport (from 3.2 $\mu g/m^3$ to 34.4 $\mu g/m^3$), and the average (absolute) discrepancy between modelled and measured values at the six sites is only -0.6 $\mu g/m^3$, with a standard deviation of 1.8 $\mu g/m^3$. Expressed in fractional terms, the mean fractional discrepancy is -5.4% (underestimation), with a standard deviation of 15.5%. This level of discrepancy is small compared to the uncertainties in concentration difference measurements, so provides no evidence that the modelling for airport sources either overestimates or underestimates significantly.

3.1.62 The comparisons presented above together indicate that the model gives a good account of the impact of airport sources on period-mean NO_x concentrations at receptors in the residential areas north of the airport. In particular, it represents well the variation in the airport concentration contribution with distance from the principal sources on the airport and the variation with east-west location in relation to the ends of the northern runway. This gives confidence that the model provides a robust basis for investigating the potential impact on residential areas of operational changes on the airport that affect the magnitude and spatial distribution of NO_x emissions, for example the abandonment of the Cranford agreement (which would then allow departures on runway 09L) and the construction of a third runway north of the current runways.

3.1.63 At Oaks Rd, close to the southern boundary of the airport the difference comparisons indicate that the modelling overestimates the contribution from airport sources by around 3 $\mu g/m^3$ (for a total airport contribution of 17 $\mu g/m^3$), although this discrepancy is only of comparable size to the judged uncertainty in measured differences in period-mean concentrations.

3.1.64 These comparisons jointly test the methodology for quantifying airport emissions and the dispersion modelling methodology that translates emissions into airborne concentrations. This raises the possibility that significant errors in emissions quantification may be fortuitously cancelling errors in dispersion modelling, an issue that was discussed in Section 1. The good agreement found above, however, applied in situations where different source groups (runway, apron, etc) were dominant, so any fortuitous cancellation would have to apply across a range of sources.

Concentration Contours for the Airport Contribution to Period-Mean NO_x concentrations

3.1.65 The above tests gives confidence in the model's ability to predict the spatial variation of the airport contribution to total NO_x concentrations in the residential areas around the airport. To show this variation, concentration contour plots have been generated based on the model values at a set of grid points, as described in the modelling methodology report. The basic receptor grid is a square grid with 100 m spacing, aligned with the OS grid axes. In addition, for the modelling of aircraft sources on the runway, the 'intelligent gridding' option in ADMS-Airport was used, which creates additional receptors at a finer spatial resolution close to the runway. These additional points help to capture the large spatial gradients close to the runway in the contribution from runway sources to period-mean NO_x concentration, although the base 100 m grid is adequate to capture the spatial gradients in the residential areas

around the airport.

3.1.66 As noted earlier, the contour plots are based on calculated concentration values that are averages over all hours of the 2008/9 period (termed earlier the 'all hours' period-mean concentration), in contrast to the values used in the comparisons with measurements discussed above, which took into account missing data in the measurements.

3.1.67 Fig 3.18 gives the contour plot for period-mean contribution from 'airport' sources (as defined earlier). The shape of the contours reflects the spatial distribution of NO_x emissions on the airport - with particularly high emission intensity at the eastern end of the northern runway – coupled with the strongly anisotropic wind rose (with its south westerly dominance). The current restriction of departures on runway 09L (the western end of the northern runway) adds to the anisotropy of the contours. Values of the airport contribution to the period-mean NO_x concentration above 30 $\mu g/m^3$ are restricted to within the main body of the airport, with values in the nearest residential communities typically within the range 10-20 $\mu g/m^3$. At the M4 motorway, the contribution from airport sources (as defined earlier) is at most around 6.3 $\mu g/m^3$ (at an easting of around OS 508800), falling to around 3.5 $\mu g/m^3$ where the M4 intersects the eastern edge of the study area (OS 512000) and around 1.5 $\mu g/m^3$ where it intersects the western edge (OS 503000).

Comparison with PSDH Results for 2002 and 2010SM

3.1.68 Fig 3.19 shows the same information as in Fig 3.18 but using colour bands for concentration ranges. The colour coding has been chosen to correspond to that used in the PSDH air quality report, to facilitate visual comparison with equivalent results for the 2002 PSDH case (Fig 10.3 in the CERC report[14]) and the 2010SM (Segregated Mode) case (Fig 10.12 in the CERC report). It should be noted that the PSDH work used a slightly different definition of 'airport' sources, which included a few landside road links and the tunnel to the CTA, but this does not have a major impact on the shape of the contours. It should also be noted that, although the colour coding has been continued to high values of NO_x close to sources on the airport, the modelling has not been optimised to represent detailed concentration variations close to airport buildings; the spatial resolution of emissions and receptors has been chosen principally with a view to predicting off-airport concentrations. However, the high-concentration colour bands in the interior of the airport provide a valuable means of checking the spatial distribution of the underlying emissions.

3.1.69 Concentration results from the PSDH work were also presented at a series of specific receptors that included the monitoring sites operating at the time and a number of other key locations. For the present discussion, a set of 13 specific receptors have been chosen to compare results from the PSDH with those from the present work, including continuous NO_2/NO_x monitoring sites common to the two sets of results plus four other sites (HD56,t HD57, HD58 and HD60) selected to represent key areas of interest not covered by the monitoring sites; the sites are marked on Fig 3.20.

3.1.70 Prior to presenting the concentration comparisons, Table 3.11 summarises relevant emissions information, showing that the 2008/9 and 2002 PSDH cases have comparable ground-level airport emissions, with the forecast 2010SM emissions somewhat higher. Table 3.12 compares the contributions to period-mean concentrations from airport sources at the selected sites,for the three cases. The set of sites span an order-of-magnitude range in total airport contribution to period mean NO_x concentrations from less than 3 $\mu g/m^3$ to greater than 30 $\mu g/m^3$.

3.1.71 At a given site, the contributions from a given category of airport sources for the three cases are broadly comparable, as expected from the magnitude of total emissions. However, there are subtle differences from one case to another that relate to differences in the spatial distribution of emissions between the cases and differences in meteorology. For example, the relatively larger aircraft contribution at Hatton Cross in 2008/9 is partly due to the significantly higher frequency in 2008/9 than in 2002[*] of the wind blowing in the 270° wind

[*] The 2008/9 wind rose is shown in Fig 3.1 in the 208/9 modelling methodology report, and the PSDH wind rose is Fig 2.1 in the CERC report for the PSDH[14].

sector*. Only wind directions in a relatively narrow range of angles around 270° bring runway emissions to the Hatton Cross site. Similarly, the relatively large contribution at Oaks Rd from non-aircraft airport emissions (principally airside vehicle emissions) is partly due to the higher frequency in 2008/9 than in 2002 of winds blowing in sectors 40° to 60° (pointing from the CTA aprons to Oaks Rd). It is worth noting that the wind blows relatively infrequently in some ranges of wind sectors, and there is much higher variability from year to year in the frequency associated with these sectors.

Evaluation of the Modelling for the Road Network Contribution

3.1.72 Road vehicle emissions on the road network around Heathrow play an important role in determining the total concentration of NO_x in residential areas close to the airport, so concentration differences were analysed separately with a focus on the road-network contribution. In the discussion below, it is important to keep in mind the 'interim' nature of the traffic model, which is discussed in the 2008/9 inventory report.

Hillingdon-Harmondsworth; Hillingdon-Harlington

3.1.73 The Hillingdon site is 40 m north of the nearest lane of the M4, so receives a major contribution from the motorway when the wind blows from southerly directions. Over part of the range of southerly wind sectors, the site also receives a contribution from the airport, but at this distance the modelled contribution is small. By choosing a 'difference' site that is also north of the airport (and without a large airport contribution), the potentially confounding effect of differences in non-road contributions can be reduced: Harlington and Harmondsworth are appropriate 'difference' sites.

3.1.74 Fig 3.21 gives the Hillingdon-Harmondsworth difference rose. Both the modelled and measured concentration differences are large for southerly winds, typically around 60-80 $\mu g/m^3$ from modelling and 80-100 $\mu g/m^3$ from measurement, but it is clear that the model systematically underestimates the concentration difference over the whole range of sectors for which the motorway is expected to give a major contribution, in particular for south-easterly wind directions. An underestimation of this magnitude is very unlikely to be attributable to measurement uncertainty alone. Table 3.13 (which serves as a master table of comparisons relating to the road network) compares the measured and modelled differences for the sector range 100° to 270°, showing that the model underestimates the contribution to the period-mean concentration difference by 20%, a discrepancy of 9.2 $\mu g/m^3$ on a measured total of 46.4 $\mu g/m^3$. Table 3.14 gives the breakdown by source of the contribution to the period-mean concentration difference from these sectors, showing that airport sources account for less than 2% of the total difference, with the road network accounting for 93%.

3.1.75 Fig 3.22 shows the contribution/wind-speed comparison for the 100° to 270° sector range. Although there is an under-prediction in the total area, in line with the discrepancy in the difference rose, it can be seen that if the model values are re-normalised to the same total as from the monitoring there would be overestimation at low wind speed and underestimation at high wind speed. This tendency, therefore, is displayed not only for aircraft sources, so some component of it, at least, is generic to the dispersion modelling as a whole.

3.1.76 Fig 3.23 gives the Hillingdon-Harlington difference rose, which has similar features to those for Hillingdon-Harmondsworth. In this case, the fractional discrepancy between modelled and measured values for the contribution from sectors 100° to 270° to the period-mean concentration is a 37% under-prediction, a discrepancy of 18.5 $\mu g/m^3$ out of a measured total of 49.7 $\mu g/m^3$. The smaller amount of under-prediction when Harmondsworth is used as the 'difference' site may result from its location closer to the M25 and M25/M4 interchange, given the evidence discussed later in this section of under-prediction of the concentration contributions from the M25. Model underestimation of the road network contribution at Harmondsworth would increase the model difference and reduce the discrepancy between

* Also, the overall frequency of departures in westerly operation was higher in 2008/9 (71.7%) compared to in 2002 (68.8%), which would put more of the emissions at the eastern end of the runway.

modelled and measured differences.

3.1.77 There is major interest currently in whether or not the present methodologies for quantifying NO_x road vehicle emissions are leading to systematic under-prediction of traffic-related emissions, and it is tempting to interpret the above results for the Hillingdon site in this light. However, before conclusions can be drawn from these results about the current set of emission factors, it is necessary to evaluate the basic traffic data used in the emissions quantification. The report on the interim traffic model[26] shows there is good agreement between traffic model output and measured total two-way flow between Junction 4 and 4b, with the comparison in the three model time periods shown in Table 3.15. However, this comparison does not provide any information on the HDV (bus/coach and HGV) fraction in the traffic, which is particularly important from an emissions perspective. It addition it does not give any information on the accuracy of modelled traffic speed, also a parameter of key importance for emissions. In relation to the latter, hourly average speed may not be enough to characterise the traffic state in relation to emissions if there are periods of flow breakdown and queuing.

3.1.78 In this context, the measured concentration difference in Fig 3.23 shows a peak at around 120°-140°, which could result from traffic slowing or queuing to exit the M4 eastbound at Junction 4, but this level of detail is not represented in the traffic data used in the modelling. A contribution to the peak may also arise from emissions on the section of the M4 Spur south of its junction with the M4, with the increased discrepancy at these angles then reflecting a modelling deficiency in the representation of this contribution.

3.1.79 In conclusion, it will be necessary to carry out a more detailed evaluation of traffic model outputs for links close to air quality monitors before conclusions can be drawn regarding the accuracy of the current set of NO_x speed-emission curves (as discussed in detail in the inventory report). It may be preferable to wait until a revised, fully calibrated traffic model becomes available before carrying out this detailed examination.

Green Gates-Oaks Rd (Road Network Contribution)

3.1.80 As noted earlier, there is particular interest in the NO_x and NO_2 concentrations at Green Gates because total NO_2 concentrations have been running close to the limit value of 40 $\mu g/m^3$ in recent years. In relation to the road network contribution, the Green Gates–Oaks Rd difference rose (Fig 3.13) indicates significant discrepancies for northerly and westerly sectors.

3.1.81 It is difficult to identify a 'clear' difference for the road network contribution at Green Gates. For angles giving a significant network contribution at the site, most other sites also have a significant network contribution. However, the key wind direction quadrants at Green Gates from this perspective are westerly (bringing pollutant from the M25 and the A3044), so the Green Gates-Oaks Rd difference itself can be used if the sector range is restricted to around 200° to 290°: at greater angles Oaks Rd starts to 'see' the nearby southern perimeter road and the various junctions with the A3044 and the M25 (J14); at smaller angles Green Gates starts to 'see' airport sources. Table 3.16 gives the breakdown by source of the modelled contribution to the period-mean concentration difference from these sectors, showing that the road network accounts for 69% of the total difference; the relevant entry in Table 3.13 gives the model-monitoring comparison for this sector range, showing that the model contribution to the period-mean concentration difference is only 40% of the measured contribution, equivalent to a discrepancy in period-mean concentration difference of 7.4 $\mu g/m^3$. The discrepancy over this sector range can account for more than 50% of the total discrepancy in period-mean NO_x concentration at Green Gates (Table 3.1).

Harmondsworth-Colnbrook

3.1.82 It is important to identify if the discrepancy at Green Gates in westerly winds arises from a source very local to the site or relates to the contribution from the western parts of the road network in general. To shed light on this, concentration differences were taken between Harmondsworth and Colnbrook for westerly wind sectors, restricting the (northerly) angular

range to reduce the contribution at Colnbrook from the M4 (and A4). The range 200° to 290° was selected, for which the road network accounts for 71% of the modelled contribution to the period-mean concentration difference. Fig 3.24 presents the difference rose for this pair of sites, showing that the model under-predicts the difference over the pertinent angular range. The relevant entry in Table 3.13 compares the modelled and measured values of the contribution to the period-mean concentration from this sector range, showing that the model underestimates the contribution by a factor of two, equivalent to an under-prediction of 5.4 $\mu g/m^3$.

3.1.83 Again, before conclusions can be drawn about the emission factors in current use, the fidelity of the traffic data has to be considered. The report on the interim road model[26] gives a comparison of modelled and observed flows on the M25 from J15 to J14 (only anticlockwise flows are available in the report), as shown in Table 3.15, with total flows under-predicted by 8%,13% and 19% in the morning-peak, inter-peak and afternoon-peak traffic model periods respectively. As with the M4 comparisons discussed earlier, no information is provided on the accuracy of the predicted HDV (bus/coach and HGV) fraction or traffic speed. Thus, it would be premature to draw conclusions from the present NO_x concentration comparisons about the performance of current methodologies for estimating road-vehicle emissions in situations where the traffic is well characterised from an emissions perspective.

Green Gates-Harmondsworth

3.1.84 There are other, more puzzling discrepancies associated with Green Gates for winds from northerly sectors, which can be examined most effectively using Green Gates-Harmondsworth differences. Fig 3.25 presents the difference rose for this site pair. The discrepancy in the westerly sectors has been discussed above using other differences, but it is striking that in the sectors 0° to 90° the model difference in Fig 3.25 is effectively zero whereas the measured difference is around 15-20 $\mu g/m^3$ in all sectors. Thus, this sector range contributes around 3.4 $\mu g/m^3$ to the total measured period-mean concentration difference, but virtually nothing to the total modelled period-mean concentration difference. The Green Gates monitoring data are fully ratified for the period and measurement uncertainties are unlikely to account for a discrepancy of this magnitude.

3.1.85 In this angle range, the site is too far from the A4 (around 200 m at closest point) and from the M4 (1.5 km) to expect a significant difference contribution from the road network. The nearby Bath Rd (nearest edge is 16 m from the monitor), although not included specifically in the modelled major road network, carries little traffic and is unlikely to be the origin of the excess concentration.

3.1.86 One possible explanation relates to the spatial resolution of the emissions taken from the LAEI. Although large point sources have been modelled individually, it cannot be ruled out that the 1-km spatial resolution of emissions from medium-sized point sources in the LAEI may be having an influence on the accuracy of modelled concentrations close to Green Gates. Alternatively, there are (so far unconfirmed) reports of some (house) construction activity on the Bath Rd close to the monitoring site at around the relevant period, but the duration and extent of any such activity is not currently known. However, at the present time the origin of the concentration excess at Green Gates in these sectors is unclear.

Oxford Avenue-Oaks Rd (Road Network Contribution)

3.1.87 As noted earlier, besides receiving a substantial contribution to period-mean NO_x concentration from airport sources, Oxford Avenue is located close to the A4 and receives a moderate contribution from the road network. Choosing the sector range from 90° to 180° avoids the major airport sources (although includes the long-stay car park south of Oxford Avenue). Table 3.17 shows that the road network accounts for 96% of the modelled contribution to period-mean concentration difference for this range of sectors.

3.1.88 The relevant entry in Table 3.13 shows that the model accounts for only 40% of measured contribution from this range of sectors (an under-prediction of 60%) equivalent to an under-prediction of 3.2 $\mu g/m^3$. Taken together with results quoted earlier for Oxford Avenue-Oaks

Rd (200°-260°), this suggests that the underestimation of the contribution from the road network for southerly wind sectors (which includes the contribution from the nearby A4) can account for around 6 μg/m^3 of the 12 μg/m^3 discrepancy in total period-mean concentrations at Oxford Avenue (Table 3.1), with the remainder deriving from neither the airport nor the A4.

3.1.89 It is worth remembering that information on the accuracy of the traffic model outputs for the A4 was not provided in the traffic model report.

LHR2-Harlington

3.1.90 As noted in the earlier discussion of the difference rose for LHR2-Oaks Rd, the measured concentration difference shows a strong peak for wind sectors around 40°, which requires further investigation. LHR2-Oaks Rd is not the best site pair for examining these wind sectors, given that Oaks Rd receives a substantial airport contribution from the relevant sectors, which complicates the interpretation. Thus, a difference site north of the airport is preferable for investigating the contribution from northerly sectors to the period-mean concentration at LHR2. Harlington was chosen for this purpose, and Fig 3.26 gives the LHR2-Harlington difference rose, showing clearly the excess contribution localised around 40°. For the sector range 270° to 100° (for which the road network dominates the contribution to the period-mean concentration difference), Table 3.13 shows that the model underestimates the difference contribution by 36%, equivalent to an under-prediction of 10.9 μg/m^3. This underestimation of the road network contribution is more than enough to account for the under-prediction in total period-mean NO_x at LHR2 shown in Table 3.1.

3.1.91 The narrow angular range associated with the excess contribution and the fact that it does not appear for other monitoring sites suggests that it derives from a local source. Although there are a number of potential sources immediately north east of LHR2, including car parks and the taxi feeder park, the most likely candidate is traffic on the Northern Perimeter Road (NPR), around the (signalised) junction with Neptune Rd (see Fig 2.2(a)). Fig 3.27 presents a (Google) satellite image at higher spatial resolution, showing the road layout near the site, including the location of the traffic signals.

3.1.92 As discussed in the 2008/9 inventory report, traffic queues were not explicitly recognised in the traffic data set available for the 2008/9 inventory. In previous airport studies (except for the PSDH[*]), AEA used a methodology in which junction delay times output by the traffic model were used to derive queue lengths and queuing emissions, but in the traffic data provided for the 2008/9 inventory junction delays were incorporated into the effective speed associated with the road link. This procedure does not necessarily lead to underestimation of total emissions on the link, but it does redistribute any increased emissions arising at/near junctions along the whole link. In the case of LHR2, this would reduce the modelled concentrations at the site. Such considerations indicate that detailed model-monitoring comparisons at sites close to road junctions require particular attention to how junction delays are to be represented from an air quality perspective.

3.1.93 It is worth remembering that information on the accuracy of the traffic model outputs for the NPR was not provided in the traffic model report.

Hayes-Cranford

3.1.94 Data from the Hayes kerbside monitoring site were not available for the PSDH model evaluation, with the site only becoming operational in 2008 (April). Table 3.1 showed a large discrepancy between modelled and measured period-mean NO_x concentrations at the site (34.4 μg/m^3). To investigate the road network contribution to this discrepancy, concentration differences between the Hayes and Cranford sites were examined. A site north of the airport was (marginally) preferred to Oaks Rd as the difference site because of the north/south gradient in the LAEI/NAEI contribution, although it restricts the angular range available to avoid the airport contribution at Cranford.

[*] AEA compiled the PSDH inventories for airport sources, but CERC quantified the emissions on the road network as part of the ADMS-Airport modelling task.

3.1.95 Fig 3.28 gives the Hayes-Cranford difference rose, showing that the model significantly underestimates the difference for southerly sectors, when the wind blows from the adjacent A437 towards the monitoring site. Restricting attention to sectors less than 220° to avoid the airport contribution at Cranford, Table 3.13 compares the modelled and measured contribution to the period-mean concentration difference from the sectors 90° to 210°, for which the road network contributes 87% of the total. The model underestimates the contribution by 44%, equivalent to 9.6 $\mu g/m^3$. It can be inferred, therefore, that the under-prediction of the contribution from all southerly sectors broadly speaking accounts for around 2/3 of the total discrepancy in period-mean concentration at Hayes, with the remainder 1/3 deriving from northerly sectors.

3.1.96 The location of the Hayes monitor is challenging from an air quality modelling perspective, situated at the kerbside of the A437 (N Hyde Rd) and on the junction with N Hyde Gardens (not part of the modelled network). There is no information on the fidelity of the modelled traffic flows, speeds and composition on the A437, and earlier comments about the modelling of junction delays apply here also (although the junction is not signalised). Thus it is not possible to draw general conclusions about current emissions factors from the comparisons presented here, but the airborne concentrations at the site would be worth re-analysing when traffic data that are well characterised from an air quality perspective are available.

3.1.97 Turning attention to northerly sectors, it is clear from Fig 3.28 that the model underestimates the concentration difference from these directions also. Table 3.1 shows that there is an especially high contribution to the period-mean concentrations at Hayes from the LAEI/NAEI sources, and ancillary modelling information shows there is an important component (around 12 $\mu g/m^3$) from rail emissions on the Great Western line. According to the modelling, the contribution to the Hayes-Cranford period-mean concentration difference from sectors 270° to 80° is 10.5 $\mu g/m^3$ whereas the measured contribution is 25.5 $\mu g/m^3$, revealing an underestimation by 15 $\mu g/m^3$. It is not possible to say from the data at one site how much of this discrepancy is local to the Hayes site or more widespread within the Hayes area. It is worth noting that there is an industrial estate north west of the site, including the Nestle plant. The latter has been modelled as a stack release (see the 2008/9 modelling methodology report), but contributes <1 $\mu g/m^3$ at the Hayes site according to the modelling.

Road Network Scaling Factor for NO_x

3.1.98 One aim of the modelling study, besides evaluating model performance, is to generate contours of total period-mean NO_2 concentration in order to gauge the spatial extent of any residential areas in which the concentration exceeded the limit value of 40 $\mu g/m^3$. If the model reproduces well the concentrations at the monitoring sites, this process can be viewed as an 'intelligent' way of interpolating and extrapolating from the measured data, guided by an understanding of source contributions, to generate the best estimate of the overall spatial distribution of concentration.

3.1.99 The difficulty that arises in the present study, therefore, is the evidence for a consistent underestimation of the contribution from the road network. Concentration contours derived from the raw modelling results, therefore, will underestimate NO_x concentrations and thus the extent of any NO_2 exceedence area.

3.1.100 As noted above, the observed discrepancies point to the need for a more detailed evaluation of traffic model outputs and how these are used to calculate emissions. It may be advantageous to defer that work until a traffic model is available that has been calibrated and validated with particular reference to those traffic characteristics that are key to the quantification of road traffic emissions and to the estimation of the road network contribution to airborne pollutant concentrations.

3.1.101 In the interim, however, a procedure has been devised that seeks to make best use of the information currently available to estimate the NO_x concentration field within the study area. This procedure attributes the non-zero average fractional discrepancy across the monitoring sites entirely to a underestimation of the road network contribution everywhere within the

area. Thus, a scaling factor is applied uniformly to the road network contribution at all points, with the magnitude chosen so that the average fractional discrepancy in total period-mean NO_x concentrations across the continuous monitoring sites reduces to zero. Applying an adjustment in this form automatically generates a larger absolute change in concentrations at sites close to roads, which is consistent with the results of the evaluation.

3.1.102 The required factor is found to be 1.212, i.e. the modelled road network contribution is increased by 21.2% everywhere in the study area. The resulting period-mean concentrations at the monitoring sites are shown in Table 3.18 and the revised scatter plot is shown in Fig 3.29. After application of the scaling factor, the correlation between modelled and measured values increases marginally from 0.89 to 0.90. The standard deviation of the model-monitoring discrepancy remains at around 12%. It cannot be ruled out that this adjustment of the road network contribution may be partly compensating for a systematic over- or under-prediction of the LAEI/NAEI/background contribution, given that the combined contribution from these components is only slowly varying across the study area so cannot be readily evaluated by difference analysis. However, this additional uncertainty is intrinsic to the simple scaling approximation.

3.1.103 Although the average discrepancy across the sites has been reduced to zero, this does not imply that there cannot be a systematic spatial variation in the residual discrepancy across the study area. It is likely that at receptors immediately south of the airport the period-mean concentrations are overestimated because of an over-prediction of the contribution from airport sources in northerly winds. Similarly, for receptors to the (north) west of the airport there may be a systematic residual underestimation because of the under-prediction of the contribution from the M25.

3.1.104 The above simple scaling process is unlikely to remove all the discrepancy relating to the road network at sites such as Hayes and LHR2, but at least some of the discrepancy at these sites is likely to be due to features specific to the site and not necessarily generalisable to other receptors. Nevertheless, the scaled NO_x concentration field may underestimate concentrations at near-road receptors that are strongly influenced by traffic queuing at junctions or are situated close to areas of the network subject to other types of flow disruption. Also a simple scaling of this type is unable to compensate fully for the 'missing' contribution at Green Gates (from north-easterly winds), so could lead to an underestimation of concentrations in Longford unless the missing source is very local to the monitoring site. Similarly, it is unable to compensate for the discrepancy at Hayes from northerly wind sectors, which will similarly lead to an underestimation of concentrations in Hayes unless the reason for the discrepancy is very local to the monitoring site.

Contours of Total Period-Mean NO_x Concentration

3.1.105 Contours of total (all-hours) period-mean NO_x concentration after applying the road network scaling factor discussed above are shown in Fig 3.30, in a colour-coded form using the same coding scheme as in the PSDH work, for ease of comparison*. As will be seen in the following section, the NO_2 limit value of 40 µg/m^3 corresponds to NO_x values within the range 70-80 µg/m^3, for the current set of results†, so there is particular interest in the off-airport areas shown in dark green, yellow and warmer colours. Fig 3.31 shows the equivalent results without applying the road network scaling factor, to enable the impact of the scaling to be visualised.

3.1.106 It should be noted that the spatial representation of sources has been judged in relation to the impact on off-airport concentrations, so spatial variations within the body of the airport are less reliable. In particular, the chosen spacing of the discrete jet sources on the runway and taxiways should be borne in mind. Also, the density of the grid receptor points results from a compromise between model run time and the smoothness of contours, so that some features of the contour shapes at the sub-100 m scale may be artefacts of the finite

* The lower concentration bands, however, have been shown hatched so that parts of the base map show through, to help locate the boundaries between colours on the map.

† There is not a fixed period-mean NO_x value corresponding to a given period-mean NO_2 value in the Jenkin methodology if there are site-to-site differences in the total oxidant concentration, which in turn depends on how much primary NO_2 is associated with the total NO_x concentration.

resolution of the grid.

3.1.107 Fig 3.30 can be compared with the equivalent figures in the CERC report for 2002 (Fig 10.1) and 2010SM (Fig 10.10). It is clear that the 2008/9 results for total NO_x concentration are much closer to the equivalent 2002 PSDH results than to the 2010SM results. However, the 75 µg/m^3 contour in the 2008/9 results does not extend as far from the airport boundary into Harlington as in the 2002 results, and a smaller area of Hayes between the Great Western railway line and M4 is above 75 µg/m^3.

Comparison with PSDH at Specific Receptors

3.1.108 It is easier to make detailed comparisons with the PSDH results by focusing on a representative set of specific receptors. Table 3.19 compares the 2008/9 results (including the road network scaling factor) for (all hours) period-mean NO_x concentration with the equivalent 2002 PSDH and 2010SM results at the 13 specific receptors introduced earlier. For the non-airport contribution, the 2008/9 results are much closer to the 2002 PSDH results than to the 2010SM results, with the average over the 13 sites 3.5% lower for 2008/9 than for the 2002 PSDH case and 42% higher than for the PSDH forecast 2010SM case. Although the calculated 2008/9 value of the total NO_x emissions on the designated road network is around 30% lower than that quoted for the 2002 PSDH case (for a closely equivalent network – see 2008/9 emission inventory report), the scaling up of the road network contribution by 21% described above has brought the calculated NO_x concentrations for 2008/9 close to the corresponding 2002 values. The PSDH forecast 2010SM NO_x concentrations are significantly lower, principally as a result of the fall in the road vehicle contribution that was expected to occur by 2010.

3.1.109 As discussed earlier, the contribution from the 'airport' sources is similar across the three cases, with the result that the total modelled NO_x concentrations for 2008/9 are similar to those for the 2002 PSDH case and higher than those for the 2010SM case. The average total NO_x concentration across the 13 sites for the 2008/9 case is 3.8% lower than for the 2002 PSDH case and 29.3% higher than for the 2010SM case.

3.2 NO_2

Total Oxidant

3.2.1 The 'Jenkin' methodology for deriving annual mean NO_2 concentrations from annual mean NO_x concentrations, described in the 2008/9 modelling methodology report, has two components: (a) the relationship between annual mean total oxidant (sum of O_3 and NO_2 concentrations) and annual mean total NO_x concentration and (b) the fraction of the total oxidant that is NO_2, as a function of NO_x concentration.

3.2.2 Given that there are ozone measurements at some of the near-Heathrow monitoring sites (Cranford, Harlington and Hillingdon), it is possible to carry out a limited test of the (a) component separate from an evaluation of (a) and (b) together (which yield annual-mean NO_2 concentrations). Table 3.20 compares the total oxidant at the three sites derived from measurement with the value derived using the Jenkin relationship

$$[OX] = B + A\,[NO_x] \qquad (1)$$

where [OX] is the annual mean oxidant concentration (ppb), B is the background oxidant (discussed in the modelling report, and assigned the value 33.5 ppb for the Heathrow region in 2008/9), A is the weighted-average primary NO_2 fraction for the site derived from the modelling* and $[NO_x]$ is the annual mean NO_x concentration at the site. It should be noted from Table 2.2(e) that the data capture for the ozone measurements at Cranford was poor in the 2008/9 period.

* The values of A used here are those derived after using the roads scaling factor, but are little different from those derived without the scaling.

3.2.3 Equation (1) is a relationship between twelve-month mean values, and is applied in the current context to period-mean concentrations. Missing data in the measurements must not be forgotten, but from the perspective of Equation (1) the measured period-mean concentrations are viewed simply as an approximation to the all-hours period-mean concentrations, with the additional uncertainty caused by missing data borne in mind at the comparison stage. (The key metric being evaluated for NO_2 is the NO_2/NO_x ratio, which is judged to be relatively insensitive to the missing data at the sites of interest.) The right-hand side of Equation (1) has been calculated using the measured value of $[NO_x]$, thus making the comparison principally a test of the values of *B* and *A*.

3.2.4 Table 3.20 shows reasonable agreement at the three sites, although the [OX] values derived from the right-hand side of (1) are on average 6% higher than the sum of the measured O_3 and NO_2 concentrations, which is within the uncertainty in the measurements. Given that there is some uncertainty in the value of *B*, there would be justification for treating it as an adjustable parameter, within the range of uncertainty, to improve the fit of modelled period-mean NO_2 concentrations with measurements. However, an adjustment of this type was not judged necessary, given the level of agreement obtained with the baseline estimate (see below).

Period-Mean NO_2 Concentrations

3.2.5 Table 3.21 compares the modelled and measured period-mean NO_2 concentrations (with the former derived from the modelled period-mean NO_x concentrations using the values of *B* and *A* appropriate to the whole twelve month period). The model results are shown both with and without the application of the NO_x road network scaling factor discussed earlier.

3.2.6 Before applying the roads scaling factor, the average fractional discrepancy (defined as *(modelled-measured)/measured*) is -1.8% (with a standard deviation, SD, of 9.7%), i.e. the model underestimates on average by 1.8%. After applying the roads scaling factor, the average fractional discrepancy is 1.6% (SD 9.7%). Neither of these values of average fractional discrepancies can be interpreted as a significant model bias.

3.2.7 Fig 3.32 shows a scatter plot of modelled versus measured period-mean NO_2 concentrations, both with and without the application of the road-network scaling factor. The correlation coefficient is 0.87 without application of the road-network scaling factor and 0.88 including the factor.

NO_2/NO_x Ratios

3.2.8 Of course, the NO_2 comparison reflects partly the underlying NO_x comparison, whereas a comparison of NO_2/NO_x ratios provides a more specific test of the Jenkin methodology for deriving period-mean NO_2 concentrations from period-mean NO_x concentrations (although this test does not remove entirely the dependence on the absolute NO_x values because of the non-linearity of the relationship). Table 3.21 shows the modelled and measured values of this ratio, both with and without the road-network scaling factor. The measured ratios range from 0.44 to 0.63 across the sites, with the modelled ratio ranging from 0.46 to 0.61 before applying the roads scaling and 0.45 to 0.60 after applying the scaling.

3.2.9 Without the road-network scaling factor, the average fractional discrepancy in the NO_2/NO_x ratios is 4.1% (i.e. the model on average overestimates the ratio by 4.1%) with a SD of 6.0%. After applying the roads scaling factor, the average overestimation reduces to 2.1% (SD 5.5%). This level of agreement is within what is expected from the (semi-empirical) Jenkin methodology, judging from the scatter on the data points used to derive the underlying $[NO_2]/[OX]$ relationship. Thus, the results indicate that the Jenkin methodology does not introduce any significant bias into the model results, so that once the bias in NO_x concentrations has been removed no further model adjustment is necessary.

Jenkin Category III versus Category II

3.2.10 It was noted in the modelling methodology report that the inter-quartile ratio of hourly monitoring values at Oaks Rd and Hatton Cross would in principle put them into Jenkin Category III rather than II (which has been used for all the results in Table 3.21), but Category II was retained on the grounds that the higher value was more likely related to the airport contribution than to a road network contribution. Table 3.22 shows the NO_2 values and the NO_2/NO_x ratios obtained using the Category III rather than Category II relationship.

3.2.11 At Oaks Rd, using the Category III relationship would lead to an under-prediction of the NO_2 concentration there. The NO_2/NO_x ratio is already underestimated compared to that from modelling using the Category II relationship (partly because NO_x is overestimated), and using the Category III relationship increases the level of underestimation of the ratio. Thus the retention of the Category II relationship at Oaks Rd is justified. At Hatton Cross, the overestimation of period-mean NO_2 concentration derives from the overestimation of period-mean NO_x and changing from Category II to Category III does not have a major impact on this overestimation, although it reduces it a little.

3.2.12 In the modelling methodology report, it was noted that the inter-quartile ratio of the hourly monitoring data at the Colnbrook site was anomalously high and, using the Jenkin category boundaries would have placed the site in category III. As seen in Table 3.22, using the Category III relationship would bring the modelled value closer to the measured value (a discrepancy of 2.1 $\mu g/m^3$ reduced to a discrepancy of 0.5 $\mu g/m^3$), but not by a significant amount.

3.2.13 In summary, there is no strong reason to depart from using the Category II relationship across the whole study area when calculating NO_2 concentration contours.

Contour Plots

3.2.14 As noted earlier for NO_x, although the primary purpose of the 2008/9 modelling study was to provide a basis for model evaluation, a subsidiary aim was to provide a more complete picture of the spatial variation in near-airport concentrations in 2008/9 than available from monitoring data alone. It is recognised that the annual-mean NO_2 objective and limit value are defined for concentrations averaged over a calendar year. However, the model values for the 2008/9 period are indicative of the potential for the 40 $\mu g/m^3$ objective to have been exceeded in 2008.

3.2.15 Fig 3.33 shows contours of modelled period-mean NO_2 concentration on a map background, with the NO_2 concentrations derived from NO_x results that include the road network scaling factor. The same colour-coding scheme has been used as in the reporting of the PSDH work[14], for ease of comparison, so areas where the limit value of 40 $\mu g/m^3$ is exceeded are shown in yellow (and 'warmer' colours). The lower concentration bands have been shown hatched so that parts of the base map can be seen, to help locate the boundaries between concentration bands on the map. For completeness, Fig 3.34 shows the equivalent results based on the NO_x concentration values without the road-network scaling factor, but only the results including the scaling factor will be discussed further below.

3.2.16 Areas of exceedence extend out into residential areas from the airport boundary, from the motorways and from the Great Western railway line, in accord with the areas of highest emission density. It should be borne in mind that these NO_2 results should be viewed as 'interim' on the grounds that they have been derived from NO_x values based on the interim traffic model results, adjusted using the simple road network scaling factor.

3.2.17 The 40 $\mu g/m^3$ contour should be taken as indicative of areas vulnerable to exceedence, but the grid results may not have the spatial resolution to determine if individual receptors close to the contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis. The limitations of the NO_2 contour plots in relation to spatial resolution are similar to those discussed earlier for the NO_x contours. In addition, when judging the risk of exceedence for near-road properties, care has to be taken to ensure that an individual receptor is located at the correct distance from the modelled road (which may differ from the position of the actual road, within the tolerance of the model's

representation of the road network).

3.2.18 Areas at risk of exceeding the short-period NO_2 limit value (using a period-mean of 60 $\mu g/m^3$ as a surrogate) are marked in red and 'hotter' colours in Fig 3.33. Period-mean concentrations above the surrogate limit are confined to areas within about 30-40 m of the centre of the M4 motorway. For the M25, period-mean concentrations above the 60 $\mu g/m^3$ surrogate limit are confined to a distance of around 40-50 m west of the M25 centre-line and about 80-90 m east of the centre-line. The caveats about spatial resolution noted above for the 40 $\mu g/m^3$ limit apply here also. It is outside the scope of the present study to determine whether or not there is relevant public exposure in the portions of these exceedence areas that lie outside the road margins.

3.2.19 As noted earlier, the site-to-site variability in the period-mean NO_2 concentrations not captured by the model has a standard deviation of around 10%. Some of this may be due to measurement uncertainties, but it is likely that a major fraction of it relates to modelling uncertainty. Thus, even if the model is unbiased on average, at any particular site there is a significant probability of measuring a 10% higher or lower period-mean concentration. Fig 3.35* presents an alternative view of the modelling results from this perspective, showing separately the areas with period-mean concentrations 36-40 $\mu g/m^3$ and 40-44 $\mu g/m^3$.

Comparison with PSDH Results

3.2.20 Comparing Fig 3.33 with the equivalent 2002 PSDH results (Fig 10.2) shows that the exceedence areas extend further out from the motorway and railway line into residential areas, despite the NO_x concentrations in 2008/9 being on average similar to or slightly lower than in the 2002 PSDH results at a given location (as discussed earlier). This implies that the NO_2/NO_x ratios are higher near roads in 2008/9, and this will be examined further below. On the other hand, the exceedence area in 2008/9 does not extend as far into Harlington from the airport boundary as in the 2002 PSDH case, reflecting the lower NO_x concentrations in this area in 2008/9.

3.2.21 These differences can be examined further using the set of 13 specific receptors introduced earlier, as shown in Table 3.23. The average modelled NO_2 concentration across these 13 sites for 2008/9 is 4.7% higher than for the 2002 PSDH case, whereas the average NO_x concentration is 3.8% lower. This shows that the modelled NO_2/NO_x ratios for 2008/9 are on average 7.9% higher than for the 2002 PSDH case, whereas they are on average 11.6% lower than for the 2010SM. The 2008/9 NO_2 concentrations in Table 3.23 are on average 14.8% higher than for the 2010SM case.

3.2.22 The largest changes in NO_2 concentrations between 2002 and 2008/9 values are at Oaks Rd and Hatton Cross, where meteorological factors play a significant part in generating changes in NO_x concentrations. It should be borne in mind, however, that the 2008/9 modelled NO_x concentration for Hatton Cross showed a significant residual overestimation compared to the measured value.

3.2.23 More insight into the differences in NO_2/NO_x ratios for the three cases can be gained by looking at the values of *B* (the background oxidant level) and *A* (the NO_x-weighted average value of the primary NO_2 fraction) that appear in the Jenkin methodology. Although CERC did not use the Jenkin methodology for the PSDH work†, effective values of *A* and *B* can be estimated from the data they provide.

3.2.24 An effective value of *B* for 2002 in the PSDH work can be derived as the sum of the rural O_3 concentration (in ppb) and NO_2 concentration (in ppb), with a reduction for the primary NO_2 associated with the rural NO_x concentration (taken to be 9.3% of the NO_x in 2002, as in Jenkin's work). This yields 32.1 ppb, only 4% below the value used in the 2008/9 work (33.5 ppb). For 2010, the primary NO_2 fraction associated with the rural NO_x is taken to be 14%,

* Fig 3.35 was prepared using the FAST software, a user-friendly tool for displaying the results of a modelling study and allowing scenario testing, licensed to BAA by AEA; the particular functionality used to generate the figure allows colour-coding of concentration contour areas without obscuring the underlying base map.

† CERC preferred to use the chemistry module provided within ADMS-Airport.

reflecting the increase in primary NO_2 fractions associated with road transport emissions. This also leads to an effective values of *B* of 32.1 ppb, using the forecast concentrations of O_3, NO_2 and NO_x given by CERC. Thus, differences in the assumed background oxidant level are not likely to be the principal source of the observed differences in NO_2/NO_x ratios.

3.2.25 For the 2002 PSDH case, most sources were assigned a primary NO_2 fraction of 10%, whereas in the 2008/9 work the weighted-average value of primary NO_2 fraction (*A*) is around 14% throughout the study area. Table 3.23 gives the modelled values at the 13 sites, which range from 13.5% to 15.3%, with higher values tending to arise at sites where the road network contribution is large. Similarly, for the 2010SM case in the PSDH work, NO_x emissions on the major road network around Heathrow were assigned a primary NO_2 fraction of 16.5% and NO_x emission on major roads in the rest of London were assigned a primary NO_2 fraction of 19.1%. This indicates that a major part of the difference in NO_2/NO_x fractions for the 3 cases derives from differences in primary NO_2 fractions. This conclusion is in line with the consensus that has emerged in the last few years that NO_2 concentrations in urban areas are not falling as expected ten years ago principally because of the increased primary NO_2 associated with road-vehicle NO_x emissions[27].

3.2.26 As noted earlier, the PSDH work did not use the Jenkin approach, so some of the differences between the NO_2/NO_x ratios for 2008/9 and those for the two PSDH cases will derive from the difference in basic methodology. Some insight into this can be gained from Fig 3.36. If *A* is artificially fixed at a constant value (rather than varying somewhat over the area, as the balance of source contributions change), then for a fixed value of *B* the Jenkin formulation yields a single curve of NO_2 concentration versus NO_x concentration (assuming all sites have been assigned to a single Jenkin Category, in this case Category II). Fig 3.36 plots this curve for three values of A, namely 5%, 10% and 15%, and also plots the modelled NO_2 and NO_x values for the three cases for the 13 sites used in Table 3.23. Clearly, the 2008/9 values all lie close to the 15% line, as expected from the *A* values in Table 3.23. The 2002 PSDH values are reasonably consistent with the 10% line although on average falling a little below it, as might be expected from the slightly lower effective value of *B*; the 2010SM values lie generally above the 15% line, consistent with an average value of *A* of around 17%. This suggests that most of the differences in average NO_2/NO_x ratios for the three cases derives from the difference in primary NO_2 fractions rather than from a change in methodology.

3.2.27 Fig 3.36 also gives an indication of how the NO_x value at which the NO_2 limit value of 40 $\mu g/m^3$ is reached varies with primary NO_2 fraction. For *A*=5%, the corresponding NO_x value (using this simple representation) is around 87 $\mu g/m^3$; for *A*=10%, it is around 80 $\mu g/m^3$; and for *A*=15% it is around 72 $\mu g/m^3$.

3.3 PM_{10}

Total Period Mean

3.3.1 Table 3.24 compares the modelled total period-mean PM_{10} concentrations at the continuous PM_{10} analysers with the measured values, and also shows the breakdown of the modelled total by source category. The average fractional discrepancy between modelled and measured total period-mean PM_{10} concentration is -0.4%, with a standard deviation of 17.5% (10 sites). Fig 3.37 shows a scatter plot of modelled versus measured period-mean PM_{10} concentrations. The correlation coefficient including all data points is only 0.15, but excluding Harmondsworth is 0.68.

3.3.2 The discrepancy at Harmondsworth is an outlier compared to the values at other sites, suggesting either an instrumental problem or the influence of a local source not included in the modelling. However, the large discrepancy is found at for all wind directions, suggesting that it does not result from a local source. It is worth noting that the instrument at Harmondsworth is a BAM (Beta Attenuation Monitor), whereas the instruments at the other sites (except Hayes) are of the TEOM type. The data from Harmondsworth have not been used in any further detailed modelling-monitoring comparisons.

3.3.3 Excluding Harmondsworth, the average fractional discrepancy is 4.3% (i.e. the model overestimates by 4.3% on average across the sites), with a standard deviation of 9.5%. The model overestimation is particularly large at Green Gates (25.7%), where the measured value is actually lower than the background value (as calculated from rural monitoring data). The average fractional discrepancy both with and without Harmondsworth is lower than the accuracy of the measurement technique (see Section 2), so the comparisons are able to demonstrate only that any model bias for total period-mean concentrations is less than the uncertainty in the measurements.

3.3.4 The modelled contribution from the designated road network and airport sources is on average only 2.3 $\mu g/m^3$ (maximum 5.2 $\mu g/m^3$, at LHR2) compared to a background level of 17.2 $\mu g/m^3$. This shows that the above comparison of total period-mean concentrations essentially evaluates only the prediction of the background contribution.

3.3.5 There is the possibility that concentration-difference comparisons may be able to add additional information on model performance for airport and road-network sources. However, PM_{10} concentration differences will be subject to systematic differences in measurement accuracy from one analyser to another. For analysers that use the same measurement technique and are part of the same network, some sources of inaccuracy are expected to cancel out. For example, all the TEOM analysers have been VCM-corrected using the same set of FDMS data. Nevertheless, systematic differences will remain, and are expected to be greater when the type of analyser is different. It is judged that the measurement uncertainties in differences are unlikely to be less than 2-3 $\mu g/m^3$ even for instruments of the same type, although this judgement is not based on any specific analysis. Only if measured concentration differences within a range of angles selected to highlight particular source groups are significantly greater than measurement uncertainties will it be possible to extract additional information on model performance from difference comparisons.

3.3.6 Besides measurement uncertainties, it is also necessary to keep in mind the possibility of 'natural' variations in the background (i.e. site-to-site variations in the background that are not captured by the modelling), which may mask differences in the concentration contributions from local sources.

3.3.7 Nevertheless, difference analysis may be able to set limits on the accuracy of the modelling for specific sources, and has been carried out for sites with the potential to yield the largest concentrations differences.

Concentration Differences for Airport Sources

LHR2-Oaks Rd

3.3.8 Fig 3.38 presents the PM_{10} concentration difference rose for LHR2-Oaks Rd. Focusing on the range of sectors bringing airport emissions to LHR2, there is a marked peak in the modelled concentration differences around 180° and a smaller peak in the measured differences at a similar angle. Table 3.25 gives the breakdown by source of the contribution to total period-mean concentration from the 150° to 270° range of sectors, showing that airport sources account for 83% of the modelled difference. Subsidiary model information shows that 87% of the modelled aircraft contribution in Table 3.25 is from brake and tyre wear emissions.

3.3.9 Tyre wear emissions have been distributed on a relatively short section of the runway (50 m long) in the touchdown zone, which for arrivals on 27R is not far from due south of the LHR2 monitor. LHR2 'sees' these emissions for a relatively narrow range of wind sectors. At smaller angles, aircraft will be arriving principally at the western end of the runway (09L), for which the touchdown zone is a long way from LHR2, and at larger angles the wind does not blow emissions on the relevant portion of the runway towards LHR2.

3.3.10 The measured concentration differences in Fig 3.38 for angles around 180° are around 4 $\mu g/m^3$, so are just about significant in relation to measurement uncertainties. Table 3.26

compares the modelled and measured values of the contribution to the total period-mean PM_{10} concentration difference from the 150° to 270° sector range, showing that the model overestimates by 42%, equivalent to a discrepancy of 0.7 μg/m^3. Taking into account measurement uncertainty, it is possible that the modelling is actually underestimating the period-mean concentrations, but taking the uncertainty on period-mean concentration difference as 3 μg/m^3 would imply that the underestimation of the airport contribution at LHR2 is unlikely to be more than a factor of two (for a modelled contribution of 2.3 μg/m^3).

3.3.11 The much larger peak in the modelling results does not necessarily imply that total emissions from runway sources have been overestimated: they may have been distributed over a section of the runway that is displaced from where the bulk of the emissions actually arise, thereby spuriously enabling wind directions giving rise to westerly operation to carry pollutant to the monitor. Similarly, the emissions may have been restricted to too small a length of runway. Inaccuracies in the spatial distribution of emissions along the runway may have a major effect at LHR2, but are likely to have a smaller effect at off-airport receptors at greater distance from the runway.

3.3.12 Fig 3.39 gives the concentration difference/wind speed comparison for the 150° to 270° sector range, showing that the model tends to overestimate at lower wind speed, as was found for NO_x. However, the agreement at wind speeds above 3 m/s is good and, even at lower wind speed, the agreement is reasonably good (typically around a factor-of-2 agreement), considering the smallness of the actual concentration differences. It is worth noting that no plume rise is associated with the brake and tyre wear emissions - the principal source contributing to the model results in Fig 3.39 - so these results reduce the likelihood that the overestimation at low wind speeds (and underestimation at high speeds) in the equivalent NO_x comparisons for airport sources can be attributed solely to inaccuracies in plume rise modelling.

3.3.13 The interpretation of the comparison in Fig 3.38 for northerly winds is complex, given that Oaks Rd receives an airport contribution for these wind sectors. The road network contribution at LHR2 will be examined later using an alternative 'difference' site.

Harlington–Oaks Rd

3.3.14 Fig 3.40 presents the difference rose for the Harlington-Oaks Rd PM_{10} concentration differences. Focusing on the range of sectors bringing airport emissions to Harlington (160° to 240°), the modelled and measured differences are similar, but they are both small (typically around 1-2 μg/m^3 in any particular sector), so the significance of the measured differences in relation to measurement uncertainties is questionable. Table 3.27 shows that airport sources account for 83% of the contribution to the period-mean PM_{10} concentration difference from this sector range, with aircraft and airside vehicles of comparable importance.

3.3.15 As shown in Table 3.26, the measured and modelled values of the contribution to the period-mean PM_{10} concentration difference from the 160° to 240° are in agreement, but this could be fortuitous given the small values involved. The model results show a small peak at 180°, deriving from brake and tyre wear emissions on the runway, whereas the monitoring results have a hint of a peak around 210°, which points from CTA apron sources towards Harlington. This suggests that the good agreement in the measured and modelled contributions from airport sources at Harlington may result from an overestimation of the contribution from runway sources balanced by an underestimation of the contribution from apron sources. However, it is important not to over-interpret the evidence from such small concentration differences (as evidenced by the Green Gates results below), bearing in mind measurement uncertainties.

Green Gates-Oaks Rd

3.3.16 The Green Gates-Oaks Rd difference rose is presented in Fig 3.41, and serves to emphasise the note of caution made earlier about over-interpreting small differences. According to the modelling, concentration differences in the sectors blowing from airport

sources to Green Gates are around 2 μg/m^3, whereas in the monitoring they are around -2 μg/m^3 to -1 μg/m^3 (i.e. concentrations at Oaks Rd are higher than at Green Gates)! There is a clear peak in the modelling results in the sector range 100° to 180°, but this amounts to a contribution to the period-mean concentration difference of only around 0.2 μg/m^3, virtually all from airport sources, with comparable contributions from aircraft and airside vehicles. In the monitoring data, there is also a hint of peak pointing towards airport sources, but the magnitude of the contribution to the total period mean difference has been cancelled by a large negative contribution to the difference.

3.3.17 A clue to what is happening is given by the total period-mean concentration results given in Table 3.24, which shows that the measured total is well below the modelled total at Green Gates, and is even below the modelled 'background' contribution. Leaving aside the possibility of instrumental problems at Green Gates – all the PM_{10} data for the site used in the analysis were ratified - this either indicates a spatial variation in the period-mean background contribution, not captured by the model and large enough to offset any contribution from the airport and local road network, or is the manifestation of uncertainties in concentration difference measurements.

3.3.18 No other difference pair provide clear information about airport sources. For Oxford Avenue-Oaks Rd, the modelled contribution from the road network is significantly larger than that from airport sources in the relevant sector range. The concentration differences between Harmondsworth and any of the other PM_{10} sites is so large that no meaningful conclusions about airport sources can be drawn, probably as a result of measurement inaccuracies.

3.3.19 On the basis of the comparisons available, there is no evidence that the contribution from airport sources to period-mean PM_{10} concentrations in residential areas around the airport is being underestimated nor that it is being overestimated by a large factor, but the conclusions drawn cannot be more definitive because of the small concentration differences involved.

Concentration Contours for the Airport Contribution to Period-Mean PM_{10} concentrations

3.3.20 Based on the above, Fig 3.42 shows contours of the contribution from airport sources to total period-mean PM_{10} concentration generated from the (all-hours) model results on the grid of receptors, without any model adjustment. The contribution is between 0.1 and 1.0 μg/m^3 in the residential areas just north of the airport, reaching around 2 μg/m^3 at the airport perimeter.

Comparison with PSDH Results for 2002 and 2010SM

3.3.21 Prior to comparing concentrations, Table 3.28 gives a brief summary of relevant emissions (the 2008/9 emissions report gives greater detail), showing that all three cases have similar ground-level aircraft emissions. The 'other airport' emissions (principally from airside vehicles and car parks) in the 2008/9 inventory are a little higher than for the 2002 PSDH case and near a factor of two higher than for the 2010SM PSDH case.

3.3.22 Table 3.29 compares the contributions to period-mean concentrations from airport sources for the three cases. The set of sites span an order-of-magnitude range in total airport contribution to period mean NO_x concentrations from less than 0.1 μg/m^3 (Colnbrook) to 2.0 μg/m^3 (LHR2). At a given site, the contributions from a given category of airport sources for the three cases are broadly comparable, as expected from the magnitude of total emissions. However, there are case-to-case variations that relate to differences in the spatial distribution of emissions and differences in meteorology. For example, the relatively large 2008/9 aircraft contribution at Hatton Cross has been explained earlier in the NO_x discussions as due partly due to the significantly higher frequency in 2008/9 than in 2002 of the wind blowing in the 270° wind sector. The impact is greater for PM_{10} than for NO_x because brake and tyre wear emissions on the runway are not subject to plume rise. Similarly, the relatively large contribution at Oaks Rd from non-aircraft airport emissions (principally airside vehicle emissions) is partly due to the higher frequency in 2008/9 than in 2002 of winds blowing in sectors 40° to 60° which point from the CTA aprons to Oaks Rd.

Concentration Differences for Road Network Sources

3.3.23 Of the sites with PM_{10} measurements, the three sites with the largest modelled road-network contribution to period-mean PM_{10} concentration are LHR2, Oxford Avenue and Hayes. None of these sites is close to a motorway.

LHR2-Harlington

3.3.24 The peak in the measured LHR2-Oaks Rd concentration-difference rose (Fig 3.38) for winds from north-easterly sectors was noted earlier, but Oaks Rd is not the best site for examining LHR2 for northerly wind sectors because it receives a major contribution from airport sources. Choosing a difference site north of the airport, Fig 3.43 presents the PM_{10} concentration difference rose for LHR2-Harlington. Focusing on the northerly range of sectors, there is a measured excess concentration at LHR2 of over 4 $\mu g/m^3$ over a wide range of sectors, which is not surprising given the proximity of the Northern Perimeter Road (NPR) to LHR2, with a particular peak around 30° to 40°, similar to the peak found for NO_x concentrations. In the NO_x case, the peak was judged most likely to arise from traffic perturbations at the junction of the NPR with Neptune Rd, and this is judged also the most likely origin of the peak for PM_{10}. There are modelled differences of comparable magnitude to measured differences in some sectors, but the additional peak is missing.

3.3.25 For the sector range 270° to 100° (for which the road network accounts for essentially all of the modelled contribution to the period-mean concentration difference), Table 3.30 shows that the model underestimates the difference contribution by 24%, equivalent to an under-prediction of 0.5 $\mu g/m^3$. Table 3.24 shows that there is good agreement between modelled and measured values of total period-mean PM_{10} concentration at LHR2, so the under-prediction in the road network contribution offsets the over-prediction in the contribution from airport sources discussed earlier. This does not imply that the combined contribution from airport and road network sources has been perfectly predicted by the model. Even leaving aside measurement uncertainties, site-to-site differences in the background contribution (and in the LAEI/NAEI contribution) that have not been captured by the model may be offsetting an inaccuracy in the modelled value for the combined contribution from airport and road network sources. Nevertheless, the evidence indicates that any inaccuracy in the modelled contribution from airport and road network sources at LHR2 is not greater than the site-to-site variability in concentrations that has not been captured by the model (which has a standard deviation of around 2 $\mu g/m^3$, according to Table 3.24).

Oxford Avenue-Cranford

3.3.26 The site at Oxford Avenue is fairly close to the A4, so can in principle give information on the road-network contribution to PM_{10} concentrations, provided sectors are chosen that do not include a significant contribution from airport sources. A 'difference' site north of the airport is selected to reduce the risk of gradients in the background contribution affecting the differences: Fig 3.44 gives the PM_{10} concentration difference rose for Oxford Avenue-Cranford. Clearly, the modelling underestimates the concentration difference for southerly sectors, for which the wind blows from the road to monitoring site, with the discrepancy around 4 $\mu g/m^3$, which may be significant compared to measurement uncertainties. It is important to bear in mind that the traffic model outputs for the A4 were not been evaluated in the report on the interim traffic model, so it is not clear how much of the model-monitoring discrepancy derives from emissions quantification and/or dispersion modelling rather than from traffic model uncertainties.

3.3.27 Focusing on the sector range 90° to 180° to avoid the airport contribution at both sites, Table 3.30 shows that the model accounts for only 26% of the measured contribution to the period-mean PM_{10} concentration difference from this sector range, a discrepancy of 0.55 $\mu g/m^3$. If this level of underestimation was maintained over all southerly sectors, the total amount of under-prediction from the road-network contribution would be around 1.0-1.5 $\mu g/m^3$. Table 3.24 shows that the total period-mean PM_{10} concentration at Oxford Avenue is under-predicted by 1.4 $\mu g/m^3$, so the under-prediction of the road-network contribution could

account for the discrepancy in total period-mean concentration. However, the predicted contributions from the airport and road network sources are smaller than the potential site-to-site variation in the background contribution, so it is important not to over-interpret the results. In a similar analysis using Oaks Rd as the difference site (and the same sector range), the model accounts for 54% of the measured contribution, a discrepancy of 0.21 $\mu g/m^3$, giving some hint of the un-modelled site-to-site variability.

Hayes-Cranford

3.3.28 Hayes is the only kerbside site used in the model evaluation. Selecting Cranford as the difference site for reasons outlined earlier for Oxford Avenue, Fig 3.45 gives the PM_{10} concentration difference rose for Hayes-Cranford. As was the case for Oxford Avenue, the modelling clearly underestimates the concentration difference for southerly sectors, for which the wind blows from the road towards the monitoring site, with the discrepancy up to around 5 $\mu g/m^3$. Again, it is important to bear in mind that the traffic model outputs for the A437 were not been evaluated in the report on the interim traffic model, so it is not clear how much of the model-monitoring discrepancy may derive from emissions quantification and/or dispersion modelling. In addition, it should be noted that the Hayes instrument is a BAM (Beta Attenuation Monitor), so there additional measured concentration differences may arise from systematic inter-analyser differences.

3.3.29 Focusing on the sector range 90° to 210° to avoid the airport contribution at Cranford, Table 3.30 shows that the model accounts for around one half of the measured contribution to the period-mean PM_{10} concentration difference from this sector range, a discrepancy of 0.9 $\mu g/m^3$. If this level of underestimation was maintained over all southerly sectors, the total amount of under-prediction from the road-network contribution would be around 3 $\mu g/m^3$. Table 3.24 shows that the total period-mean PM_{10} concentration at Hayes is under-predicted by only 1.0 $\mu g/m^3$, so other contributions at Hayes must be overestimated to result in this level of agreement. However, these differences are small compared to measurement uncertainties.

Concentration Contours for Total Period-Mean PM_{10} Concentrations

3.3.30 On average, total period-mean PM_{10} concentrations are not under-predicted across the sites (discounting Harmondsworth) – Table 3.24 – but the comparisons presented above suggest there may be under-prediction of the road-network contribution (which is compensated by an over-prediction of the background (or LAEI/NAEI) contribution). However, the evidence is not strong, given the small magnitude of concentration differences compared to measurement uncertainties and the potential for un-modelled site-to-site variability in the background contribution. In addition, there is a question of how generalisable are the results for these three sites to the network as a whole, particularly to near-motorway receptors, given that the fidelity of the traffic data close to the sites has not been evaluated. Furthermore, discrepancies at LHR2 and Hayes may relate to localised flow perturbations at junctions. In consequence, therefore, the information provided by the PM_{10} evaluation is an inadequate basis for making a whole-network adjustment to modelled concentrations, so no adjustment factors have been applied to the (all-hours) model results on the grid of receptors used for generating contour plots. However, the potential for model underestimation close to junctions and to other regions of flow disturbance should be noted.

3.3.31 Fig 3.46 shows contours of modelled total period-mean PM_{10} concentrations, using the same colour coding for concentration as in the PSDH contour plots for 2002[*] (Fig 10.6 in the PSDH PSDH air quality report), for ease of comparison. Red and 'warmer' colours in the figure denote areas with period-mean PM_{10} concentration above 40 $\mu g/m^3$ (the limit value for annual-mean PM_{10} concentration). It is recognised that the annual-mean PM_{10} objective and limit value are defined for concentrations averaged over a calendar year. However, the model values for the 2008/9 period are indicative of the potential for the 40 $\mu g/m^3$ limit to have been exceeded in 2008. Off-airport values above 40 $\mu g/m^3$ are confined to areas within the road margins of the M4 and within about 30 m of the centre of the M25 (with

[*] PM_{10} contour plots were given for only the 2002 case in the PSDH air quality report.

concentration values east of the road centre higher than those west). Yellow (and warmer colours) in Fig 3.46 denotes values above 30 μg/m^3, so the contour for 31.5 μg/m^3 (the surrogate for the 24-hour limit) will be slightly inside the margins of the yellow area. Values above 31.5 μg/m^3 in 2008/9, according to the model, were confined to areas within about 30 m from the centre of the M4 and about 50 m from the centre of the M25. It is outside the scope of the present study to determine whether or not there is relevant public exposure in the narrow portions of these exceedence areas that lie outside the road margins.

3.3.32 It should be noted that the elevated concentration close to the northern runway are less prominent in Fig 3.46 than in the equivalent PSDH figure, principally because tyre-wear emissions have been confined to a smaller area of the runway in the 2008/9 modelling than in the PSDH work (and show up as small areas of higher concentration on the runway); brake-wear emissions have been distributed along the landing roll, as in the PSDH work.

3.3.33 The yellow and red areas on the contour plot should be taken as indicative of areas vulnerable to exceedence of the relevant limit, but the grid results may not have the spatial resolution to determine if individual receptors close to the relevant contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis. The spatial limitations of the PM_{10} contour plots are similar to those discussed earlier for the NO_x contours. In addition, when judging the risk of exceedence for near-road properties, care has to be taken to ensure that an individual receptor is located at the correct distance from the modelled road (which may differ from the position of the actual road, within the tolerance of the model's representation of the road network).

3.3.34 It is unfortunate that there were no near-motorway monitoring data available for PM_{10} comparisons, given that the model gives period-mean concentrations above the limit value close to the edge of the carriageway for sections of the M25 and M4. However, the Hillingdon PM_{10} monitor (40 m from the edge of the carriageway) was operational up to October 2007. The period-mean gravimetric-equivalent (TEOM*1.3) value for the last full twelve month period was 27.3 μg/m^3 and the value in the calendar year 2006 was 29.3 μg/m^3. If the gravimetric-equivalent value in 2008/9 was also 27.3 μg/m^3, the VCM-corrected value is likely to have been around 23.5 μg/m^3, judging from the range of corrections at other nearby sites, which is comparable to the modelled value of 23.2 μg/m^3. It is likely, however, that the measured value in 2008/9 would have been lower than in 2007, given the trend from previous years, so the model may be over-predicting by a few μg/m^3 in 2008/9 at this site.

3.3.35 The Staines M25B site operated by the Highways Agency/TRL is outside the study area and, as noted in Section 2, is so close to the motorway that it is sensitive to fine details of the spatial representation of emissions on the motorway that are beyond the spatial resolution of the modelling. Nevertheless, the south-west corner of the study area includes part of the same stretch of the M25 (J13 to J14) as that adjacent to the monitor, so a cross-check on the concentration at an equivalent distance from the modelled road was judged worthwhile. The annual-mean PM_{10} concentration at the site in 2008 (calendar year) was 26.3 μg/m^3 (TEOM*1.3), which is likely to yield a lower value when VCM-corrected. The monitoring site is 30 m from the centre-line of the motorway, close to the clockwise hard shoulder. According to the modelling, the period-mean concentration at this distance from the road is around 30 μg/m^3 which, although below the surrogate limit value of 31.5 μg/m^3, is higher than the measured value. This may indicate that concentrations very close to the M25 are overestimated, although the concentration gradients are steep this close to the road and the model may not overestimate at a few tens of metres further from the motorway.

3.3.36 In conclusion, in the absence of further opportunities for model evaluation close to motorways, the predicted areas of exceedence for PM_{10} close to the margins of the M4 and M25 should be treated with caution.

Comparison with PSDH Results for Total Period-Mean PM_{10} Concentration

3.3.37 Table 3.31 compares the modelled period-mean PM_{10} concentrations for 2008/9 with equivalent values for the 2002 PSDH and 2010SM cases. The contributions from airport sources have been compared earlier. The non-airport total cannot be broken down further

because the PSDH split between road-network sources and other LAEI sources is different from that in the 2008/9 modelling.

3.3.38 The total non-airport contribution in the 2008/9 results is on average closer to the PSDH value for the 2010SM case than for the 2002 PSDH case, as expected from the dominant influence of the rural background contribution. In turn, this leads to total PM_{10} concentrations that are on average closer to the PSDH results for the 2010SM case than to the results for the 2002 PSDH case.

3.4 $PM_{2.5}$

3.4.1 Three sites with $PM_{2.5}$ data were identified in Section 2 for inclusion in the comparison exercise, namely Oaks Rd, Green Gates and Harmondsworth. The Harmondsworth data were obtained using an OSIRIS system (see Section 2) and the data for Oaks Rd and Green Gates using a TEOM instrument. Further discussion of the limitations of the $PM_{2.5}$ monitoring data is given in Section 2.

3.4.2 Table 3.32 compares measured and modelled values of total period-mean $PM_{2.5}$ concentrations at the three sites*, and gives a breakdown of the modelled value by source. Clearly, the background component is the dominant contributor (9.6 $\mu g/m^3$), with the airport and road network sources together contributing at most 1.2 $\mu g/m^3$.

3.4.3 The agreement between measured and modelled values is within the expected measurement uncertainty for Oaks Rd and Green Gates, but there is significant over-prediction at Harmondsworth, by 41% (3.4 $\mu g/m^3$). The average fractional discrepancy between modelled and measured values is 17% and the average absolute discrepancy is 1.5 $\mu g/m^3$.

3.4.4 Even leaving aside measurement uncertainties, the comparison between modelled and measured total period-mean $PM_{2.5}$ values is not likely to provide any detailed information on the performance of the modelling for airport and road-network sources, given that their combined contribution is smaller than the uncertainty in the modelled value for the contribution from all other sources (principally the background contribution). The comparisons can indicate only that the combined contribution from the airport and the road network is not being under-predicted by a large factor (because then it would become apparent, despite uncertainties in the modelled background) but cannot indicate if the combined contribution is being over-predicted. The upper bound on the combined contribution is loosened further when measurement uncertainties are taken into account.

3.4.5 Similarly, for $PM_{2.5}$, concentration differences will be unable to provide any detailed information on the contribution from airport and road network sources – even leaving aside measurement uncertainties - given that the differences will be smaller than the expected site-to-site variability in the contribution from other sources that is not captured by the model. The different measurement technique used at Harmondsworth would further complicate the interpretation of differences involving that site.

3.4.6 Thus, in conclusion, no source-specific model evaluation is possible for $PM_{2.5}$, and the comparisons of total period-mean concentrations are able only to confirm that the predicted total concentrations are within the range expected based on the monitoring data and its uncertainties.

3.4.7 Fig 3.47 shows contours of modelled total period-mean $PM_{2.5}$ concentration. The 25 $\mu g/m^3$ level, shown in magenta, is of interest because of the objective (and limit) value for $PM_{2.5}$ (see Table 1.1), although this does not come into force until 2020 (2015). According to the modelling, values above 25 $\mu g/m^3$ were confined to areas within about 30 m of the centre-line of the M25 and within the road margins of a few other links of the major road network. The 20 $\mu g/m^3$ level is also of interest in terms of the Stage 2 indicative limit value (from 2015, subject to review by 2013). Areas with values above 20 $\mu g/m^3$ are shown in red (and

* For $PM_{2.5}$, the distinction between 'period-mean' and 'all-hour period mean' was ignored.

magenta) on Fig 3.47.

3.4.8 Although no detailed evaluation of the model predictions for the airport and road vehicle contributions has been possible, it is important to recognise that concentrations of $PM_{2.5}$ and PM_{10} are not unrelated. For combustion sources, it is likely that the contribution to PM_{10} concentration is very similar to the contribution to $PM_{2.5}$ concentrations (i.e. the particles that make up most of the PM_{10} mass are small enough that they also make up most of the $PM_{2.5}$ mass). This is not necessarily the case for fugitive emissions from brake and tyre wear, but the differences even for these sources is unlikely to be much more than a factor of two. Thus any observations made about the performance of the modelling for PM_{10} are likely to apply largely to $PM_{2.5}$. Thus, it is unlikely that the contribution to $PM_{2.5}$ concentrations from aircraft sources is being underestimated by a more than a factor of two, and areas close to motorways with predicted period-mean concentrations above 20 or 25 $\mu g/m^3$ should be treated with caution.

4 Conclusions

NO_x

4.1 Total period-mean NO_x concentrations are predicted with an average fractional discrepancy (defined as *(modelled value-measured value/measured value)*) of -5.2% (i.e. the model under-predicts on average by 5.2% across the sites), with a standard deviation of 12.2% (12 sites), where the latter is a measure of the site-to-site variability in the measured values that has not been captured by the model. Assuming the measurement uncertainty (one standard deviation) for long-period average NO_2 concentrations from continuous analysers to be around 5%, the observed bias is highly unlikely to be explained by statistical measurement fluctuations for a finite sample of 12 sites. Similarly, a large fraction of the unexplained site-to-site variability is unlikely to be attributable to measurement uncertainties. Thus, the model is slightly biased towards under-prediction of total period-mean NO_x concentrations.

4.2 The three sites with the largest contribution from emissions on the road network have significant negative values of the fractional discrepancy, suggesting that there is a systematic underestimation of this contribution, which is offset by an overestimation of other contributions across the sites leading to a quite small average fractional discrepancy.

Airport Sources

4.3 A comparison of measured and modelled NO_x concentration differences between sites north of the airport and Oaks Rd (south of the airport) for selected wind directions indicates that the model has no significant tendency either to overestimate or to underestimate the contribution of airport sources* to the period-mean NO_x concentrations at receptors in the residential areas north of the airport, to the level of accuracy allowed by measurement uncertainties. In particular, it represents well the variation in the airport concentration contribution with distance from the principal sources on the airport and the variation with east-west location in relation to the ends of the northern runway.

4.4 This gives confidence that the model provides a good basis for investigating the potential impact on residential areas of operational changes on the airport that affect the magnitude and spatial distribution of NO_x emissions, for example the abandonment of the Cranford agreement (which would then allow departures on runway 09L) and the construction of a third runway north of the current runways. It also indicates that the model tendency to underestimate total period-mean NO_x concentrations is unlikely to arise from the modelling of airport sources.

4.5 A breakdown of the concentration differences across the airport by wind speed indicates a tendency for the model to overestimate at low wind speeds and underestimate at high wind speeds. Thus the remarkable level of agreement (for sites north of the airport) between modelled and measured values of the airport contribution to period-mean NO_x concentration is partly fortuitous, arising from a compensation between the two tendencies, and may not be maintained to the same extent if the met data in a given year exhibited a markedly different wind speed distribution to that in 2008/9. Nevertheless, given that the agreement is reasonably good in every wind-speed bin, it would require a major shift in wind-speed frequency distribution to generate a significant discrepancy. The observed trend with wind speed could point to inaccuracies in the plume-rise modelling for aircraft sources, but the evidence from comparisons involving little influence from aircraft sources indicates that this cannot be the full explanation.

4.6 At Oaks Rd, close to the southern boundary of the airport, concentration-difference comparisons indicate that the modelling overestimates the contribution from airport sources by around 3 $\mu g/m^3$ (for a total airport contribution of 17 $\mu g/m^3$). The apparent greater

* Defined to include all sources within the airport perimeter plus elevated (LTO) aircraft sources, although the latter make a small contribution to ground-level concentrations once they are above a few hundred metres in height.

overestimation of the airport contribution at Oaks Rd than at sites north of the airport may derive partly from the tendency noted above for the model to overestimate at low wind speeds, which has a greater effect south of the airport due to the greater probability of low wind speeds for northerly winds than for southerly winds. Nevertheless, the discrepancy at Oaks Rd is only of comparable size to the judged uncertainty in measured differences in period-mean concentrations.

4.7 Given the evidence that the modelling is a reliable basis for predicting the spatial variation of the contribution from airport sources to period-mean NO_x concentrations around the airport, contours of this contribution have been derived from model results on a spatial grid of receptor points. These indicate that NO_x contributions from airport sources above 30 $\mu g/m^3$ in 2008/9 were confined to areas within the airport boundary, with the contribution in the nearest residential areas in the range 10-20 $\mu g/m^3$. The modelled contribution from airport sources falls to at most 6.3 $\mu g/m^3$ at the M4 motorway, but varies in an east-west direction along the motorway as a result of the contour shape, which is governed by the prevalence of south-westerly winds coupled with the spatial distribution of sources on the airport. Contour shapes show some differences from those calculated for 2002 in the PSDH work, partly as a result of the opening of T5 and partly due to a greater frequency of westerly winds in 2008/9 than in 2002.

4.8 A detailed comparison of the 2008/9 modelled values of the airport contribution at 13 representative sites with corresponding values from the PSDH work shows that the 2008/9 values are broadly comparable to those for the PSDH 2002 and 2010SM cases, which is in line with the magnitude of the estimated airport emissions for the three cases. There are some detailed differences from the PSDH results not related to emission differences that principally reflect differences in the wind rose between 2008/9 and 2002.

Road-Network Sources

4.9 Comparison of concentration differences for pairs of sites with one of the sites (Hillingdon, LHR2, Hayes, Oxford Avenue) strongly affected by a nearby road indicates that the modelling underestimates the contribution to period-mean NO_x concentrations from emissions on the major road network around Heathrow; this reinforces the evidence provided by an examination of the discrepancies in total period-mean concentrations noted earlier. The extent of the underestimation is significantly greater than can be attributed solely to measurement errors on concentration difference.

4.10 It is tempting to interpret the these results as confirmation of recent evidence that NO_x emissions factors for road vehicles are being underestimated. However, it would be premature to draw such conclusions before the basic traffic data used in the emissions quantification have been fully evaluated. There is evidence that modelled total traffic flow on the M4 motorway adjacent to the Hillingdon site is well represented, but there is no information on how realistic are the predictions of HDV (bus/coach and HGV) fraction and vehicle speed, parameters that are particularly important from an emissions perspective. For the M25, it appears that, in addition, total flows are underestimated.

4.11 There is some evidence from the concentration differences that a key contributor to the discrepancies at near-road receptors relates to network intersections or other areas of flow disturbance, which lead to traffic queues, flow breakdown or changes in speed. It is possible to account for queues in the emissions methodology if they are explicitly recognised in the traffic data, but in the set of data available for the 2008/9 inventory link any delays were absorbed into effective link speeds, thereby not allowing the spatial distribution of queuing emissions to be represented. It is recommended that this deficiency is removed in future traffic data sets generated for air quality assessment purposes. With reference to speed data, it may not be enough to provide hourly-averaged speed if this speed is the net effect of periods of smooth flow interspersed with periods of flow breakdown.

4.12 There appears to be an additional discrepancy between modelling and measurements at Green Gates, not attributable to airport sources and not readily explained in terms of under-prediction of the contribution from the major road network around Heathrow. This may point

to a local source not included in the modelling, although measurement uncertainties for concentration differences may also have played a part. Although large point sources have been modelled individually, it cannot be ruled out that the 1-km spatial resolution of emissions from medium-sized point sources in the LAEI may be having an influence on the accuracy of modelled concentrations close to Green Gates.

4.13 There are also additional discrepancies in NO_x concentrations at Hayes that cannot be explained in terms of under-prediction of the road network contribution. Hayes has a particularly large contribution from area sources representing emissions from the LAEI and NAEI inventories (including a substantial contribution from the Great Western railway line). However, there is not enough information to determine if the discrepancy arises from sources local to the site or is more widespread in Hayes.

4.14 The observed discrepancies point to the need for a more detailed evaluation of traffic model outputs and how these are used to calculate emissions. It may be advantageous to defer that work until a traffic model is available that has been calibrated and validated with particular reference to those traffic characteristics that are key to the quantification of road traffic emissions and to the estimation of the road-network contribution to airborne pollutant concentrations.

4.15 In the interim, in order to generate a 'best-estimate' modelled NO_x concentration field around the airport, the road-network NO_x contribution was scaled everywhere by a constant factor (1.21) chosen so that the average discrepancy between modelled and measured period-mean NO_x concentrations across the 12 monitoring sites reduced to zero. This simple procedure has the merit of increasing the concentrations more in absolute terms in areas where the road network makes a large contribution, reflecting the evidence from the monitoring data, but is unlikely to remove all the discrepancy relating to the road network at sites such as Hayes and LHR2 (although at least some of the discrepancy at these sites may be due to features specific to the site and not necessarily generalisable to other receptors). Also, the scaled NO_x concentration field may still underestimate concentrations at near-road receptors that are strongly influenced by traffic queuing at junctions or are situated close to areas of the network subject to other types of flow disruption.

4.16 Although the average discrepancy across the sites has been reduced to zero, it is likely that there is a residual tendency towards overestimation at receptors immediately south of the airport because of an over-prediction of the contribution from airport sources in northerly winds. Similarly, for receptors to the (north) west of the airport there may be a systematic residual underestimation because of the under-prediction of the contribution from the M25.

4.17 The contour plot of period-mean NO_x concentration based on the set of 2008/9 results that include the road-network scaling factor is much closer in appearance to the equivalent plot for the PSDH 2002 case than for the PSDH 2010SM case. However, the NO_x 75 $\mu g/m^3$ contour in the 2008/9 results (approximately equivalent to the NO_2 40 $\mu g/m^3$ contour) does not extend as far from the airport boundary into Harlington as in the 2002 results; also, a smaller area of Hayes between the railway line and the M4 is above 75 $\mu g/m^3$.

4.18 A more detailed comparison with the PSDH results for 13 representative sites shows that the non-airport contribution in 2008/9 is much closer to the equivalent PSDH contribution for 2002 than for the 2010SM cases, with the average over the 13 sites 3.5% lower for 2008/9 than for the 2002 PSDH case and 42% higher than for the PSDH forecast 2010SM case. Although the calculated 2008/9 value of the total NO_x emissions on the designated road network is around 30% lower than that quoted for the 2002 PSDH case (for a closely equivalent network), the scaling up of the road network contribution by 21% largely offsets this reduction. Combining the airport and non-airport contributions, the average total NO_x concentration across the 13 sites for the 2008/9 case is 3.8% lower than for the 2002 PSDH case and 29.3% higher than for the 2010SM case.

NO_2

4.19 The availability of ozone measurements at three of the monitoring sites included in the analysis allows a separate test of the component of the methodology for deriving NO_2 concentrations from NO_x concentrations that predicts the total oxidant (sum of O_3 and NO_2) concentration from the background oxidant and the local NO_x concentrations. The modelled values agreed with measured values within the level of accuracy of the measurements, with an average fractional discrepancy between modelled and measured values of 6% (overestimation).

4.20 A comparison of modelled and measured period-mean NO_2 concentrations at the 13 monitoring sites included in the study – using the modelled NO_2 concentrations derived from NO_x concentrations that include the road-network scaling factor – gives an average fractional discrepancy of 1.6% (i.e. the model overestimates by on average 1.6%), with a standard deviation of 9.7%. For comparison, using NO_x concentrations that do not include the road-network scaling factor, the average fractional discrepancy in period-mean NO_2 concentrations is -1.8% (i.e. an underestimation of 1.8%), with a standard deviation of 9.7%. Neither of the two values of average fractional discrepancy can be interpreted as a significant model bias.

4.21 The performance of the Jenkin approach for deriving period-mean NO_2 concentrations from period-mean NO_x concentrations can be separated from the performance of the modelling for NO_x concentrations to some extent (though not fully) by comparing NO_2/NO_x ratios. Using the NO_x results that include the road-network scaling, the average fractional discrepancy in the NO_2/NO_x ratios is 2.1% (i.e. the model on average overestimates the ratio by 2.1%) with a standard deviation of 5.5%. For comparison, without the road-network scaling factor, the average fractional discrepancy is 4.1% with a standard deviation of 6.0%. This level of agreement is within what is expected from the semi-empirical (Jenkin) methodology used for this study, judging from the scatter on the data points used to derive the underlying $[NO_2]/[OX]$ relationship. Thus, the results indicate that the Jenkin methodology does not introduce any significant bias into the model results, so that once the bias in NO_x concentrations has been removed no further model adjustment is necessary.

4.22 The NO_2 concentration results on a grid of receptors have been used to generate contours of period-mean NO_2 concentration in 2008/9. Areas of exceedence of the annual-mean limit (40 $\mu g/m^3$) extend out into residential areas from the airport boundary, from the motorways and from the Great Western railway line, in accord with the areas of highest emission density. The grid results may not have the spatial resolution to determine if individual receptors close to the contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis. It should be borne in mind that the NO_2 contours presented should be viewed as 'interim' on the grounds that they have been derived from NO_x values based on the interim traffic model results, adjusted using the simple road-network scaling factor.

4.23 Comparing the 2008/9 NO_2 contour plot with the equivalent 2002 PSDH plot shows that the exceedence areas extend further out from the motorway and railway line into residential areas, despite the NO_x concentrations in 2008/9 being on average similar to or slightly lower than in the 2002 PSDH results at a given location, implying that the NO_2/NO_x ratios are higher in 2008/9. On the other hand, the exceedence area in 2008/9 does not extend as far into Harlington from the airport boundary as in the 2002 PSDH case, reflecting the lower NO_x concentrations in this area. The increase in NO_2/NO_x ratios can be traced primarily to the higher average primary NO_2 fraction in 2008/9 compared to that applicable to the 2002 analysis, principally resulting from the higher fractions now associated with road-traffic NO_x emissions.

4.24 Examining the changes from the PSDH results in more detail at the 13 representative receptors shows that the average modelled NO_2 concentration across these sites for 2008/9 is 4.7% higher than for the 2002 PSDH case, whereas the average NO_x concentration is 3.8% lower. as noted above. Thus, the modelled NO_2/NO_x ratios for 2008/9 are on average 7.9% higher than for the 2002 PSDH case, whereas they are lower than for the PSDH

2010SM case by on average 11.6%.

PM_{10}

4.25 Based on data from the ten continuous PM_{10} analysers in the study area, the average fractional discrepancy between modelled to measured total period-mean PM_{10} concentration is -0.4 %, with a standard deviation of 17.5%. The measured value at Harmondsworth is an outlier, suggesting either an instrumental problem or the influence of a local source not included in the modelling. It is worth noting that the instrument at Harmondsworth is a BAM (Beta Attenuation Monitor), whereas the instruments at the other sites (except Hayes) are of the TEOM type.

4.26 Excluding Harmondsworth, the average fractional discrepancy is 4.3% (i.e. the model overestimates by 4.3% on average), with a standard deviation of 9.5%. The average fractional discrepancy both with and without Harmondsworth is lower than the accuracy of the measurement techniques, so the comparison is able to demonstrate only that any model bias for total period-mean concentrations is less than the uncertainty in the measurements.

4.27 The modelled contribution from the designated road network and airport sources is on average only 2.3 $\mu g/m^3$ (maximum 5.2 $\mu g/m^3$, at LHR2) compared to a modelled background contribution of 17.2 $\mu g/m^3$, so the model-monitoring comparisons of total period-mean concentration mainly assess the background contribution. Furthermore, the smallness of the modelled contribution from airport and road-network sources highlights the difficulty of evaluating the performance of the modelling for these sources even using difference analysis, given that the expected differences are only comparable to 'natural' variation in the background (i.e. site-to-site variations in the background that are not captured by the modelling) and less than measurement uncertainties.

Airport Sources

4.28 Comparison of modelled and measured PM_{10} concentration differences between LHR2 and Oaks Rd and between Harlington and Oaks Rd indicates that the underestimation or overestimation of the contribution from airport sources to period-mean PM_{10} concentrations, if any, is less than estimated measurement uncertainties.

4.29 For LHR2, the model appears to overestimate the contribution from emissions on the runway (principally from brake and tyre wear), which could result from inaccuracies in the spatial distribution of the emissions rather than in the magnitude of the total emissions. Taking the measurement uncertainty on the period-mean concentration difference as 3 $\mu g/m^3$ would imply that any underestimation of the airport contribution at LHR2 is at most a factor of two (for a modelled contribution of 2.3 $\mu g/m^3$). At Harlington, there is good agreement between the modelled and measured concentration difference in a wind direction range giving a dominant contribution from airport sources. However, the differences are less than 1 $\mu g/m^3$, which is less than the estimated measurement uncertainties.

4.30 The measured PM_{10} concentration difference between Green Gates and Oaks Rd for wind directions giving an an airport contribution at Green Gates is negative whereas the modelled difference is positive, although small in magnitude in both cases. This emphasises the difficulty in interpreting such small differences.

4.31 Based on the model results, the contribution from airport sources to total period-mean PM_{10} concentration in 2008/9 was between 0.1 and 1.0 $\mu g/m^3$ in the residential areas just north of the airport (out of a total of around 20 $\mu g/m^3$), reaching around 2 $\mu g/m^3$ at the airport perimeter.

4.32 Comparing the 2008/9 model results for the contribution from airport sources to period-mean PM_{10} concentrations with equivalent results from the PSDH for the 2002 and 2010SM cases shows that at a given location the contributions are broadly comparable, as expected from the magnitude of airport emissions for the three cases. The principal differences in the 2008/9 results can be related to differences in meteorology.

Road-Network Sources

4.33 The three sites with the largest modelled road-network contribution to period-mean PM_{10} concentration are LHR2, Oxford Avenue and Hayes. None of these sites is close to a motorway. Comparison of modelled and measured concentration differences for LHR2-Harlington shows a missing modelled contribution to period-mean PM_{10} concentrations at LHR2 deriving from a narrow range of north-easterly wind directions, similar to that found for NO_x at LHR2. In the NO_x case, the peak was judged most likely to arise from traffic perturbations at the junction of the NPR with Neptune Rd, and this is judged also the most likely origin of the peak for PM_{10}. The total contribution to the period-mean concentration represented by the missing peak, however, is less than 1 $\mu g/m^3$.

4.34 The comparisons chosen to highlight the road-network contribution suggest that it may be under-predicted (with a compensating over-prediction of the background or LAEI/NAEI contributions). However, the evidence is not strong, given the small magnitude of concentration differences compared to measurement uncertainties and the potential for un-modelled site-to-site variability in the background contribution. In addition, there is a question of how generalisable are the results for these three sites to the network as a whole, particularly to near-motorway receptors, given that the fidelity of the traffic data close to the sites has not been evaluated. Furthermore, discrepancies at LHR2 and Hayes may relate to localised flow perturbations at junctions. Thus, the information provided by the PM_{10} evaluation is an inadequate basis for making a whole-network adjustment to modelled concentrations, so no adjustment factors have been applied to the model results on the grid of receptors used for generating contour plots. However, the potential for model underestimation close to junctions and to other regions of flow disturbance should be noted.

4.35 Contour plots based on the modelling results show that off-airport values above the 40 $\mu g/m^3$ limit value for annual mean PM_{10} concentration within the study area in 2008/9 were confined to areas within the road margins of the M4 and other major roads and within about 30 m of the centre of the M25 (with concentration values east of the M25 road centre higher than those west). Off-airport values above the surrogate annual mean value of 31.5 $\mu g/m^3$, used to test the limit on 24-hour mean concentrations, were principally confined to areas within about 30 m from the centre of the M4 and about 50 m from the centre of the M25. These areas should be taken as indicative of areas vulnerable to exceedence of the relevant limit, but the grid results may not have the spatial resolution to determine if individual receptors close to the relevant contour are within or outside the exceedence area, which would require closer investigation on a receptor-by-receptor basis.

4.36 The data used in the evaluation for PM_{10} does not provide a good test of the model at distances of a few tens of metres from a major motorway, so the predicted areas of exceedence close to the margins of the M4 and M25 should be treated with caution. There is some tentative evidence that the modelled 2008/9 PM_{10} concentrations close to the margins of these motorways are overestimates.

4.37 A comparison of the 2008/9 values for total PM_{10} concentration with equivalent values for the PSDH 2002 and 2010SM cases, using 13 representative receptor locations, shows that the 2008/9 values are on average closer to the PSDH results for the 2010SM case than to the results for the 2002 PSDH case, principally reflecting the fall in the background contribution since 2002.

$PM_{2.5}$

4.38 There were only three $PM_{2.5}$ monitoring sites operating in the study area in 2008/9 (Oaks Rd, Green Gates and Harmondsworth). In the modelling, the background component is the dominant contributor (9.6 $\mu g/m^3$) at these sites, with the airport and road network sources together contributing at most 1.2 $\mu g/m^3$.

4.39 The agreement between measured and modelled values is within the expected measurement uncertainty for Oaks Rd and Green Gates but there is significant over-

prediction at Harmondsworth, by 41% (3.4 μg/m^3)*. The average fractional discrepancy between modelled and measured values is 17% and the average absolute discrepancy is 1.5 μg/m^3.

4.40 Even leaving aside measurement uncertainties, the comparison between modelled and measured total period-mean $PM_{2.5}$ values was unable to provide any detailed information on the performance of the modelling for airport and road network sources, given that their combined contribution is smaller than the uncertainty in the modelled contribution from all other sources (principally the background contribution).

4.41 Similarly, comparisons of $PM_{2.5}$ concentration differences are unable to provide any detailed information on the contribution from airport and road network sources, given that the modelled differences are smaller than the site-to-site variability in the contribution from other sources that is not captured by the model (and smaller than expected measurement uncertainties on concentration differences). The different measurement technique used at Harmondsworth (OSIRIS) further complicates the interpretation of differences involving that site. Thus, no source-specific model evaluation was possible for $PM_{2.5}$, and the comparisons of total period-mean concentrations were able only to confirm that the predicted total concentrations are within the range expected based on the monitoring data and its uncertainties.

4.42 Contour plots of total period-mean $PM_{2.5}$ concentration indicate that, according to the modelling, the values above 25 μg/m^3 limit/objective (coming into force in 2020/2015 respectively) were confined largely to areas within about 30 m of the M25. The caveats placed earlier on modelled PM_{10} concentrations at such close proximity to the M4 and M25 motorways apply to $PM_{2.5}$ also.

* It is worth noting that the instrument at Harmondsworth is of the OSIRIS (light-scattering) type, whereas the other two sites have TEOM instruments

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Tables and Figures

Table 1.1 Relevant air quality strategy objectives and EU limit values for selected pollutants

Pollutant	Objective	Metric[a]	Date[b]	European obligations	Date[b]
Nitrogen dioxide (NO_2)	200 µg/m^3 not to be exceeded more than 18 times per year	1 hour mean	31.12.2005	200 µg/m^3 not to be exceeded more than 18 times per year	1.1.2010
	40 µg/m^3	annual mean	31.12.2005	40 µg/m^3	1.1.2010
Particles[c] (PM_{10})	50 µg/m^3 not to be exceeded more than 35 times a year	24 hour mean	31.12.2004	50 µg/m^3 not to be exceeded more than 35 times a year	1.1.2005
	40 µg/m^3	annual mean	31.12.2004	40 µg/m^3	1.1.2005
Particles[d] ($PM_{2.5}$)	25 µg/m^3	annual mean	2020	Limit value 25 µg/m^3	1.1.2015
		annual mean		Stage 2 indicative limit value of 20 µg/m^3	1.1.2020[e]
				Exposure concentration obligation of 20 µg/m^3	1.1.2015[e]
	Target of 15% reduction in concentrations at urban background	annual mean	between 2010 and 2020	Exposure reduction target relative to the 2010 AEI[f] (0% to 20% reduction)	2020

[a] Averaging period
[b] Date to be achieved by and maintained thereafter
[c] The objectives given here for PM_{10} do not apply in Scotland.
[d] AQS objectives for $PM_{2.5}$ have not been included in Regulations for the purpose of Local Air Quality Management. (The limit value given here for $PM_{2.5}$ does not apply in Scotland.)
[e] Will be reviewed by the European Commission by 2013
[f] The three-year running annual mean or AEI is calculated from the $PM_{2.5}$ concentration averaged across all urban background locations in the UK (ie. the AEI for 2010 is the mean concentration measured over 2008, 2009 and 2010).

Table 2.1 Monitoring site information

Site name	Short name	Easting	Northing	Network	Pollutants	Location
Heathrow LHR2	LHR2	508393	176742	LAQN	NO, NO_2, PM_{10} (TEOM), O_3, CO	Within boundary fence of airport. Approx. 180 m north of runway 27R centre-line, 500 m from the end. Approx. 19 m south of centre of Northern Perimeter Road, near junction with Neptune Road. Fig 2.2 (a)
Heathrow Oaks Road	Oaks Rd	505729	174496	Airport	NO, NO_2, PM_{10} (TEOM), $PM_{2.5}$, O_3	Alongside residential road in residential area adjacent to parkland. Approx. 200 m south of Southern Perimeter Road. Fig 2.2 (b)
Heathrow Green Gates	Green Gates	505185	176922	Airport	NO, NO_2, PM_{10} (TEOM), $PM_{2.5}$	In parkland adjacent to residential area, approx. 400 m north of west end of runway 09L. Fig 2.2 (c)
Slough Colnbrook	Colnbrook	503542	176827	Slough	NO, NO_2, PM_{10} (TEOM)	In grounds of Pippins primary school, between residential and industrial areas. Approx. 500 m west of the M25. Fig 2.2 (d)
London Hillingdon Harmondsworth	Harmondsworth	505561	177661	Hillingdon	NO, NO_2, PM_{10} (BAM), PM_{10} (Osiris), $PM_{2.5}$ (Osiris), PM_1 (Osiris), TSP (Osiris)	Alongside minor road on outskirts of Harmondsworth village, adjacent to residential and commercial areas and parkland. Approx 900 m north of airport perimeter road. Fig 2.2 (e)
London Hillingdon	Hillingdon	506945	178609	AURN	NO, NO_2, O_3, SO_2, CO	At end of Sipson Road cul-de-sac, in a residential area bounded on the south by the M4. Approx. 40 m north of the nearest lane of the M4. Fig 2.2 (f)
Hillingdon Sipson	Sipson	507325	177280	Hillingdon	NO, NO_2	At the end of Ashby Way, a cul-de-sac in a residential area adjacent to parkland. Approx. 300 m north of the A4 (T) Bath Road. Fig 2.2 (g)
London Harlington	Harlington	508299	177809	AURN	NO, NO_2, PM_{10} (TEOM), $PM_{2.5}$, O_3, CO	Alongside minor road amidst farmland, approx. 300 m west of outskirts of Harlington and 1 km north of airport perimeter road. Fig 2.2 (h)
London Hillingdon 3 Oxford Avenue	Oxford Ave	509551	176974	LAQN	NO, NO_2, PM_{10} (TEOM)	In residential area, approx. 10 m from centre of residential road Oxford Avenue, and approx. 30 m north of centre of A4 Bath Road. Approx. 300 m north-east of Northern Perimeter Road. Fig 2.2 (i)
Hillingdon Hayes	Hayes	510283	178905	Hillingdon	NO, NO_2, PM_{10} (BAM)	On the corner of busy A437 North Hyde Road and side-road North Hyde Gardens in mixed residential, commercial and industrial area. Approx. 10 m from edge of North Hyde Road, approx. 1 m from kerb of North Hyde Gardens. Fig 2.2 (j)
Hounslow 2 - Cranford	Cranford	510371	177198	LAQN	NO, NO_2, PM_{10} (TEOM), O_3, SO_2	In residential area adjacent to parkland. Fig 2.2 (k)
Hounslow Hatton Cross	Hatton Cross	509332	174997	LAQN	NO, NO_2, PM_{10} (TEOM)	At end of Myrtle Grove cul-de-sac, adjacent to parkland. Approx. 100 m south-east of A30 (T) Great South West Road. Fig 2.2 (l)

Table 2.2 (a) Data characteristics for NO_x

Short name	Data source[a]	Ratification status[b]	Data capture (%)	Longest run of missing data (hours)	Period mean ($\mu g/m^3$)	Max hourly average ($\mu g/m^3$)	25th %ile of hourly averages ($\mu g/m^3$)	75th %ile of hourly averages ($\mu g/m^3$)	IQR[c]
LHR2	HAW	R	99.1	24	115.3	993.0	48.0	160.0	3.33
Oaks Rd	HAW	R	92.5	356	58.7	592.0	17.0	82.0	4.82
Green Gates	HAW	R	85.4	1205	75.2	894.0	29.0	88.0	3.03
Colnbrook	HAW	R	99.5	27	56.1	722.0	15.0	69.0	4.60
Harmondsworth	HA	P 1/1/09-31/3/09	93.2	399	63.6	672.0	23.0	74.0	3.22
Hillingdon	HAW	R	82.1	1224	108.1	861.0	40.0	145.0	3.63
Sipson	HAW	R	99.6	4	68.4	3719.0	27.0	82.0	3.04
Harlington	HAW	R	88.9	802	62.7	810.0	25.0	74.0	2.96
Oxford Ave	LA	P 1/9/08-31/3/09	90.8	439	83.7	785.4	36.1	106.6	2.95
Hayes	HAW	R	84.3	733	124.8	1207.0	53.0	157.0	2.96
Cranford	LA	P 27/2/09-31/3/09	81.7	424	64.0	793.3	25.0	74.7	2.99
Hatton Cross	LA	P 20/2/09-31/3/09	81.4	897	66.7	704.6	21.6	85.7	3.97

[a] HAW= www.heathrowairwatch.org.uk; LA = www.londonair.org.uk; HA = www.hillingdon-air.info
[b] R= ratified; P=provisional between dates shown, ratified otherwise
[c] IQR: Inter-quartile ratio= 75th percentile value/25th percentile value

Table 2.2 (b) Data characteristics for NO_2

Short name	Data source[a]	Ratification status[b]	Data capture (%)	Longest run of missing data (hours)	Period mean (µg/m^3)	Max hourly average (µg/m^3)	Number of hours >200 µg/m^3	99.8th %ile of hourly values
LHR2	HAW	R	99.1	24	52.4	168.0	0	139
Oaks Rd	HAW	R	92.5	356	36.9	160.0	0	127
Green Gates	HAW	R	85.4	1205	40.7	166.0	0	128
Colnbrook	HAW	R	99.5	27	32.0	160.0	0	121
Harmondsworth	HA	P 1/1/09-31/3/09	93.2	399	34.3	124.0	0	107
Hillingdon	HAW	R	82.1	1224	50.8	178.0	0	143
Sipson	HAW	R	99.6	4	38.9	592.0	2	122
Harlington	HAW	R	88.9	802	34.9	147.0	0	112
Oxford Ave	LA	P 1/9/08-31/3/09	90.8	439	43.8	146.0	0	120
Hayes	HAW	R	84.3	733	54.9	204.0	4	180
Cranford	LA	P 27/2/09-31/3/09	81.7	424	36.2	151.9	0	117
Hatton Cross	LA	P 20/2/09-31/3/09	81.4	897	34.4	150.1	0	115

[a] HAW= www.heathrowairwatch.org.uk; LA = www.londonair.org.uk; HA = www.hillingdon-air.info
[b] R= ratified; P=provisional between dates shown, ratified otherwise

Table 2.2 (c) Data characteristics for PM_{10}

Short name	Data source[a]	Ratification status[b]	Data capture (%)	Longest run of missing data (hours)	Raw period mean ($\mu g/m^3$)	Corrected period mean[c] ($\mu g/m^3$)	Maximum hourly mean ($\mu g/m^3$)	Number of 24-hour periods >50 $\mu g/m^3$	90th %ile of 24-hour means ($\mu g/m^3$)
LHR2	HAW	R	96.8	70	20.8	23.9	122.1	13.0	44.9
Oaks Rd	HAW	R	93.3	406	16.6	19.7	114.1	7.0	37.2
Green Gates	HAW	R	98.0	70	13.8	16.8	95.1	1.0	32.4
Colnbrook	HAW	R	98.0	70	16.2	19.2	134.7	5.0	36.6
Harmondsworth (BAM)	HA	P 1/1/09-31/3/09	86.0	565	42.0	34.7	678.0	45.0	57.0
Harmondsworth (Osiris)	HA	P 1/1/09-31/3/09	86.9	971	25.8	-	157.0	13.0	45.8
Harlington	HAW	R	87.3	562	17.9	21.0	126.5	8.0	38.5
Oxford Ave	LA	P 30/3/09-31/3/09	94.3	154	20.9	22.9	257.5	2.0	39.4
Hayes	HAW	R	83.0	733	27.3	22.5	135.0	4.0	39.0
Cranford	LA	P 4/3/09-31/3/09	88.3	467	17.7	18.9	91.7	1.0	33.3
Hatton Cross	LA	P 20/2/09-31/3/09	70.1	2397	18.7	20.7	156.1	0.0	34.2

[a] HAW= www.heathrowairwatch.org.uk; LA = www.londonair.org.uk; HA = www.hillingdon-air.info
[b] R= ratified; P=provisional between dates shown, ratified otherwise
[c] Correction depends on type of analyser: TEOM data have been corrected using VCM method; BAM corrected by dividing by 1.2

Table 2.2 (d) Data characteristics for $PM_{2.5}$

Short name	Data source[a]	Ratification status[b]	Data capture (%)	Longest run of missing data (hours)	Period mean ($\mu g/m^3$)	Maximum hourly mean ($\mu g/m^3$)
Oaks Rd	HAW	R	95.3	356	11.6	50.0
Green Gates	HAW	R	98.6	5	11.0	50.0
Harmondsworth (Osiris)	HA	P 1/1/09-31/3/09	86.9	971	8.3	84.0

[a] HAW= www.heathrowairwatch.org.uk; HA = www.hillingdon-air.info
[b] R= ratified; P=provisional between dates shown, ratified otherwise

Table 2.2 (e) Data characteristics for ozone

Short name	Data source[a]	Ratification status[b]	Data capture (%)	Longest run of missing data (hours)	Period mean ($\mu g/m^3$)
Hillingdon	HAW	R	99.1	27	29.0
Harlington	HAW	R	98.9	27	33.7
Cranford	LA	P 4/3/09-31/3/09	77.0	623	32.9

[a] HAW= www.heathrowairwatch.org.uk; LA = www.londonair.org.uk
[b] R= ratified; P=provisional between dates shown, ratified otherwise

Table 2.3 Comparison of predicted and measured number of daily of exceedence of 50 $\mu g/m^3$ PM_{10}

Site	Period mean ($\mu g/m^3$)	Number of days >50 ($\mu g/m^3$)	
		Predicted	Measured
LHR2	23.9	10.0	13
Oaks Rd	19.7	3.0	7
Green Gates	16.8	0.6	1
Colnbrook	19.2	2.5	5
Harmondsworth	34.7	47.9	45
Harlington	21.0	4.7	8
Oxford Avenue	22.9	7.9	2
Hayes	22.5	7.2	4
Cranford	18.9	2.2	1
Hatton Cross	20.7	4.3	0

Table 3.1 Comparison of modelled period-mean NO_x concentrations[a] with measured values for continuous NO_x/NO_2 analysers[b]

Site	Modelled period-mean NO_x concentrations ($\mu g/m^3$)										Measured ($\mu g/m^3$)	FD[d]
	Airport					Off-airport				Grand total ($\mu g/m^3$)		
	Aircraft	APU	Airside vehicles	Other airport[c]	Airport sub-total	Road traffic	LAEI/NAEI	Background	Off-airport sub-total			
LHR2	25.13	3.27	3.63	0.94	32.98	35.22	25.47	14.31	75.00	107.98	115.26	-6.3
Oaks Road	8.99	3.62	3.49	1.00	17.10	9.90	23.82	14.27	47.99	65.09	58.68	10.9
Green Gates	1.38	1.19	1.38	0.36	4.31	16.09	26.03	14.92	57.04	61.35	75.20	-18.4
Colnbrook	1.10	0.35	0.46	0.15	2.06	13.53	24.23	14.31	52.06	54.13	56.12	-3.5
H'worth	1.22	0.85	1.02	0.25	3.35	14.37	26.52	13.90	54.78	58.13	63.59	-8.6
Hillingdon	1.95	0.85	0.84	0.31	3.95	48.44	29.63	13.92	91.99	95.95	108.15	-11.3
Sipson	5.51	2.17	2.26	0.70	10.64	13.24	27.53	14.24	55.01	65.65	68.39	-4.0
Harlington	5.53	1.36	1.47	0.53	8.88	13.64	29.80	14.49	57.94	66.81	62.74	6.5
Oxford Ave	9.68	1.27	1.46	1.00	13.42	17.21	26.76	14.14	58.12	71.54	83.66	-14.5
Hayes	2.52	0.50	0.57	0.33	3.92	31.08	40.54	14.84	86.47	90.39	124.81	-27.6
Cranford	4.54	0.86	0.93	0.91	7.23	12.75	28.81	14.94	56.49	63.72	64.04	-0.5
Hatton Cross	11.35	2.65	2.82	1.63	18.45	18.54	25.33	14.25	58.12	76.57	66.66	14.9
Average										73.11	78.94	-5.2
SD										16.57	23.79	12.2

[a] These values are prior to applying the road-network scaling factor

[b] All values shown to two decimal places to avoid the accumulation of rounding errors in forming ratios and sub-totals, but this is not indicative of the precision of either the model or measured values

[c] Includes car parks and stationary sources

[d] Fractional Discrepancy=100*(model-measured)/measured

Table 3.2 Comparison of period-mean NO_x concentrations and all-hours period-mean NO_x concentrations

Site	NO_x DC (%)	Period mean ($\mu g/m^3$)	All- hours period mean ($\mu g/m^3$)	Diff[a] ($\mu g/m^3$)
LHR2	99.1	107.98	107.98	0.00
Oaks Road	92.5	65.09	63.63	1.46
Green Gates	85.4	61.35	58.96	2.40
Colnbrook	99.5	54.13	54.10	0.03
Harmondsworth	93.2	58.13	58.45	-0.32
Hillingdon	82.1	95.95	94.01	1.94
Sipson	99.6	65.65	65.79	-0.14
Harlington	88.9	66.81	66.41	0.41
Oxford Ave	90.8	71.54	71.84	-0.30
Hayes	84.3	90.39	89.16	1.23
Cranford	81.7	63.72	62.53	1.20
Hatton Cross	81.4	76.57	77.02	-0.45

[a] Diff=(Period mean-All hours period mean)

Table 3.3 Comparison of model and measured contributions to the period-mean difference in NO_x concentration between pairs of analysers, for sector ranges chosen to highlight the airport source contribution

(a) southerly wind sectors

Difference selected	Sector range (deg)[a]	NO_x concentration contribution ($\mu g/m^3$)		Disc[b] ($\mu g/m^3$)	FD[c] (%)
		Modelled	Measured		
LHR2-Oaks Rd	170-270	35.36	34.35	1.01	2.9
Sipson-Oaks Rd	120-240	12.47	13.67	-1.20	-8.8
Harlington-Oaks Rd	160-240	9.51	7.94	1.57	19.8
Harmondsworth-Oaks Rd	110-190	3.26	4.27	-1.02	-23.8
Green Gates-Oaks Rd	100-180	3.04	3.19	-0.15	-4.8
Oxford Avenue-Oaks Rd	200-260	17.75	21.93	-4.18	-19.1

[a] Angle is the direction from which the wind blows, clockwise from north; sector ranges are inclusive
[b] Disc (absolute discrepancy)=modelled-measured
[c] Fractional Discrepancy=100*(modelled-measured)/measured

(b) northerly wind sectors

Difference selected	Sector range (deg)[a]	NO_x concentration contribution ($\mu g/m^3$)		Disc[b] ($\mu g/m^3$)	FD[c] (%)
		Modelled	Measured		
Oaks Rd-Harlington	330-90	11.91	9.16	2.75	30.0
Oaks Rd-Harmondsworth	330-90	12.41	9.47	2.95	31.1
Oaks Rd-Sipson	330-90	12.46	7.98	4.48	56.0

[a] Angle is the direction from which the wind blows, clockwise from north; sector ranges are inclusive
[b] Disc (absolute discrepancy)=modelled-measured
[c] Fractional Discrepancy=100*(modelled-measured)/measured

Table 3.4 Breakdown by source category of the contribution to the period-mean LHR2-Oaks Rd NO_x concentration difference from wind direction sectors 170° to 270° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
LHR2	23.60	3.33	3.57	0.56	31.07	5.76	4.80	10.56	41.63
Oaks Rd	0.00	0.00	0.00	0.00	0.00	1.71	4.55	6.26	6.26
Difference	23.60	3.33	3.57	0.56	31.07	4.05	0.25	4.30	35.36

[a] Includes car parks and stationary sources

Table 3.5 Comparison of modelled and measured contributions to LHR2-Oaks Rd concentration difference (from wind direction sectors 170° to 270° inclusive) for hours selected by mode of runway operation

Mode	Concentration contribution (µg/m^3)[a]	
	Modelled	Monitored
Dep 27R/Arr 27L	22.85	22.00
Dep 27L/Arr 27R	9.78	10.28

[a] The two contribution do not sum to the total in Table 3.3
because there are other contributions from easterly operation and from hours with departures on both runways

Table 3.6 Breakdown by source category of the contribution to the period-mean Sipson-Oaks Rd NO_x concentration difference from wind direction sectors 120° to 240° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Sipson	5.24	2.09	2.11	0.56	10.00	3.23	3.84	7.07	17.06
Oaks Rd	0.00	0.00	0.00	0.01	0.01	0.81	3.78	4.59	4.60
Difference	5.24	2.09	2.11	0.55	9.99	2.42	0.05	2.48	12.47

[a] Includes car parks and stationary sources

Table 3.7 Breakdown by source category of the contribution to the period-mean Harlington-Oaks Rd NO_x concentration difference from wind direction sectors 160° to 240° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Harlington	5.14	1.33	1.39	0.40	8.25	1.65	3.23	4.88	13.14
Oaks Rd	0.00	0.00	0.00	0.00	0.00	0.65	2.98	3.63	3.63
Difference	5.14	1.33	1.39	0.40	8.25	1.00	0.26	1.25	9.51

[a] Includes car parks and stationary sources

Table 3.8 Breakdown by source category of the contribution to the period-mean Harmondsworth-Oaks Rd NO_x concentration difference from wind direction sectors 110° to 190° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Harmondsworth	1.08	0.67	0.82	0.19	2.75	0.72	1.92	2.64	5.39
Oaks Rd	0.00	0.01	0.00	0.03	0.04	0.34	1.75	2.10	2.13
Difference	1.08	0.66	0.81	0.16	2.71	0.38	0.17	0.54	3.26

[a] Includes car parks and stationary sources

Table 3.9 Breakdown by source category of the contribution to the period-mean Green Gates-Oaks Rd NO_x concentration difference from wind direction sectors 100° to 180° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Green Gates	1.06	0.84	0.99	0.20	3.07	0.47	1.71	2.18	5.25
Oaks Rd	0.02	0.02	0.02	0.11	0.17	0.40	1.64	2.05	2.22
Difference	1.04	0.81	0.97	0.09	2.90	0.07	0.06	0.13	3.04

[a] Includes car parks and stationary sources

Table 3.10 Breakdown by source category of the contribution to the period-mean Oxford Avenue-Oaks Rd NO_x concentration difference from wind direction sectors 200° to 260° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Oxford Avenue	9.13	1.28	1.40	0.53	12.33	6.47	3.02	9.49	21.82
Oaks Rd	0.00	0.00	0.00	0.00	0.00	1.09	2.98	4.07	4.07
Difference	9.13	1.28	1.40	0.53	12.33	5.38	0.04	5.42	17.75

[a] Includes car parks and stationary sources

Table 3.11 Emissions summary pertinent to Table 3.11 concentration comparisons

Case	Ground-level NO_x emissions (tonne/year)	
	Aircraft[a]	Other airport[b]
2008/9	1637.41	278.91
2002 PSDH	1661.63	263.49
2010SM	2126.15	184.07

[a] Includes APUs and engine testing
[b] Excludes heating plant

Table 3.12 Comparison of 2008/9, 2002 PSDH and 2010SM contributions from airport sources to period-mean NO_x concentrations

Site	PSDH name	Easting	Northing	Contribution to period-mean NO_x concentrations ($\mu g/m^3$)								
				Aircraft+APU+engine testing			Other airport			Total airport		
				2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM
LHR2	LHR2	508399	176744	28.5	31.2	37.1	4.6	6.5	3.6	33.1	37.7	40.7
Oxford Avenue	LHR4	509550	176997	11.0	12.5	14.1	2.6	3.0	2.3	13.6	15.5	16.4
Cranford	LHR5	510370	177195	5.7	6.3	7.4	1.9	1.9	1.2	7.7	8.2	8.6
Hatton Cross	LHR7	509333	175002	14.2	10.7	13.3	4.8	3.4	1.7	19.0	14.1	15.0
Oaks Rd	LHR8	505739	174497	11.8	7.5	10.4	4.4	1.8	1.6	16.2	9.3	12.0
Colnbrook	LHR14	503535	176829	1.5	2.1	2.7	0.6	0.5	0.5	2.1	2.6	3.2
Green Gates	LHR15	505185	176922	2.9	3.6	5.7	1.8	1.2	1.8	4.7	4.8	7.5
Hillingdon	LHR16	506945	178609	2.6	3.7	4.8	1.1	1.2	0.9	3.6	4.9	5.7
Harlington	LHR18	508279	177792	6.7	8.5	10.5	2.0	2.7	1.5	8.7	11.2	12.0
HD60	HD60	505736	177752	2.1	3.2	4.6	1.3	1.1	1.1	3.3	4.3	5.7
HD58	HD58	508414	177125	13.1	16.3	19.0	3.2	4.5	2.4	16.3	20.8	21.4
HD57	HD57	508758	177718	7.7	9.3	11.2	2.0	2.5	1.5	9.7	11.8	12.7
HD56	HD56	509798	178634	3.9	5.0	6.1	1.2	1.3	0.8	5.0	6.3	6.9
Average				8.6	9.2	11.3	2.4	2.4	1.6	11.0	11.7	12.9

Table 3.13 Comparison of model and measured contributions to the period-mean difference in NO_x concentration between pairs of analysers, for selected sector ranges chosen to highlight the road network source contribution

Difference selected	Sector range (deg)[a]	NO_x concentration contribution ($\mu g/m^3$)		Disc[b] ($\mu g/m^3$)	FD[c] (%)
		Modelled	Measured		
Hillingdon-Harmondsworth	100-270	37.20	46.37	-9.17	-19.8
Hillingdon-Harlington	100-270	31.18	49.71	-18.53	-37.3
Green Gates- Oaks Rd	200-290	4.82	12.17	-7.35	-60.4
Harmondsworth-Colnbrook	200-290	5.18	10.58	-5.40	-51.1
Oxford Avenue-Oaks Rd	90-180	2.16	5.38	-3.22	-59.9
LHR2-Harlington	270-100	19.81	30.74	-10.93	-35.6
Hayes-Cranford	90-210	12.37	21.97	-9.59	-43.7

[a] Angle is the direction from which the wind blows, clockwise from north; sector ranges are inclusive
[b] Disc (absolute discrepancy)=modelled-measured
[c] Fractional Discrepancy=100*(modelled-measured)/measured

Table 3.14 Breakdown by source category of the contribution to the period-mean Hillingdon-Harmondsworth NO_x concentration difference from wind direction sectors 100° to 270° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Hillingdon	1.95	0.85	0.84	0.30	3.95	40.01	10.09	50.10	54.06
Harmondsworth	1.15	0.89	1.00	0.25	3.30	5.33	8.23	13.56	16.86
Difference	0.80	-0.03	-0.16	0.05	0.66	34.68	1.86	36.54	37.20

[a] Includes car parks and stationary sources

Table 3.15 Comparison of measured and modelled traffic flows on the M4 between Junctions 4 and 4b[26]

(**a) two-way flows on M4 between Junctions 4 and 4b**

Model period		Flow (PCU[a]/hour)	
		Observed	Modelled
Morning peak	0800-0900	12392	12645
Inter peak	1000-1600	9894	9571
Evening peak	1700-1800	11942	11834

[a] PCU – Passenger Car Units

(b) one way flows on M25 between Junctions 15 and 14

Model period		Flow (PCU[a]/hour)	
		Observed	Modelled
Morning peak	0800-0900	8626	7910
Inter peak	1000-1600	7236	6377
Evening peak	1700-1800	7345	5943

[a] PCU – Passenger Car Units

Table 3.16 Breakdown by source category of the contribution to the period-mean Green Gates-Oaks Rd NO_x concentration difference from wind direction sectors 200° to 290° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Green Gates	0.02	0.07	0.08	0.04	0.20	6.05	7.46	13.51	13.71
Oaks Rd	0.02	0.00	0.00	0.00	0.02	2.75	6.13	8.87	8.89
Difference	0.00	0.07	0.08	0.04	0.18	3.31	1.33	4.64	4.82

[a] Includes car parks and stationary sources

Table 3.17 Breakdown by source category of the contribution to the period-mean Oxford Avenue-Oaks Rd NO_x concentration difference from wind direction sectors 90° to 180° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Oxford Avenue	0.13	0.00	0.00	0.31	0.44	2.68	3.17	5.85	6.29
Oaks Rd	0.12	0.14	0.09	0.36	0.72	0.61	2.80	3.41	4.13
Difference	0.00	-0.14	-0.09	-0.04	-0.28	2.06	0.37	2.44	2.16

[a] Includes car parks and stationary sources

Table 3.18 Comparison of (scaled) modelled period-mean NO_x concentrations with measured values for continuous NO_x/NO_2 analysers[a]

Site	Modelled period-mean NO_x concentrations ($\mu g/m^3$)										Measured ($\mu g/m^3$)	FD[c]
	Airport					Off-airport				Grand total ($\mu g/m^3$)		
	Aircraft	APU	Airside vehicles	Other airport[b]	Airport sub-total	Road traffic	LAEI/NAEI	Background	Off-airport sub-total			
LHR2	25.13	3.27	3.63	0.94	32.98	42.68	25.47	14.31	82.46	115.44	115.26	0.2
Oaks Road	8.99	3.62	3.49	1.00	17.10	12.00	23.82	14.27	50.09	67.19	58.68	14.5
Green Gates	1.38	1.19	1.38	0.36	4.31	19.50	26.03	14.92	60.45	64.76	75.20	-13.9
Colnbrook	1.10	0.35	0.46	0.15	2.06	16.39	24.23	14.31	54.93	56.99	56.12	1.6
H'worth	1.22	0.85	1.02	0.25	3.35	17.41	26.52	13.90	57.83	61.18	63.59	-3.8
Hillingdon	1.95	0.85	0.84	0.31	3.95	58.71	29.63	13.92	102.26	106.21	108.15	-1.8
Sipson	5.51	2.17	2.26	0.70	10.64	16.04	27.53	14.24	57.82	68.45	68.39	0.1
Harlington	5.53	1.36	1.47	0.53	8.88	16.53	29.80	14.49	60.82	69.70	62.74	11.1
Oxford Ave	9.68	1.27	1.46	1.00	13.42	20.86	26.76	14.14	61.77	75.18	83.66	-10.1
Hayes	2.52	0.50	0.57	0.33	3.92	37.67	40.54	14.84	93.05	96.97	124.81	-22.3
Cranford	4.54	0.86	0.93	0.91	7.23	15.45	28.81	14.94	59.19	66.42	64.04	3.7
Hatton Cross	11.35	2.65	2.82	1.63	18.45	22.47	25.33	14.25	62.05	80.50	66.66	20.8
Average										77.42	78.94	0.0
SD										18.78	23.79	12.0

[a] All values shown to two decimal places to avoid the accumulation of rounding errors in forming ratios and sub-totals, but this is not indicative of the precision of either the model or measured values
[b] Includes car parks and stationary sources
[c] Fractional Discrepancy=100*(model-measured)/measured

Table 3.19 Comparison of model results for period-mean NO_x concentrations: 2008/9 (including road network scaling), 2002 PSDH and 2010SM

Site	PSDH name	Easting	Northing	Period mean NO_x concentrations ($\mu g/m^3$)								
				Airport			Non-airport			Total		
				2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM
LHR2	LHR2	508399	176744	33.1	37.7	40.7	82.3	70.9	50.3	115.4	108.6	91.0
Oxford Avenue	LHR4	509550	176997	13.6	15.5	16.4	62.0	62.4	43.1	75.6	77.9	59.5
Cranford	LHR5	510370	177195	7.7	8.2	8.6	57.5	59.3	40.8	65.1	67.5	49.4
Hatton Cross	LHR7	509333	175002	19.0	14.1	15.0	62.0	62.0	42.0	81.0	76.1	57.0
Oaks Rd	LHR8	505739	174497	16.2	9.3	12.0	49.4	49.4	34.0	65.7	58.7	46.0
Colnbrook	LHR14	503535	176829	2.1	2.6	3.2	54.9	61.1	41.5	57.0	63.7	44.7
Green Gates	LHR15	505185	176922	4.7	4.8	7.5	57.5	57.7	39.0	62.2	62.5	46.5
Hillingdon	LHR16	506945	178609	3.6	4.9	5.7	99.9	119.9	71.9	103.6	124.8	77.6
Harlington	LHR18	508279	177792	8.7	11.2	12.0	60.6	60.2	42.0	69.3	71.4	54.0
HD60	HD60	505736	177752	3.3	4.3	5.7	59.4	58.3	39.5	62.7	62.6	45.2
HD58	HD58	508414	177125	16.3	20.8	21.4	55.2	58.2	41.2	71.5	79.0	62.6
HD57	HD57	508758	177718	9.7	11.8	12.7	66.1	67.9	47.4	75.7	79.7	60.1
HD56	HD56	509798	178634	5.0	6.3	6.9	66.5	76.0	54.9	71.5	82.3	61.8
Average				11.0	11.7	12.9	64.1	66.4	45.2	75.1	78.1	58.1

Table 3.20 Comparison of measured and calculated period-mean total oxidant at sites with ozone measurements

Site	Calculated oxidant				Measured oxidant			FD[c] (%)
	B (ppb)	*A*[a]	$[NO_x]$[b] (ppb)	$[OX]_{calc}$ (ppb)	$[O_3]$ (ppb)	$[NO_2]$ (ppb)	$[OX]_{meas}$ (ppb)	
Cranford	33.5	0.138	33.62	38.12	16.45	19.00	35.45	7.5
Harlington	33.5	0.138	32.94	38.04	16.86	18.32	35.18	8.1
Hillingdon	33.5	0.153	56.77	42.17	14.50	26.66	41.16	2.5
Average								6.0

[a] *A* – calculated for all hours of the period
[b] Measured NO_x value used here
[c] Fractional Discrepancy=100*(calculated-measured)/measured

Table 3.21 Comparison of period-mean NO_2 concentrations and NO_2/NO_x ratios

	Without roads scaling factor						With roads scaling factor					
	Period-mean NO_2 concs ($\mu g/m^3$)		FD[a]	NO_2/NO_x			Period-mean NO_2 concs ($\mu g/m^3$)		FD[a]	NO_2/NO_x		
Site ID	Modelled	Measured	(%)	Modelled	Measured	Ratio[a]	Modelled	Measured	%	Modelled	Measured	FD[a]
LHR2	49.92	52.39	-4.7	0.46	0.45	1.7	51.91	52.39	-0.9	0.45	0.45	-1.1
Oaks Road	37.08	36.94	0.4	0.57	0.63	-9.5	37.87	36.94	2.5	0.56	0.63	-10.5
Green Gates	35.77	40.66	-12.0	0.58	0.54	7.8	37.09	40.66	-8.8	0.57	0.54	6.0
Colnbrook	32.85	31.96	2.8	0.61	0.57	6.6	34.05	31.96	6.5	0.60	0.57	4.9
H'worth	34.45	34.30	0.4	0.59	0.54	9.9	35.68	34.30	4.0	0.58	0.54	8.2
Hillingdon	47.80	50.79	-5.9	0.50	0.47	6.1	50.91	50.79	0.2	0.48	0.47	2.1
Sipson	37.25	38.89	-4.2	0.57	0.57	-0.2	38.29	38.89	-1.5	0.56	0.57	-1.6
Harlington	37.60	34.91	7.7	0.56	0.56	1.2	38.67	34.91	10.8	0.55	0.56	-0.3
Oxford Ave	39.48	43.76	-9.8	0.55	0.52	5.2	40.74	43.76	-6.9	0.54	0.52	3.3
Hayes	45.46	54.86	-17.1	0.50	0.44	14.4	47.46	54.86	-13.5	0.49	0.44	11.4
Cranford	36.49	36.19	0.8	0.57	0.57	1.3	37.51	36.19	3.7	0.56	0.57	0.0
Hatton Cross	41.20	34.38	19.8	0.54	0.52	4.3	42.50	34.38	23.6	0.53	0.52	2.4
Average			-1.8			4.1			1.6			2.1
SD			9.7			6.0			9.7			5.5

[a] Fractional Discrepancy= 100*(modelled-measured)/measured

Table 3.22 Effect of assigning sites to Jenkin Category III rather than Category II

	NO_2 concentration ($\mu g/m^3$)			NO_2/NO_x ratio		
	Modelled		Measured	Modelled		Measured
Site	Category II	Category III		Category II	Category III	
Oaks Rd	37.87	35.95	36.94	0.56	0.54	0.63
Colnbrook	34.05	32.48	31.96	0.60	0.57	0.57
Hatton Cross	42.50	40.18	34.38	0.53	0.50	0.52

Table 3.23 Comparison of model results for period-mean NO_2 concentrations: 2008/9 (including road network scaling), 2002 PSDH and 2010SM

Site	PSDH name	A	NO_2 (µg/m^3)			NO_x (µg/m^3)			NO_2/NO_x		
			2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM
LHR2	LHR2	0.143	52.4	47.7	45.7	115.4	108.6	90.9	0.45	0.44	0.50
Oxford Avenue	LHR4	0.143	40.9	39.8	36.9	75.6	77.9	59.5	0.54	0.51	0.62
Cranford	LHR5	0.138	37.1	36.0	32.5	65.1	67.4	49.4	0.57	0.53	0.66
Hatton Cross	LHR7	0.143	42.7	36.7	32.9	81.0	76.0	57.0	0.53	0.48	0.58
Oaks Rd	LHR8	0.135	37.1	31.5	28.9	65.7	58.6	46.1	0.57	0.54	0.63
Colnbrook	LHR14	0.140	34.0	34.4	30.0	57.0	63.7	44.7	0.60	0.54	0.67
Green Gates	LHR15	0.140	36.1	34.0	31.0	62.2	62.6	46.5	0.58	0.54	0.67
Hillingdon	LHR16	0.153	50.0	47.3	40.5	103.6	124.7	77.6	0.48	0.38	0.52
Harlington	LHR18	0.138	38.6	38.3	35.3	69.3	71.4	54.0	0.56	0.54	0.65
HD60	HD60	0.137	36.2	34.1	30.5	62.7	62.7	45.1	0.58	0.54	0.68
HD58	HD58	0.141	39.4	41.5	39.1	71.5	79.1	62.6	0.55	0.52	0.62
HD57	HD57	0.140	40.9	39.9	36.9	75.7	79.8	60.0	0.54	0.50	0.62
HD56	HD56	0.136	39.3	41.2	37.5	71.5	82.3	61.9	0.55	0.50	0.61
Average		0.141	40.3	38.6	35.2	75.1	78.1	58.1	0.55	0.51	0.62

Table 3.24 Comparison of modelled and measured period-mean PM_{10} concentrations[a]

Site	Modelled period-mean NO_x concentrations (µg/m^3)										Measured (µg/m^3)	FD[c]
	Airport					Off-airport				Grand total (µg/m^3)		
	Aircraft	APU	Airside vehicles	Other airport[b]	Airport sub-total	Road traffic	LAEI/NAEI	Background	Off-airport sub-total			
LHR2	1.58	0.07	0.30	0.06	2.00	3.19	1.52	17.28	21.99	23.99	23.94	0.20
Oaks Road	0.26	0.07	0.29	0.05	0.67	1.01	1.52	17.33	19.86	20.53	19.69	4.25
Green Gates	0.11	0.02	0.12	0.03	0.27	1.55	1.55	17.76	20.86	21.13	16.82	25.68
Colnbrook	0.04	0.01	0.04	0.01	0.09	1.27	1.72	17.26	20.24	20.33	19.18	6.01
H'worth (BAM)	0.04	0.02	0.08	0.02	0.16	1.29	1.57	16.66	19.53	19.69	34.67	-43.22
Harlington	0.15	0.03	0.12	0.03	0.33	1.54	1.76	17.19	20.49	20.82	20.96	-0.68
Oxford Ave	0.26	0.03	0.13	0.05	0.46	2.08	1.48	17.44	20.99	21.46	22.87	-6.18
Hayes	0.06	0.01	0.05	0.02	0.14	2.53	1.88	16.99	21.40	21.54	22.54	-4.43
Cranford	0.13	0.02	0.08	0.03	0.26	1.32	1.51	17.75	20.57	20.83	18.92	10.11
Hatton Cross	0.37	0.04	0.22	0.06	0.69	1.76	1.39	17.69	20.84	21.52	20.67	4.12
Average										21.19	22.03	-0.41
SD										1.15	4.92	17.50

[a] All values shown to two decimal places to avoid the accumulation of rounding errors in forming ratios and sub-totals, but this is not indicative of the precision of either the model or measured values
[b] Includes car parks and stationary sources
[c] Fractional Discrepancy=100*(model-measured)/measured

Table 3.25 Breakdown by source category of the contribution to the period-mean LHR2-Oaks Rd PM_{10} concentration difference from wind direction sectors 150° to 270° inclusive

Site	Airport contribution (µg/m^3)					Off-airport contribution (µg/m^3)			Grand total (µg/m^3)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
LHR2	1.49	0.07	0.30	0.04	1.90	0.54	0.43	0.97	2.87
Oaks Rd	0.00	0.00	0.00	0.00	0.00	0.19	0.38	0.57	0.57
Difference	1.49	0.07	0.30	0.04	1.90	0.35	0.05	0.40	2.30

[a] Includes car parks and stationary sources

Table 3.26 Comparison of model and measured contributions to the period-mean difference in PM_{10} concentration between pairs of analysers, for selected sector ranges chosen to highlight the airport source contribution

Difference selected	Sector range (deg)[a]	PM_{10} concentration contribution ($\mu g/m^3$)		Disc[b] ($\mu g/m^3$)	FD[c] (%)
		Modelled	Measured		
LHR2-Oaks Rd	150-270	2.30	1.62	0.68	42.1
Harlington-Oaks Rd	160-240	0.43	0.44	-0.01	-2.7

[a] Angle is the direction from which the wind blows, clockwise from north; sector ranges are inclusive
[b] Disc (absolute discrepancy)=modelled-measured
[c] Fractional Discrepancy=100*(modelled-measured)/measured

Table 3.27 Breakdown by source category of the contribution to the period-mean Harlington-Oaks Rd PM_{10} concentration difference from wind direction sectors 160° to 240° inclusive

Site	Airport contribution ($\mu g/m^3$)					Off-airport contribution ($\mu g/m^3$)			Grand total ($\mu g/m^3$)
	Aircraft	APU	Airside vehicles	Other airport[a]	Airport sub-total	Road traffic	LAEI/ NAEI	Off-airport sub-total	
Harlington	0.14	0.03	0.12	0.03	0.32	0.18	0.25	0.43	0.74
Oaks Rd	0.00	0.00	0.00	0.00	0.00	0.09	0.22	0.31	0.31
Difference	0.14	0.03	0.12	0.03	0.32	0.09	0.02	0.11	0.43

[a] Includes car parks and stationary sources

Table 3.28 Emissions summary pertinent to Table 3.29 concentration comparisons

Case	Ground-level PM_{10} emissions (tonne/year)	
	Aircraft[a]	Other airport[b]
2008/9	36.34	23.08
2002 PSDH	36.85	20.12
2010SM	37.73	13.33

[a] Includes main engines, APUs, engine testing and aircraft brake and tyre wear
[b] Excludes heating plant

Table 3.29 Comparison of 2008/9, 2002 PSDH and 2010SM contributions from airport sources to period-mean PM_{10} concentrations

Site	PSDH name	Easting	Northing	Contribution to period-mean PM_{10} concentrations ($\mu g/m^3$)								
				Aircraft+APU+engine testing			Other airport			Total airport		
				2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM
LHR2	LHR2	508399	176744	1.63	1.22	1.32	0.36	0.46	0.25	2.00	1.68	1.57
Oxford Avenue	LHR4	509550	176997	0.29	0.26	0.22	0.18	0.20	0.13	0.46	0.46	0.35
Cranford	LHR5	510370	177195	0.15	0.14	0.12	0.12	0.12	0.07	0.26	0.26	0.19
Hatton Cross	LHR7	509333	175002	0.43	0.24	0.23	0.30	0.23	0.11	0.74	0.47	0.34
Oaks Rd	LHR8	505739	174497	0.30	0.16	0.17	0.34	0.13	0.12	0.64	0.29	0.29
Colnbrook	LHR14	503535	176829	0.05	0.05	0.05	0.05	0.03	0.04	0.09	0.08	0.09
Green Gates	LHR15	505185	176922	0.14	0.11	0.15	0.14	0.08	0.14	0.28	0.19	0.29
Hillingdon	LHR16	506945	178609	0.06	0.11	0.13	0.08	0.08	0.06	0.14	0.19	0.19
Harlington	LHR18	508279	177792	0.18	0.25	0.26	0.16	0.18	0.10	0.33	0.43	0.36
HD60	HD60	505736	177752	0.06	0.11	0.14	0.10	0.08	0.08	0.16	0.19	0.22
HD58	HD58	508414	177125	0.45	0.50	0.51	0.24	0.31	0.17	0.70	0.81	0.68
HD57	HD57	508758	177718	0.21	0.24	0.24	0.15	0.17	0.10	0.36	0.41	0.34
HD56	HD56	509798	178634	0.09	0.12	0.11	0.08	0.09	0.06	0.18	0.21	0.17
Average				0.31	0.27	0.28	0.18	0.17	0.11	0.49	0.44	0.39

Table 3.30 Comparison of model and measured contributions to the period-mean difference in PM_{10} concentration between pairs of analysers, for selected sector ranges chosen to highlight road-network emissions

Difference selected	Sector range (deg)[a]	PM_{10} concentration contribution ($\mu g/m^3$)		Disc[b] ($\mu g/m^3$)	FD[c] (%)
		Modelled	Measured		
LHR2-Harlington	270-100	1.64	2.15	-0.52	-24.0
Oxford Avenue-Cranford	90-180	0.19	0.74	-0.55	-74.5
Hayes-Cranford	90-210	0.81	1.69	-0.87	-51.7

[a] Angle is the direction from which the wind blows, clockwise from north; sector ranges are inclusive
[b] Disc (absolute discrepancy)=modelled-measured
[c] Fractional Discrepancy=100*(modelled-measured)/measured

Table 3.31 Comparison of 2008/9, 2002 PSDH and 2010SM period-mean PM_{10} concentrations

Site	PSDH name	Easting	Northing	Period mean NO_x concentrations (µg/m^3)								
				Airport			Non-airport			Total		
				2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM	2008/9	2002 PSDH	2010SM
LHR2	LHR2	508399	176744	2.00	1.68	1.57	21.87	24.01	20.88	23.87	25.69	22.45
Oxford Avenue	LHR4	509550	176997	0.46	0.46	0.35	20.79	23.60	20.63	21.25	24.06	20.98
Cranford	LHR5	510370	177195	0.26	0.26	0.19	20.07	23.58	20.60	20.33	23.84	20.79
Hatton Cross	LHR7	509333	175002	0.74	0.47	0.34	20.74	23.60	20.57	21.48	24.07	20.91
Oaks Rd	LHR8	505739	174497	0.64	0.29	0.29	19.69	23.07	20.27	20.33	23.36	20.56
Colnbrook	LHR14	503535	176829	0.09	0.08	0.09	20.19	23.44	20.48	20.28	23.52	20.57
Green Gates	LHR15	505185	176922	0.28	0.19	0.29	20.30	23.36	20.46	20.58	23.55	20.75
Hillingdon	LHR16	506945	178609	0.14	0.19	0.19	23.09	25.89	22.03	23.23	26.08	22.22
Harlington	LHR18	508279	177792	0.33	0.43	0.36	20.41	23.77	20.84	20.75	24.20	21.20
HD60	HD60	505736	177752	0.16	0.19	0.22	20.22	23.56	20.65	20.38	23.75	20.87
HD58	HD58	508414	177125	0.70	0.81	0.68	20.00	23.57	20.68	20.70	24.38	21.36
HD57	HD57	508758	177718	0.36	0.41	0.34	21.04	24.00	20.94	21.40	24.41	21.28
HD56	HD56	509798	178634	0.18	0.21	0.17	20.24	24.21	21.15	20.41	24.42	21.32
Average				0.49	0.44	0.39	20.66	23.82	20.78	21.15	24.26	21.17

Table 3.32 Comparison of modelled and measured period-mean $PM_{2.5}$ concentrations[a]

Site	Modelled period-mean NO_x concentrations (µg/m^3)									Measured (µg/m^3)	FD[c]
	Airport					Off-airport				Grand total (µg/m^3)		
	Aircraft	APU	Airside vehicles	Other airport[b]	Airport sub-total	Road traffic	LAEI/NAEI	Background	Off-airport sub-total			
Oaks Road	0.17	0.06	0.25	0.05	0.53	0.62	1.04	9.63	11.29	11.83	11.58	2.2
Green Gates	0.07	0.02	0.10	0.02	0.22	1.00	1.07	9.63	11.70	11.92	10.96	8.8
H'worth	0.03	0.02	0.07	0.01	0.13	0.85	1.11	9.63	11.60	11.73	8.33	40.9
Average					0.30	0.82				11.83	10.29	17.3
SD										0.10	1.73	20.71

[a] All values shown to two decimal places to avoid the accumulation of rounding errors in forming ratios and sub-totals, but this is not indicative of the precision of either the model or measured values

[b] Includes car parks and stationary sources

[c] Fractional Discrepancy=100*(model-measured)/measured

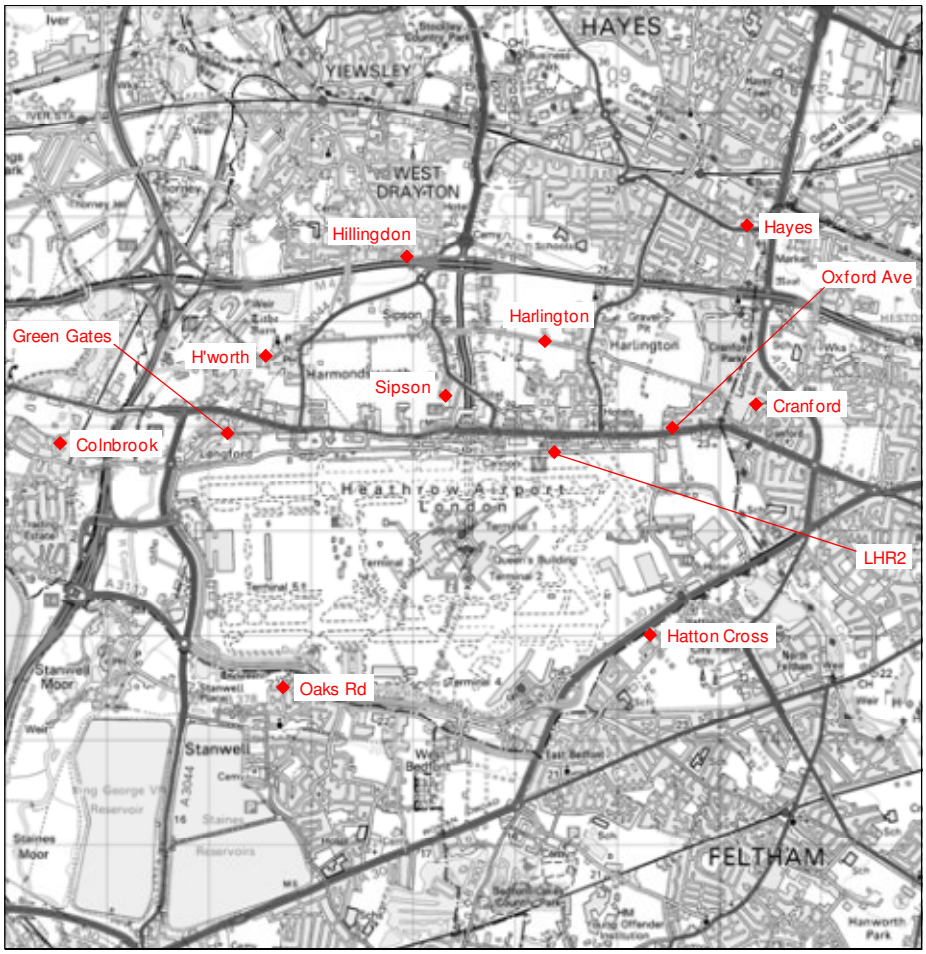

Fig 2.1 Location of monitoring sites used in the study

Fig 2.2 (a) LHR2 (Extent of picture: 170 m × 110 m approx.)

Fig 2.2 (b) Oaks Road (Extent of picture: 170 m × 110 m approx.)

Fig 2.2 (c) Green Gates (Extent of picture: 340 m × 220 m approx.)

Fig 2.2 (d) Colnbrook (Extent of picture: 340 m × 220 m approx.)

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Fig 2.2 (e) Harmondsworth (Extent of picture: 170 m × 110 m approx.)

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Fig 2.2 (f) Hillingdon (Extent of picture: 170 m × 110 m approx.)

Fig 2.2 (g) Sipson (Extent of picture: 170 m × 110 m approx.)

Fig 2.2 (h) Harlington (Extent of picture: 170 m × 110 m approx.)

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Fig 2.2 (i) Oxford Avenue (Extent of picture: 170 m × 110 m approx.)

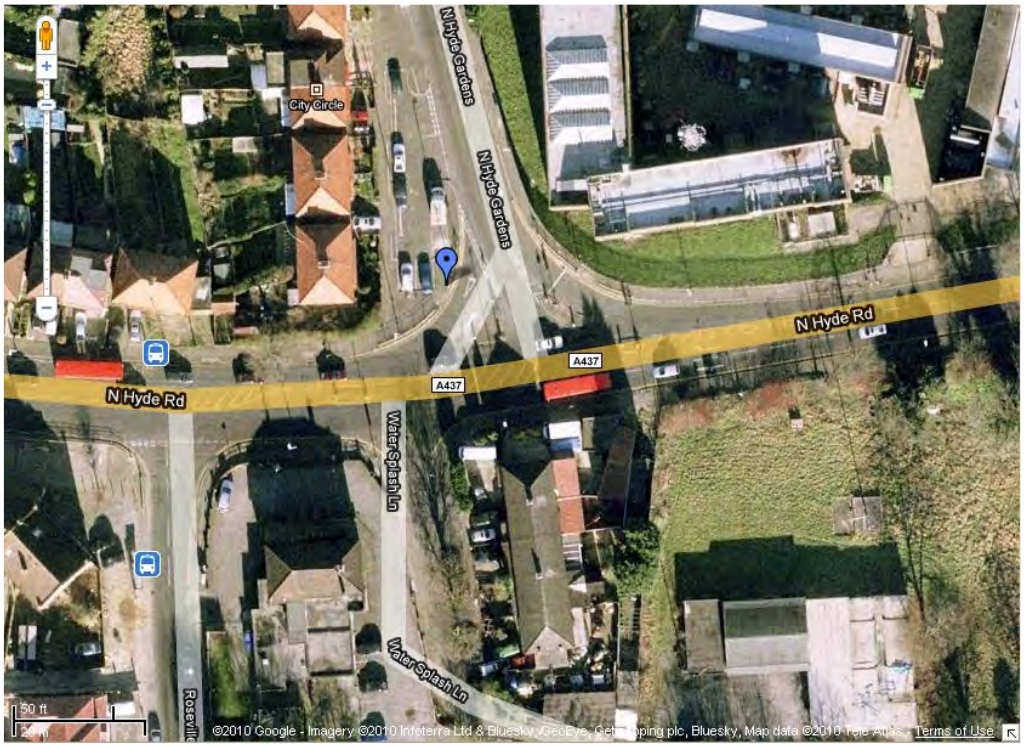

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Fig 2.2 (j) Hayes (Extent of picture: 170 m × 110 m approx.)

Fig 2.2 (k) Cranford (Extent of picture: 340 m × 220 m approx.)

Fig 2.2 (l) Hatton Cross (Extent of picture: 340 m × 220 m approx.)

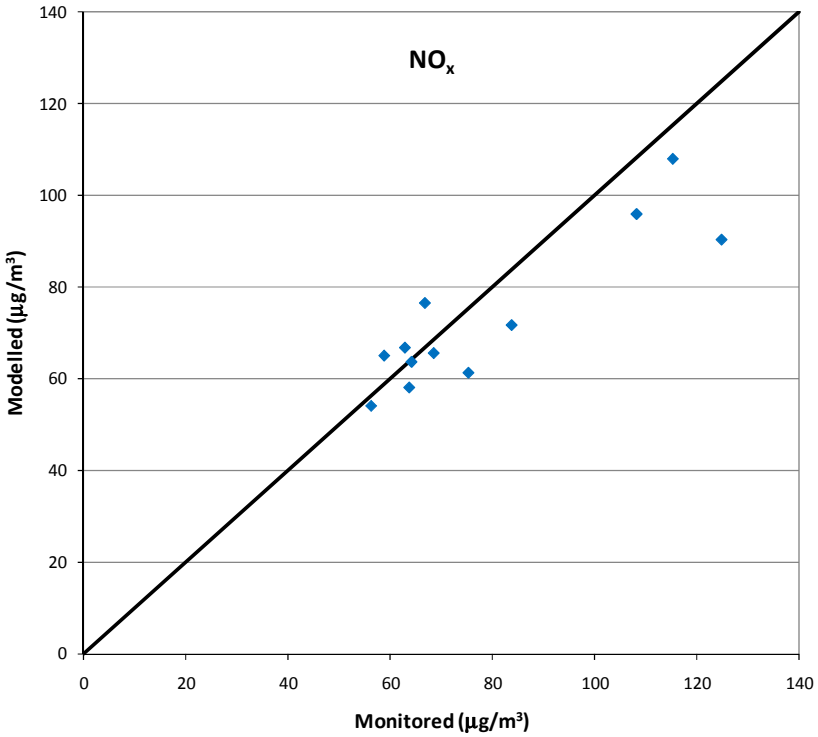


Fig 3.1 Scatter plot of modelled versus measured period-mean concentration (also shows the 1:1 line)

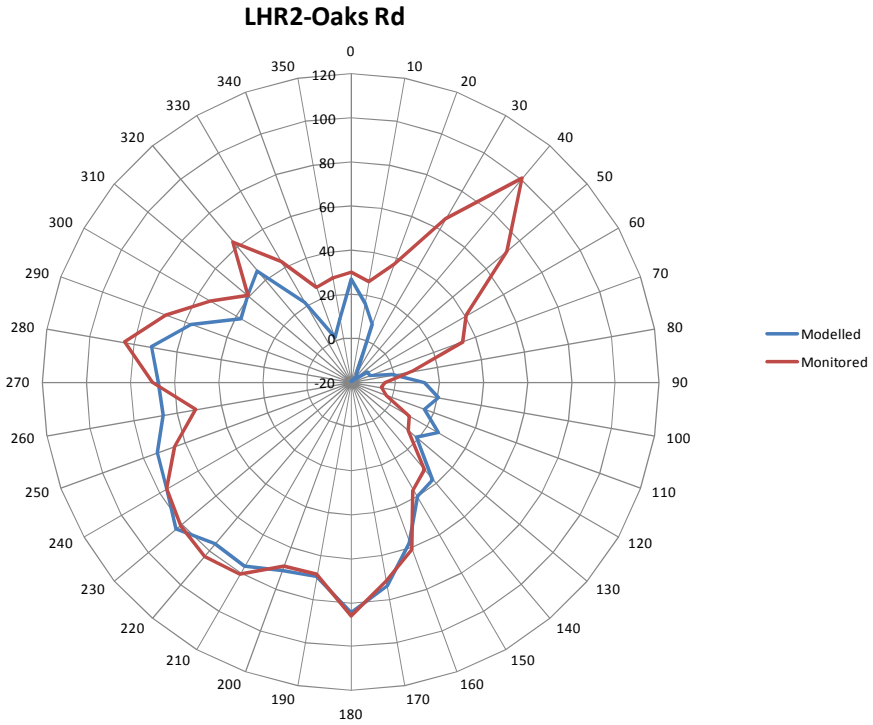


Fig 3.2 The average difference in NO_x concentration ($\mu g/m^3$) between LHR2 and Oaks Rd as a function of wind direction

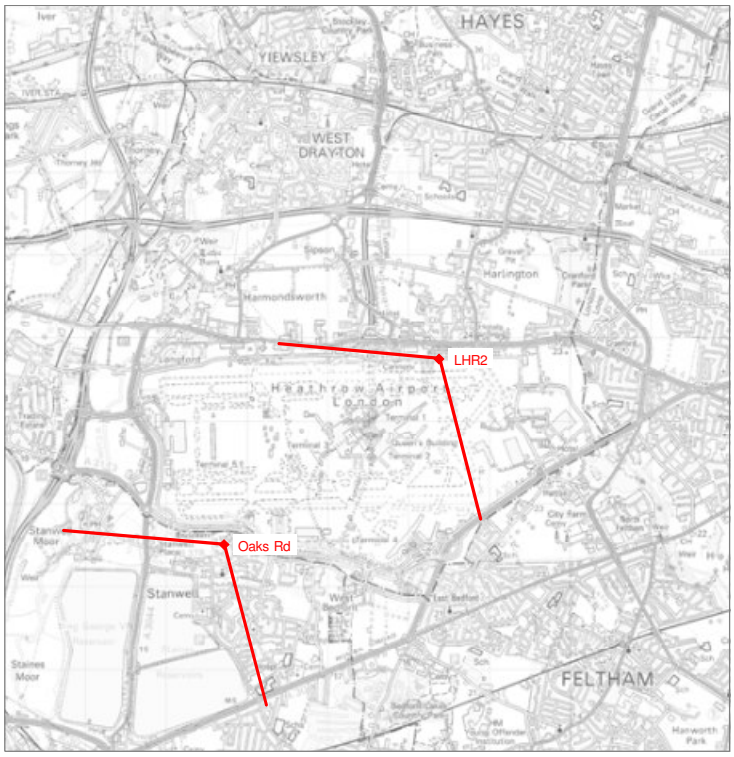


Fig 3.3 Shows the 170° to 270° sector range as seen from LHR2 and Oaks Rd (NB: each sector is assumed to spans a ±5° about its mid-line)

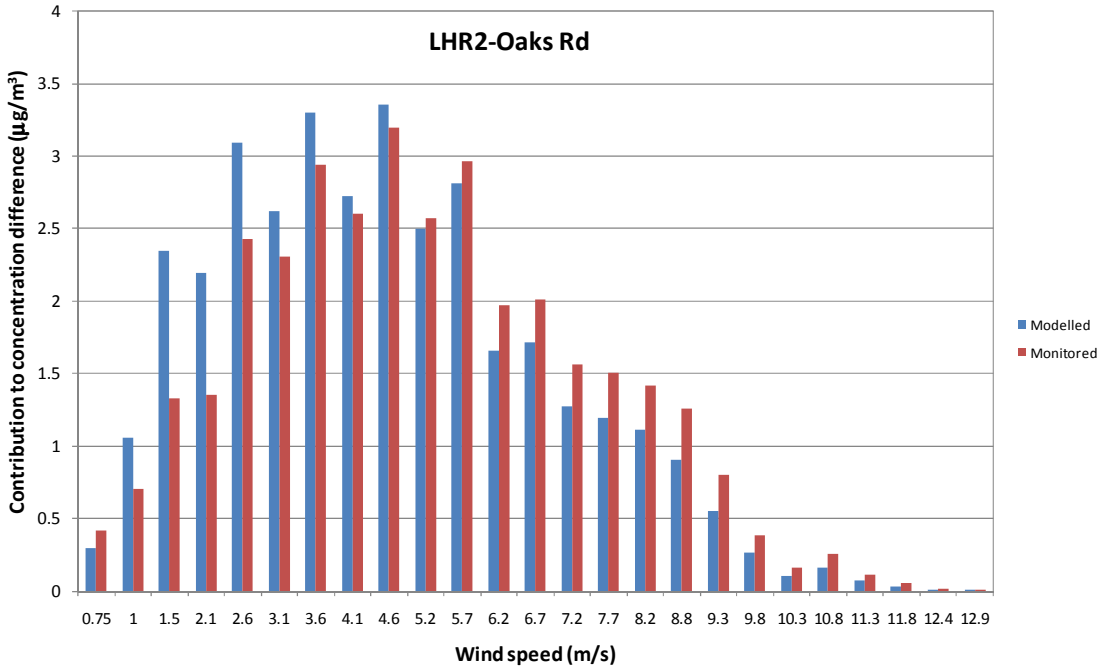


Fig 3.4 LHR2-Oaks Rd concentration difference contribution from wind sectors 170° to 270° inclusive as a function of wind speed

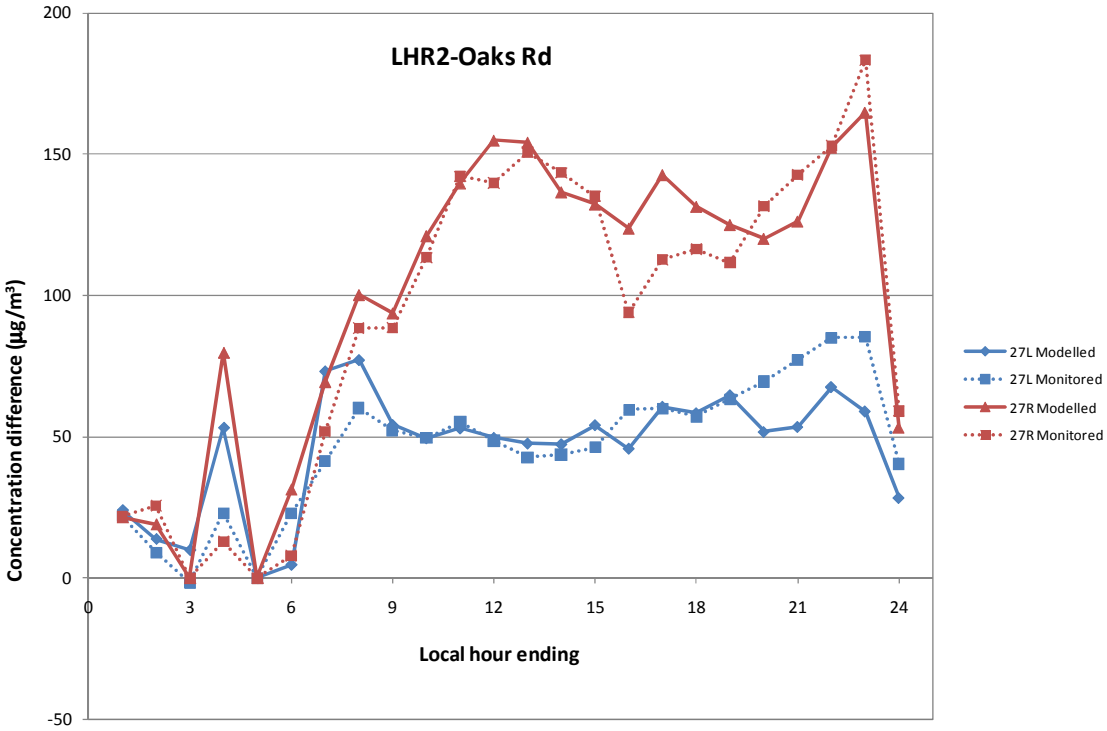
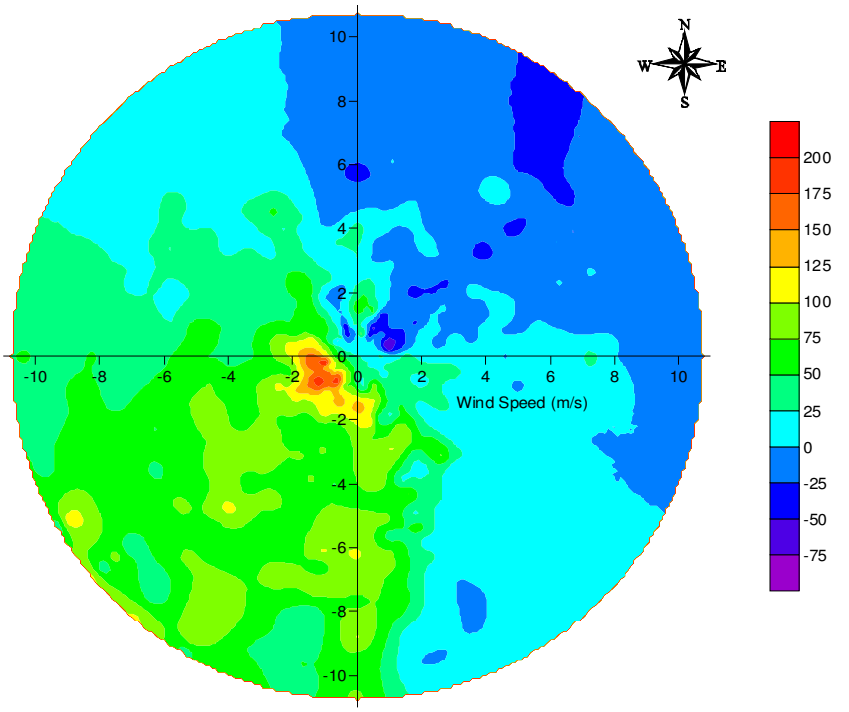
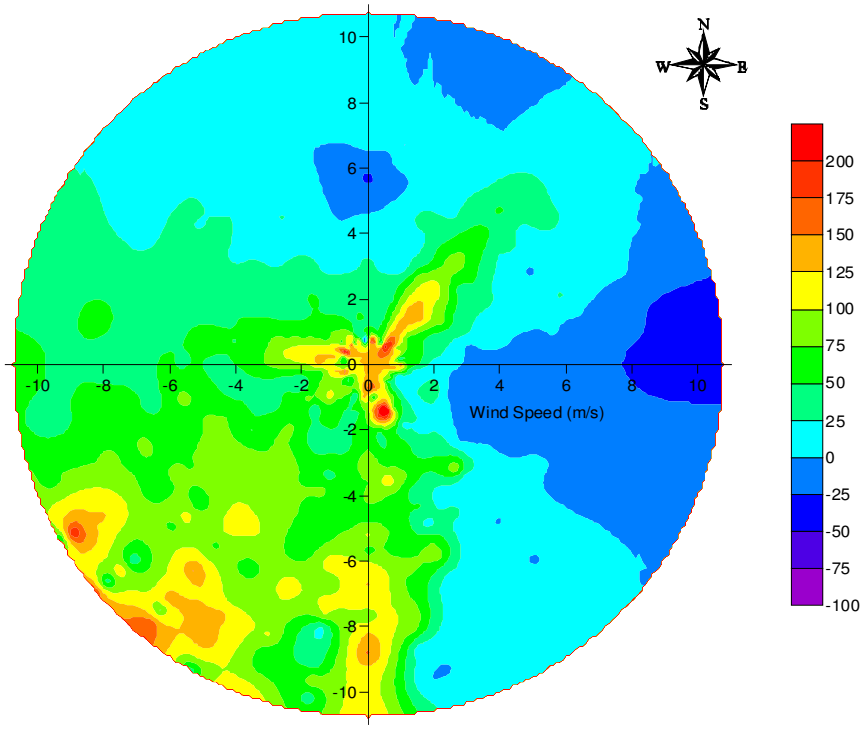


Fig 3.5 LHR2-Oaks Rd NO_x concentration difference by departure runway and hour of day



(a) modelling



(b) monitoring

Fig 3.6 Bi-polar plots for LHR2-Oaks Rd

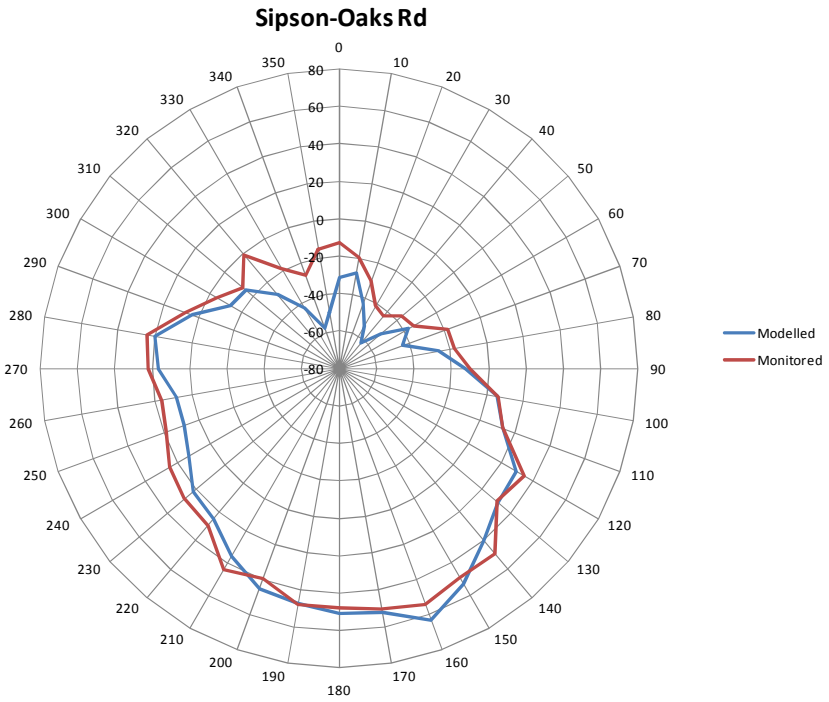


Fig 3.7 The average difference in NO_x concentration (µg/m^3) between Sipson and Oaks Rd as a function of wind direction

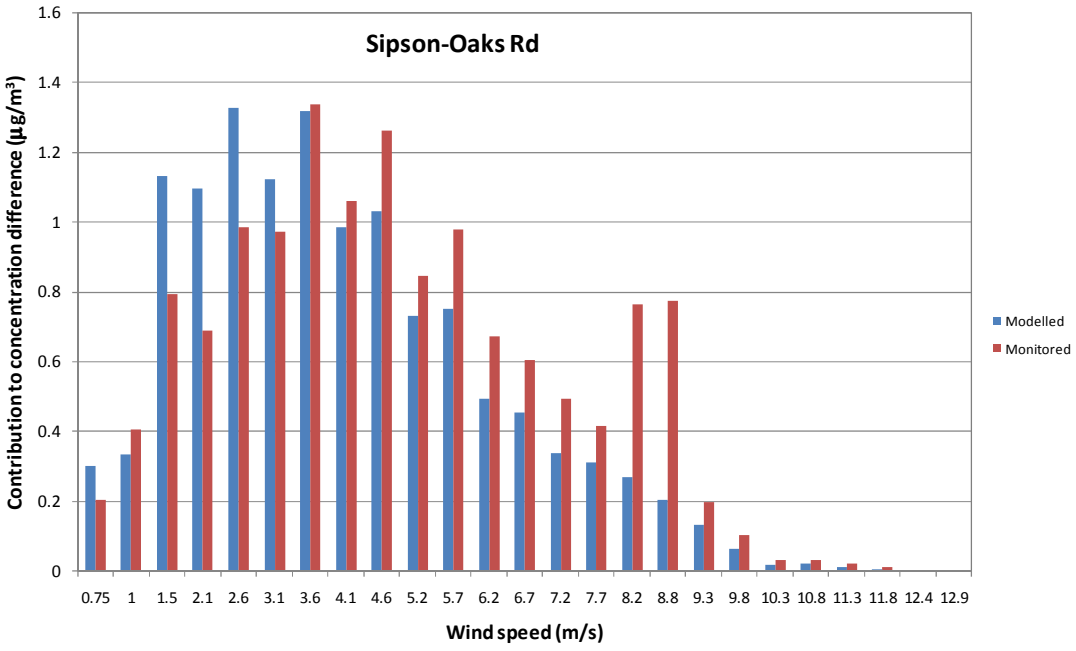
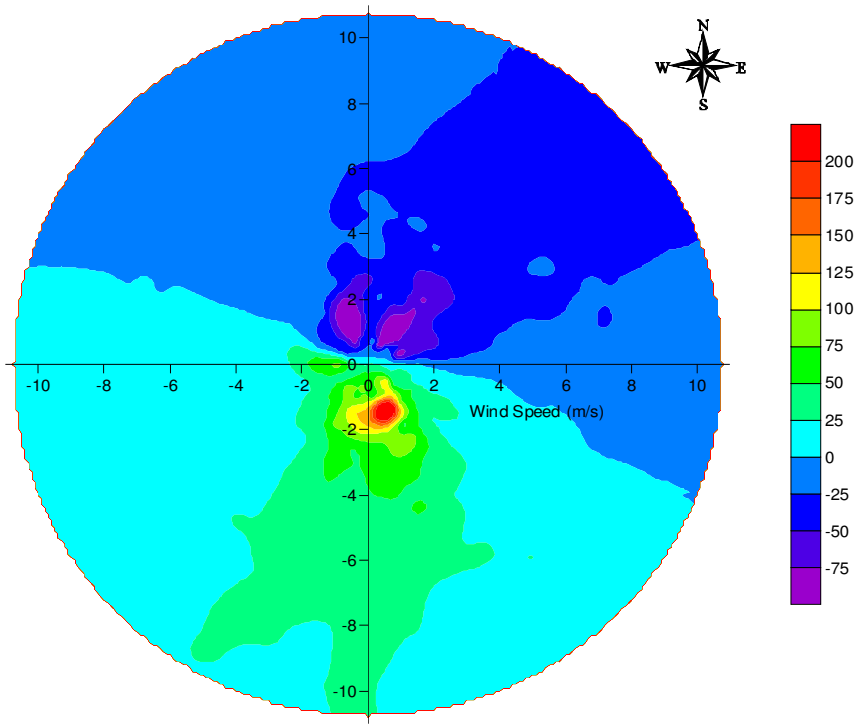
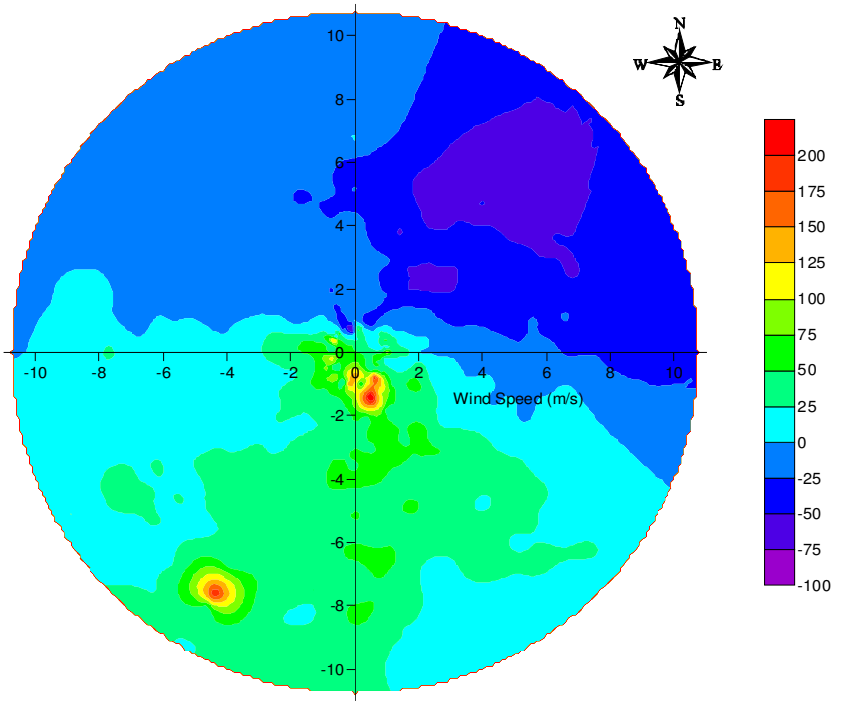


Fig 3.8 Sipson-Oaks Rd concentration difference contribution from wind sectors 120° to 240° inclusive as a function of wind speed



(a) modelling



(b) monitoring

Fig 3.9 Bi-polar plots for Sipson-Oaks Rd

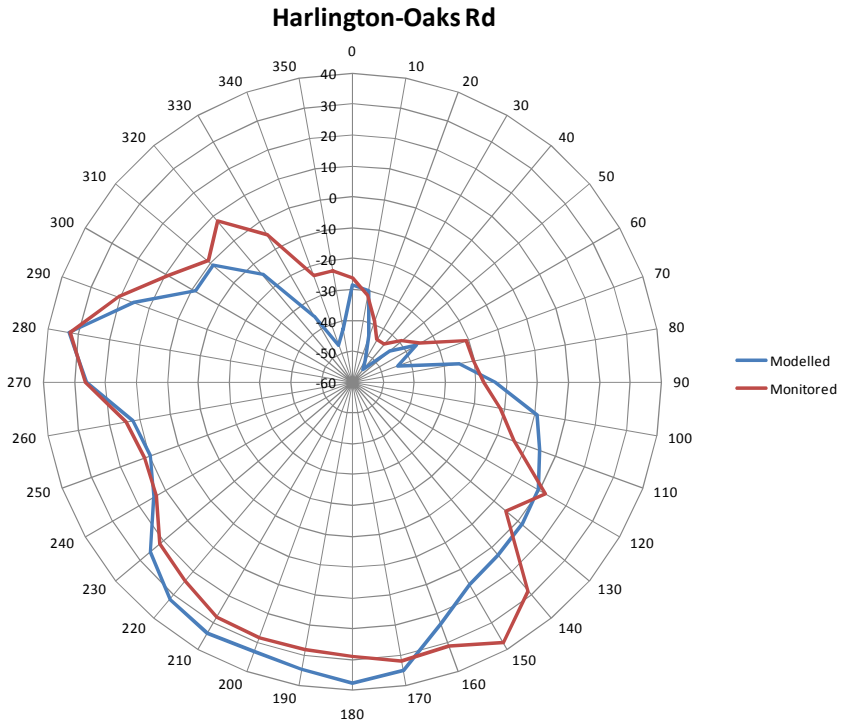


Fig 3.10 The average difference in NO_x concentration ($\mu g/m^3$) between Harlington and Oaks Rd as a function of wind direction

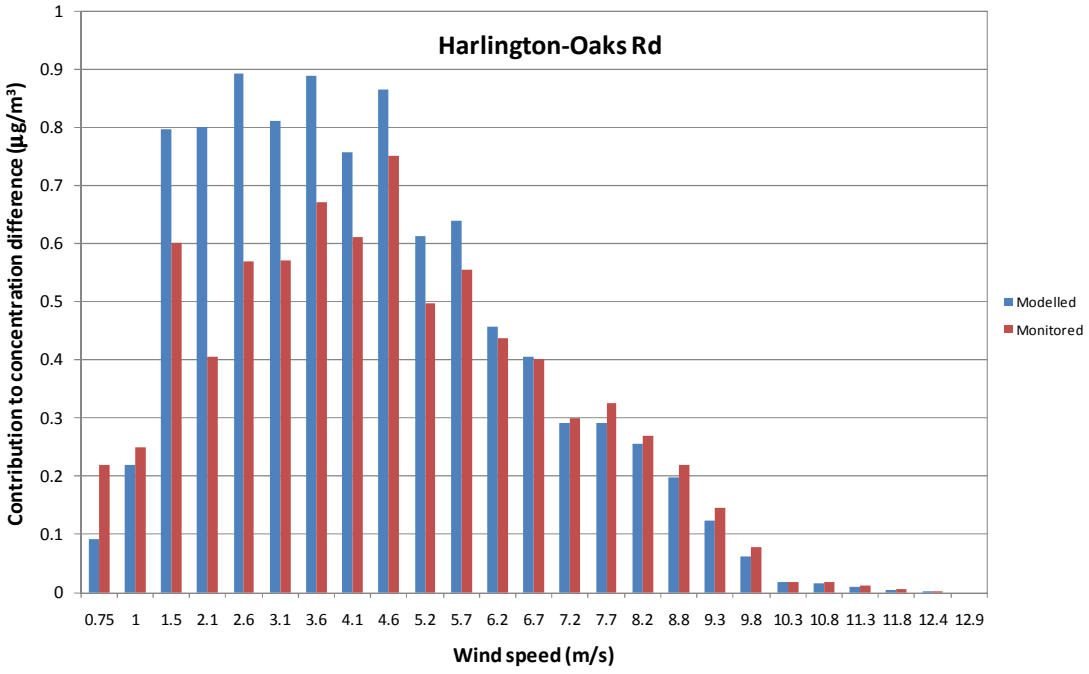


Fig 3.11 Harlington-Oaks Rd concentration difference contribution from wind sectors 160° to 240° inclusive as a function of wind speed

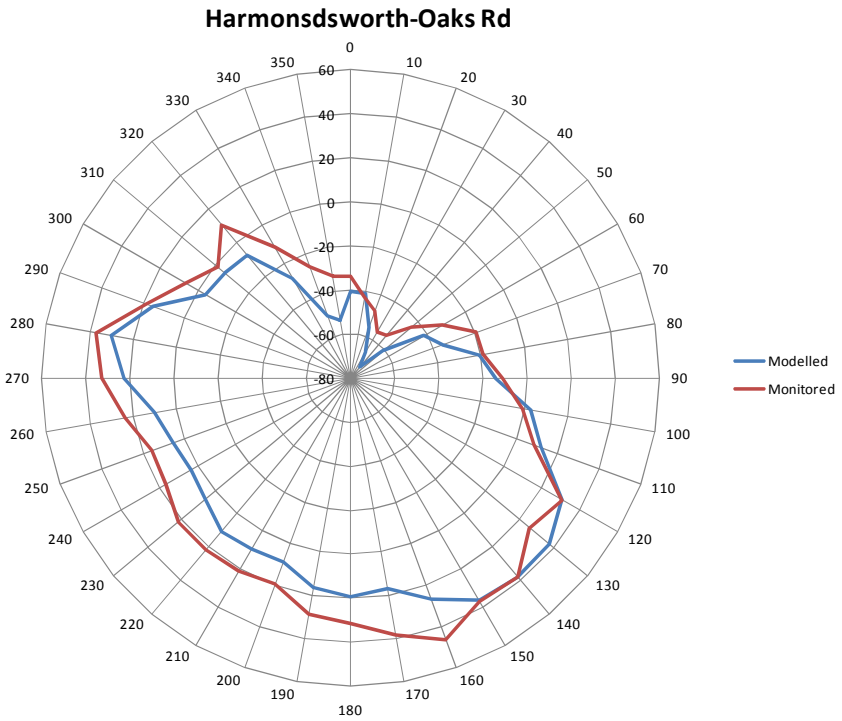


Fig 3.12 The average difference in NO_x concentration ($\mu g/m^3$) between Harmondsworth and Oaks Rd as a function of wind direction

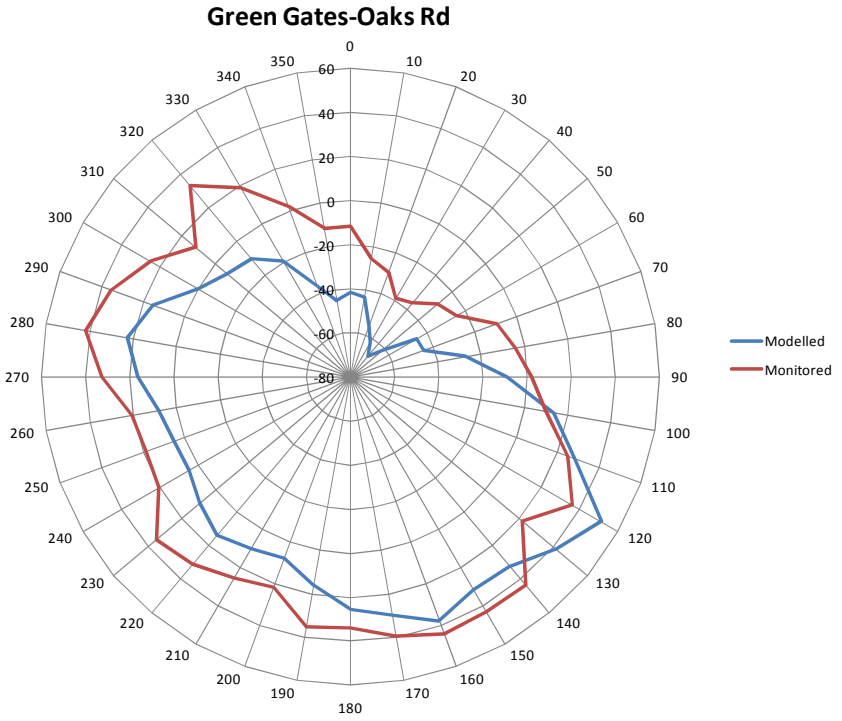


Fig 3.13 The average difference in NO_x concentration ($\mu g/m^3$) between Green Gates and Oaks Rd as a function of wind direction

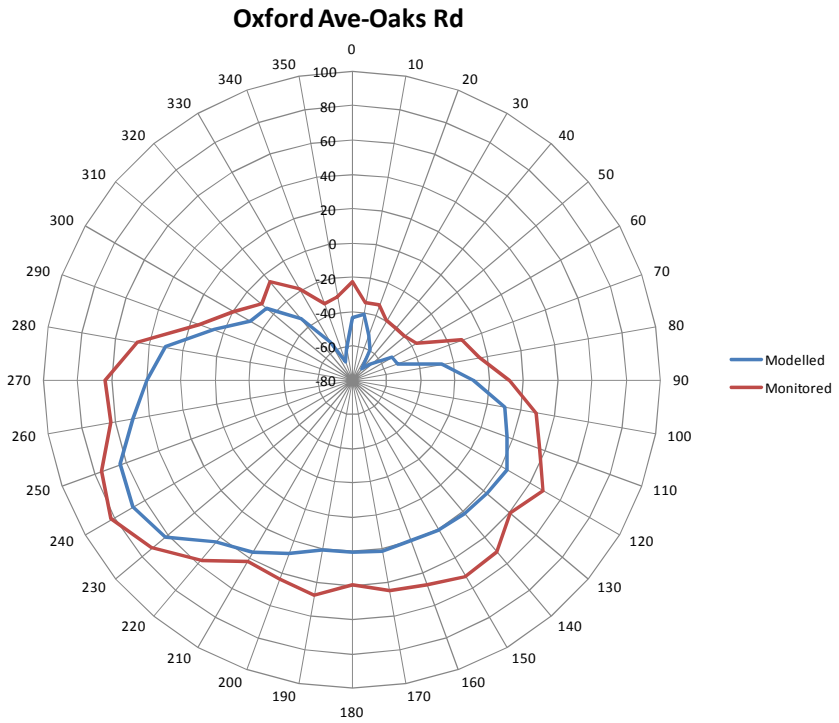


Fig 3.14 The average difference in NO_x concentration (µg/m^3) between Oxford Avenue and Oaks Rd as a function of wind direction

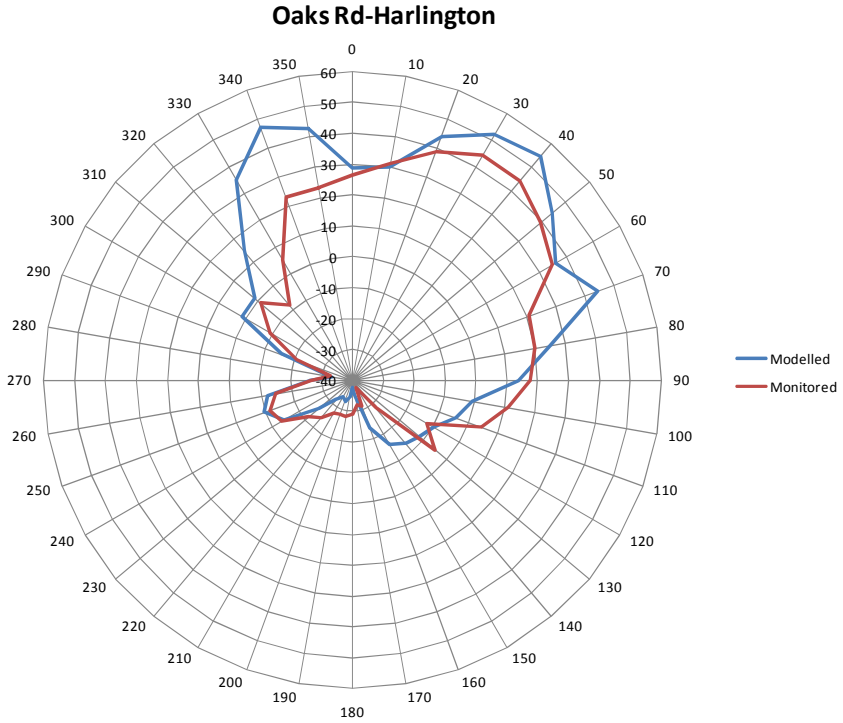


Fig 3.15 The average difference in NO_x concentration (µg/m^3) between Oaks Rd and Harlington as a function of wind direction

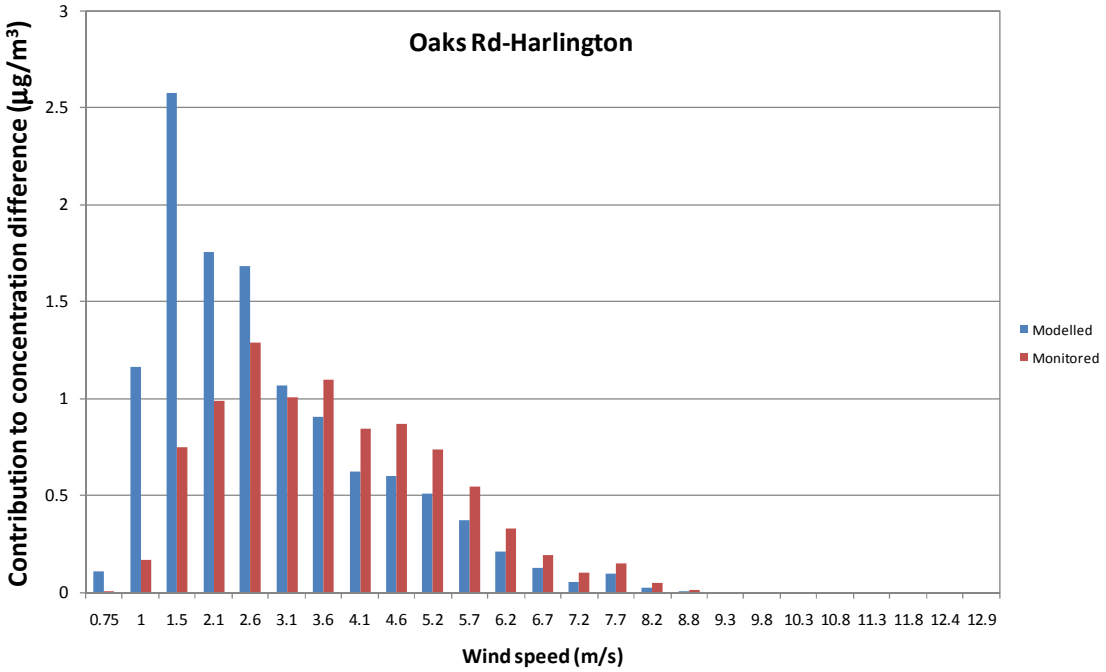


Fig 3.16 Oaks Rd-Harlington concentration difference contribution from wind sectors 330° to 90° inclusive as a function of wind speed

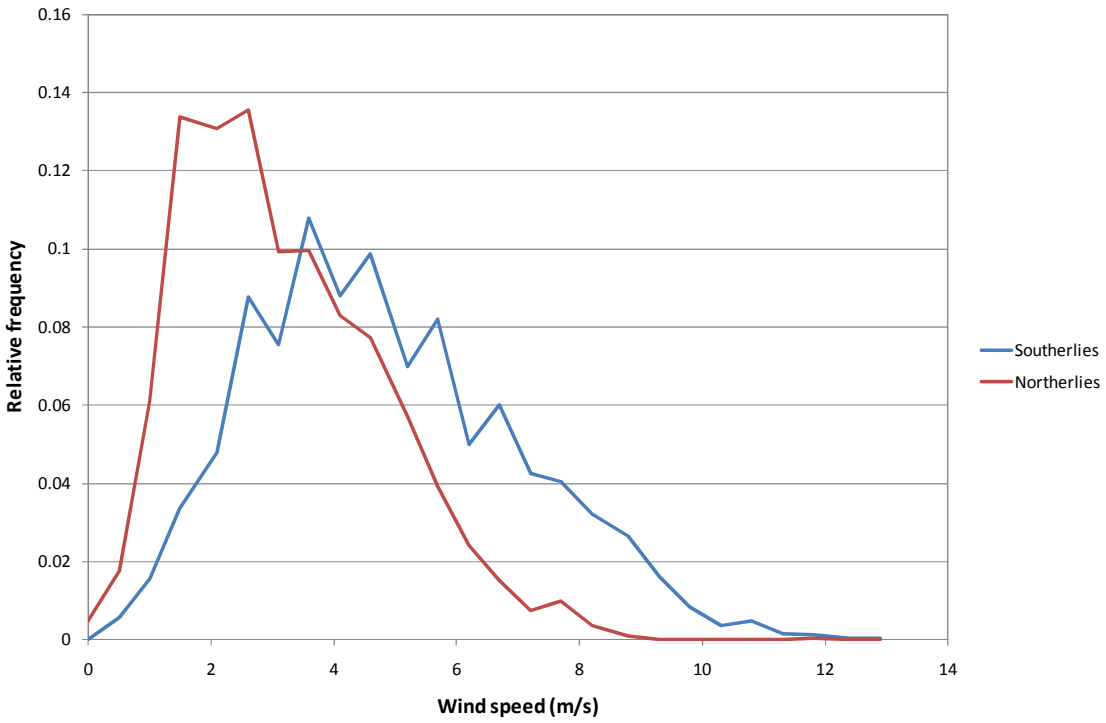


Fig 3.17 Wind speed frequency distribution shown separately for southerly (170°-270°) and northerly (330°-90°) sectors

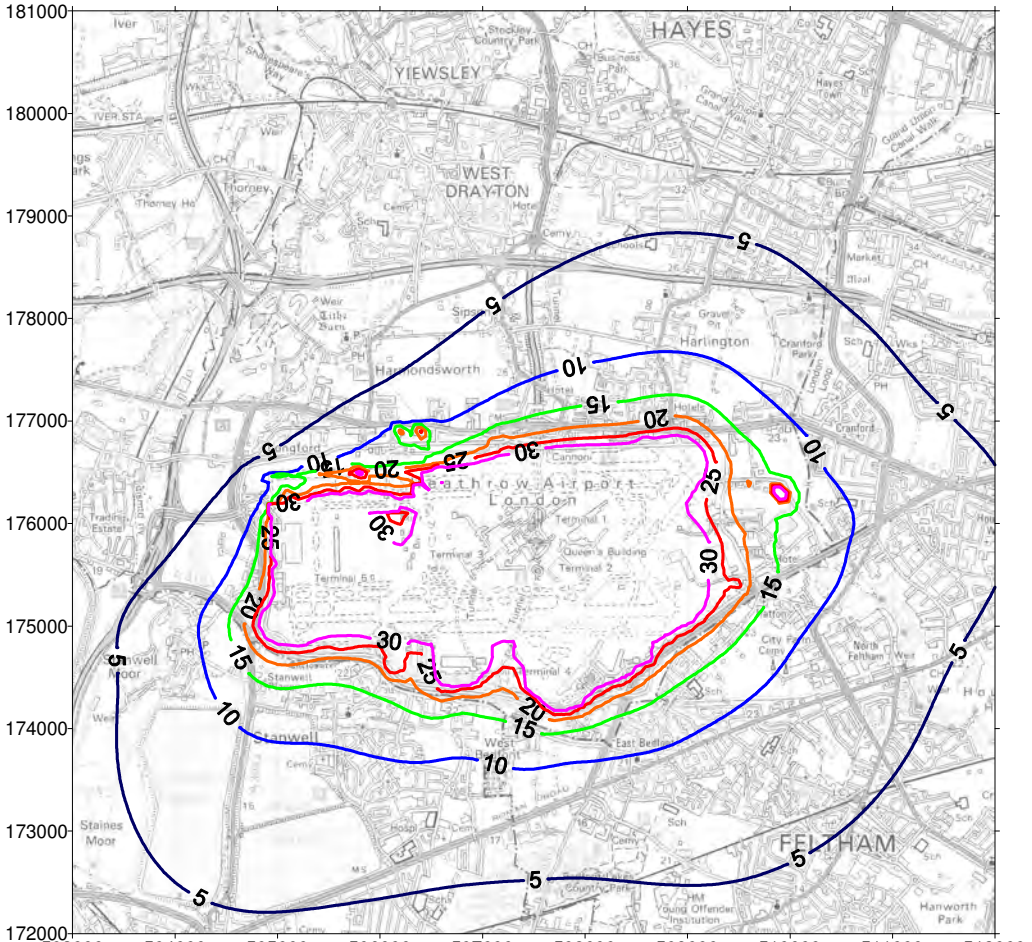


Fig 3.18 Airport contribution to 2008/9 period-mean NO_x concentrations: contours shown for 5 µg/m^3 to 30 µg/m^3

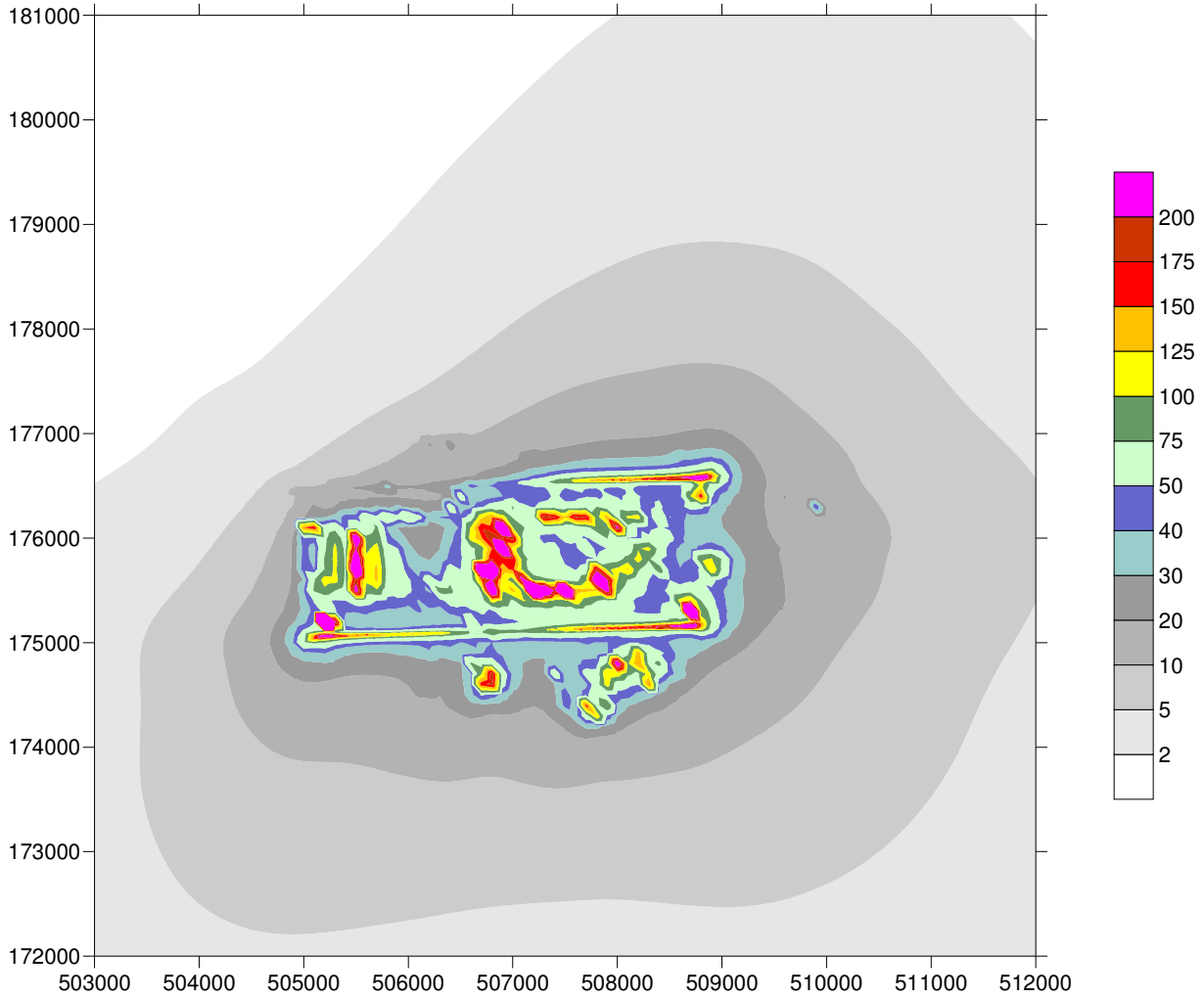


Fig 3.19 Airport contribution to 2008/9 period-mean NO_x concentrations, with PSDH colour coding

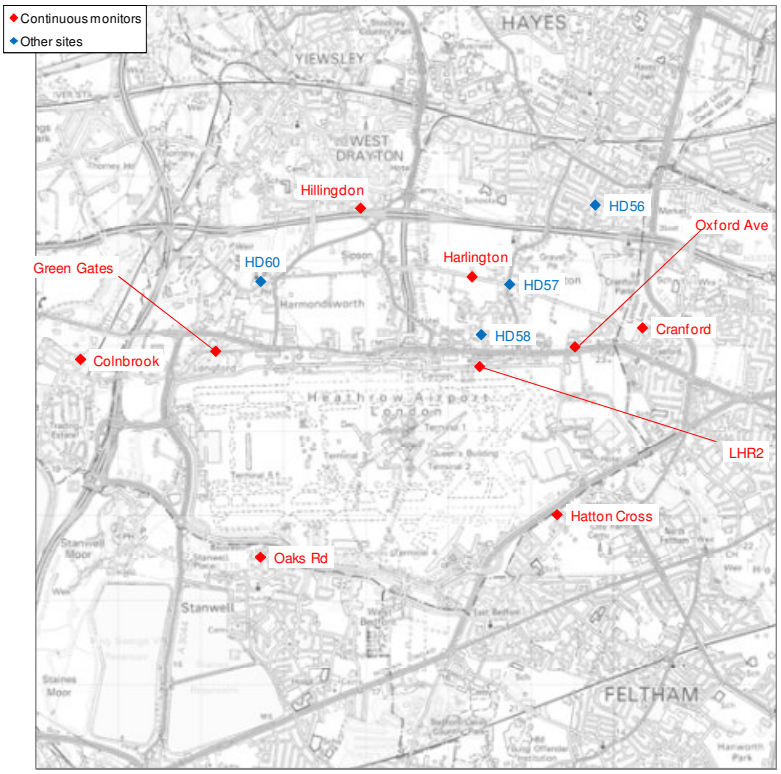


Fig 3.20 Set of receptor points used for comparisons with PSDH results

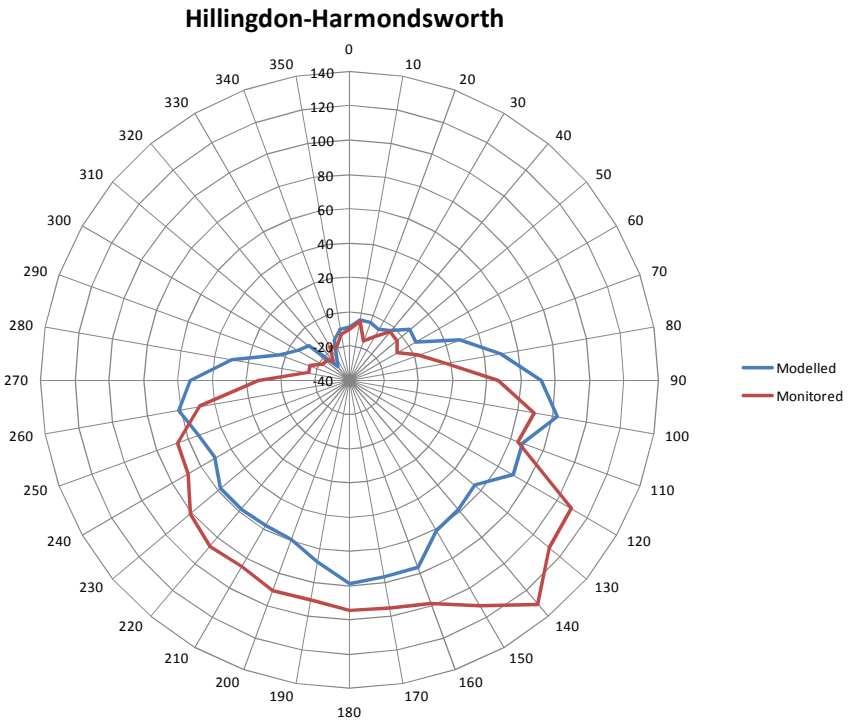


Fig 3.21 The average difference in NO_x concentration ($\mu g/m^3$) between Hillingdon and Harmondsworth as a function of wind direction

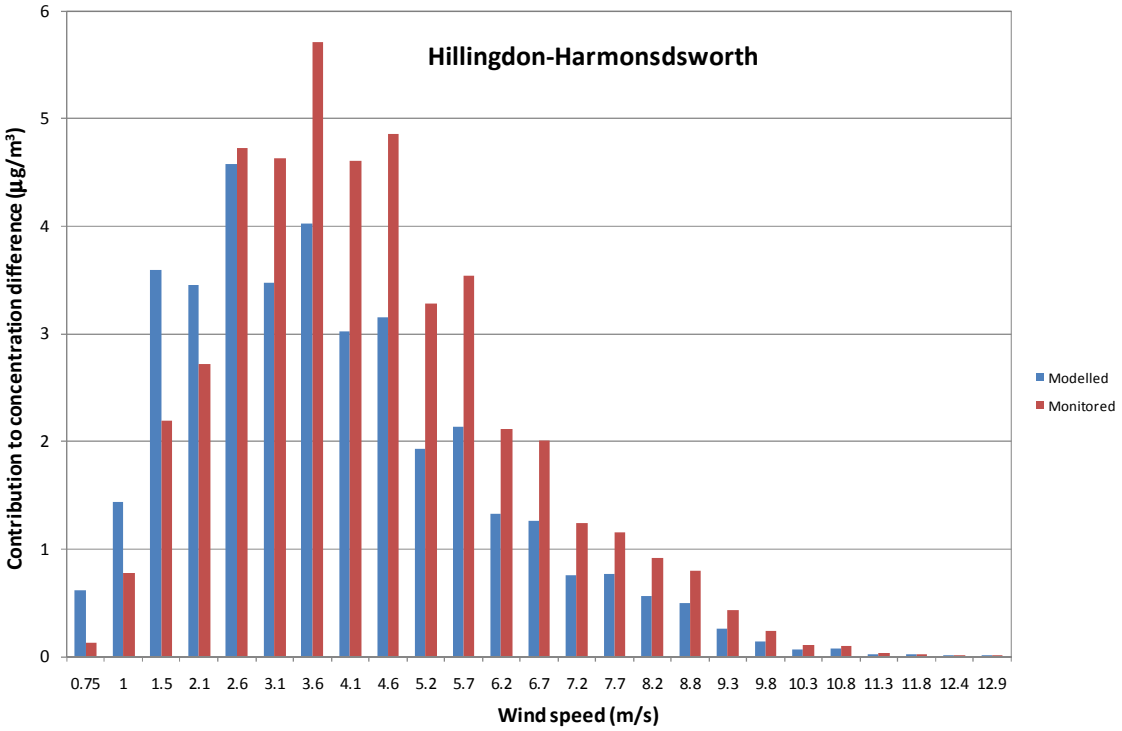


Fig 3.22 Hillingdon-Harmondsworth concentration difference contribution from wind sectors 100° to 270° inclusive as a function of wind speed

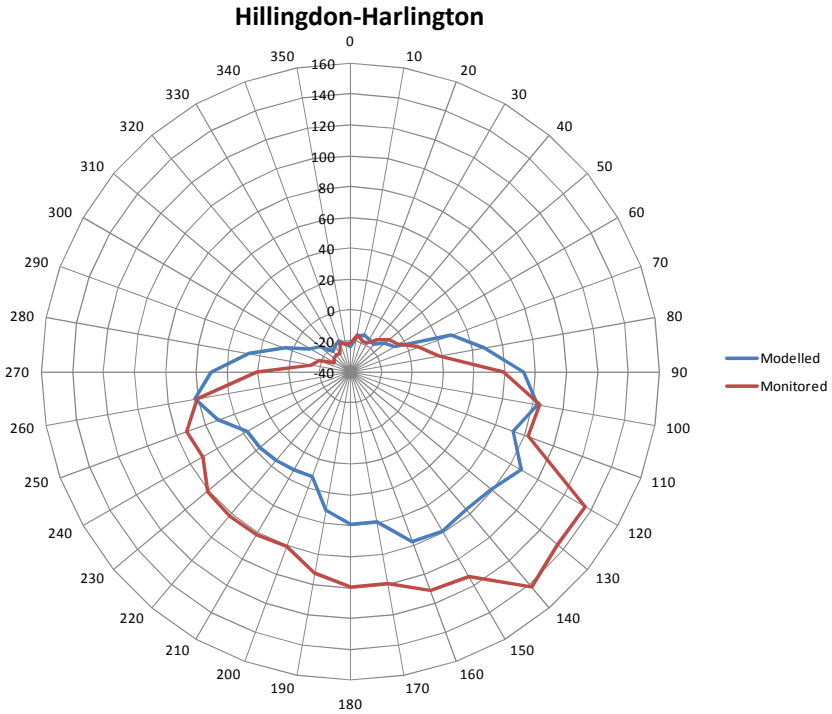


Fig 3.23 The average difference in NO_x concentration (µg/m^3) between Hillingdon and Harlington as a function of wind direction

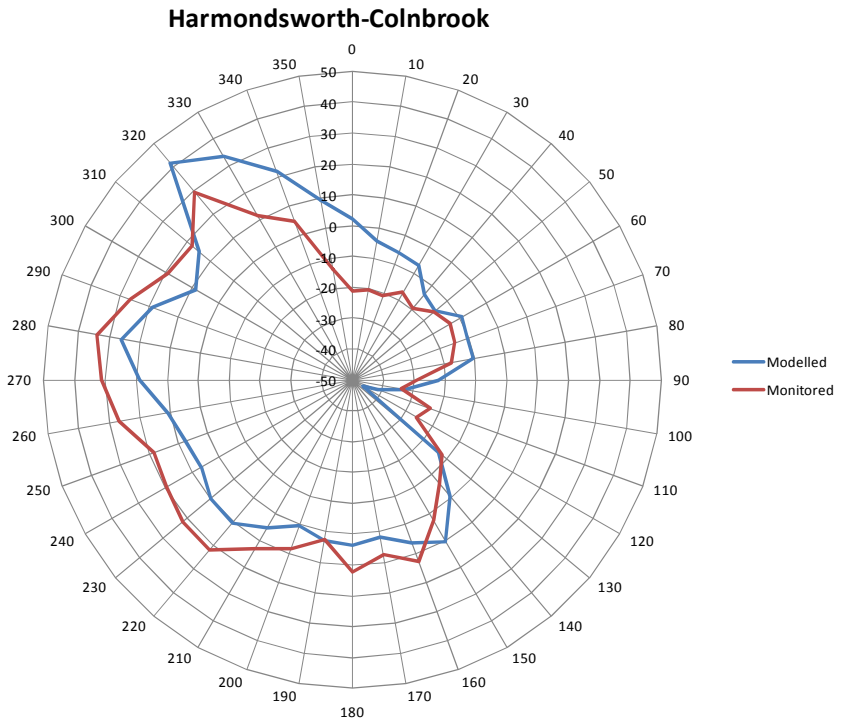


Fig 3.24 The average difference in NO_x concentration (µg/m^3) between Harmondsworth and Colnbrook as a function of wind direction

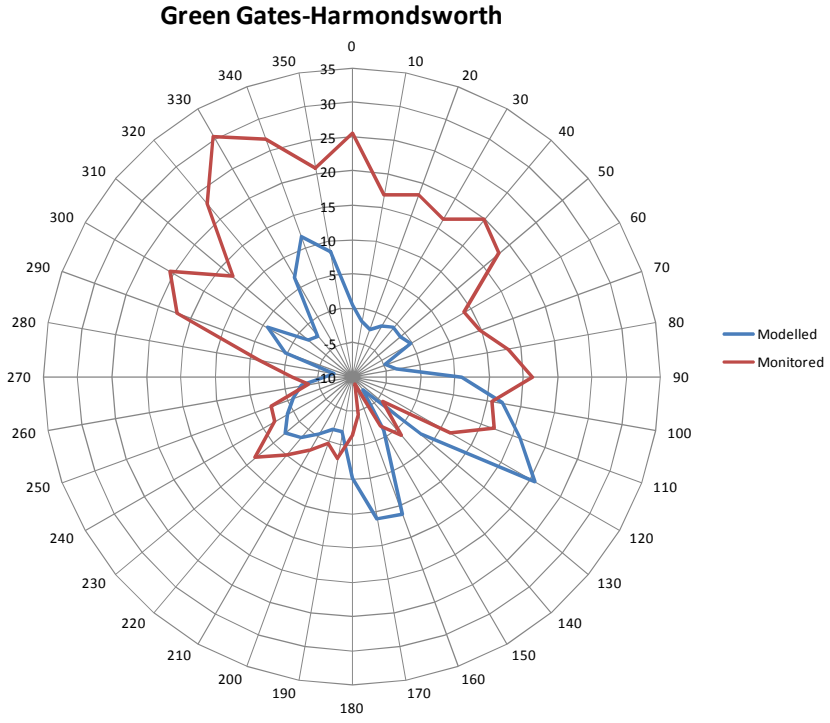


Fig 3.25 The average difference in NO_x concentration (µg/m^3) between Green Gates and Harmondsworth as a function of wind direction

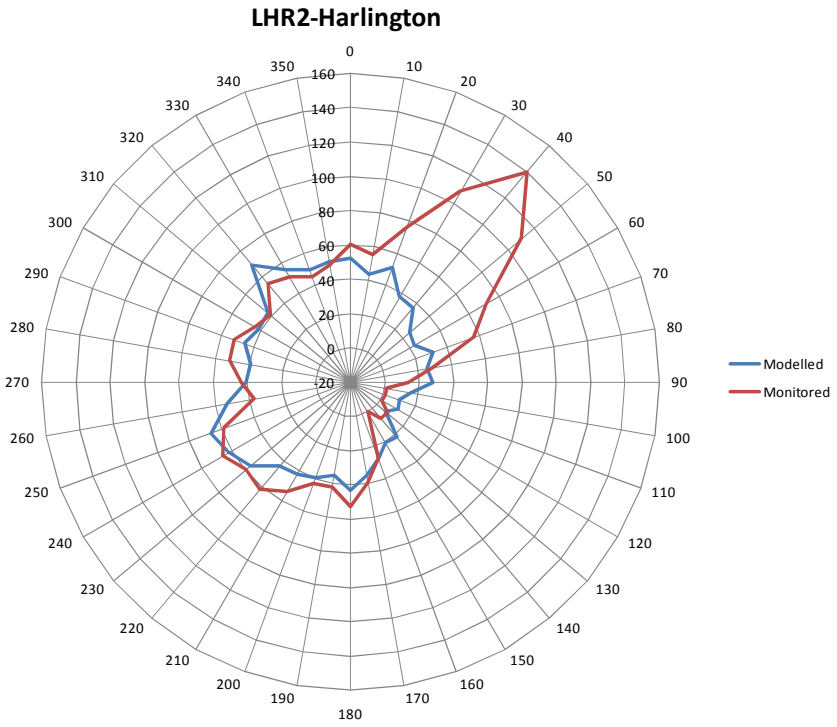


Fig 3.26 The average difference in NO_x concentration (µg/m^3) between Green Gates and Harmondsworth as a function of wind direction

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Fig 3.27 Google satellite image showing LHR2 in relation to junction of Northern Perimeter Rd with Neptune Rd . (Extent of picture: 170 m × 110 m approximately)

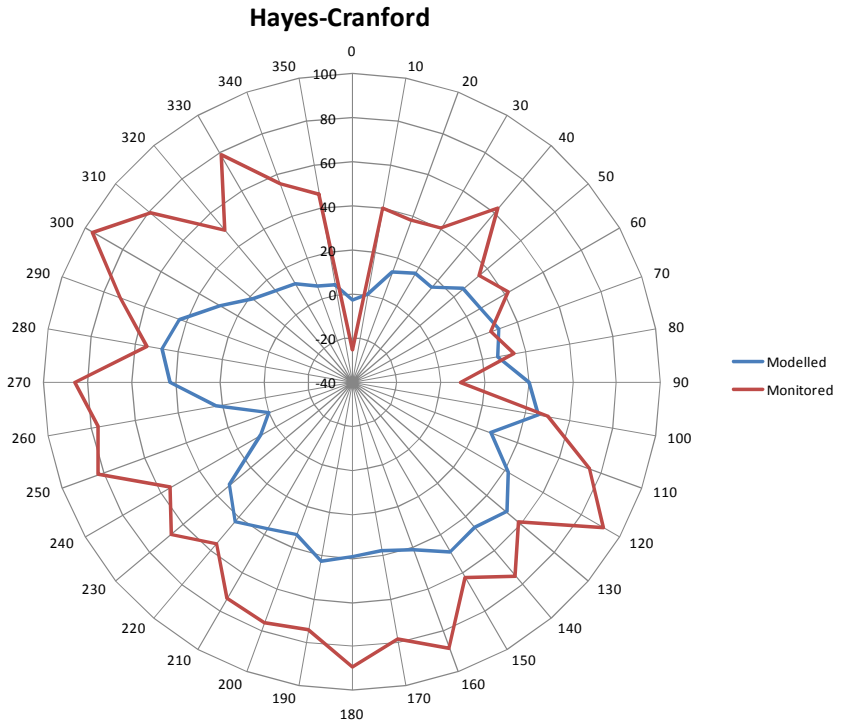


Fig 3.28 The average difference in NO_x concentration ($\mu g/m^3$) between Hayes and Cranford as a function of wind direction

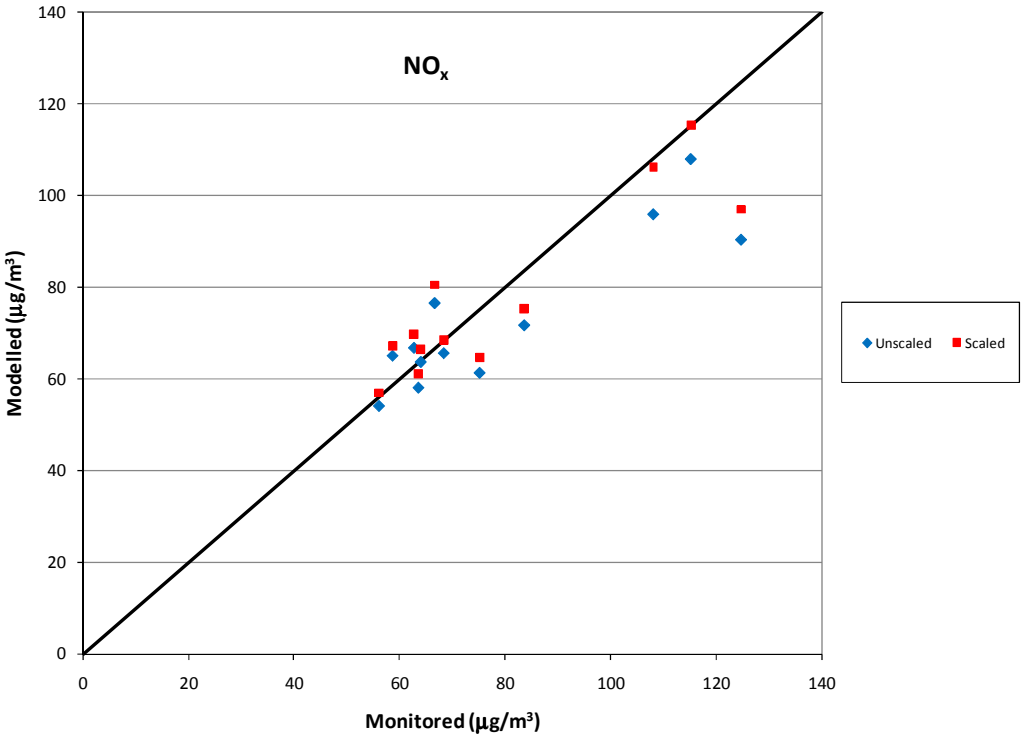


Fig 3.,29 Effect on NO_x scatter plot of including the road network scaling factor

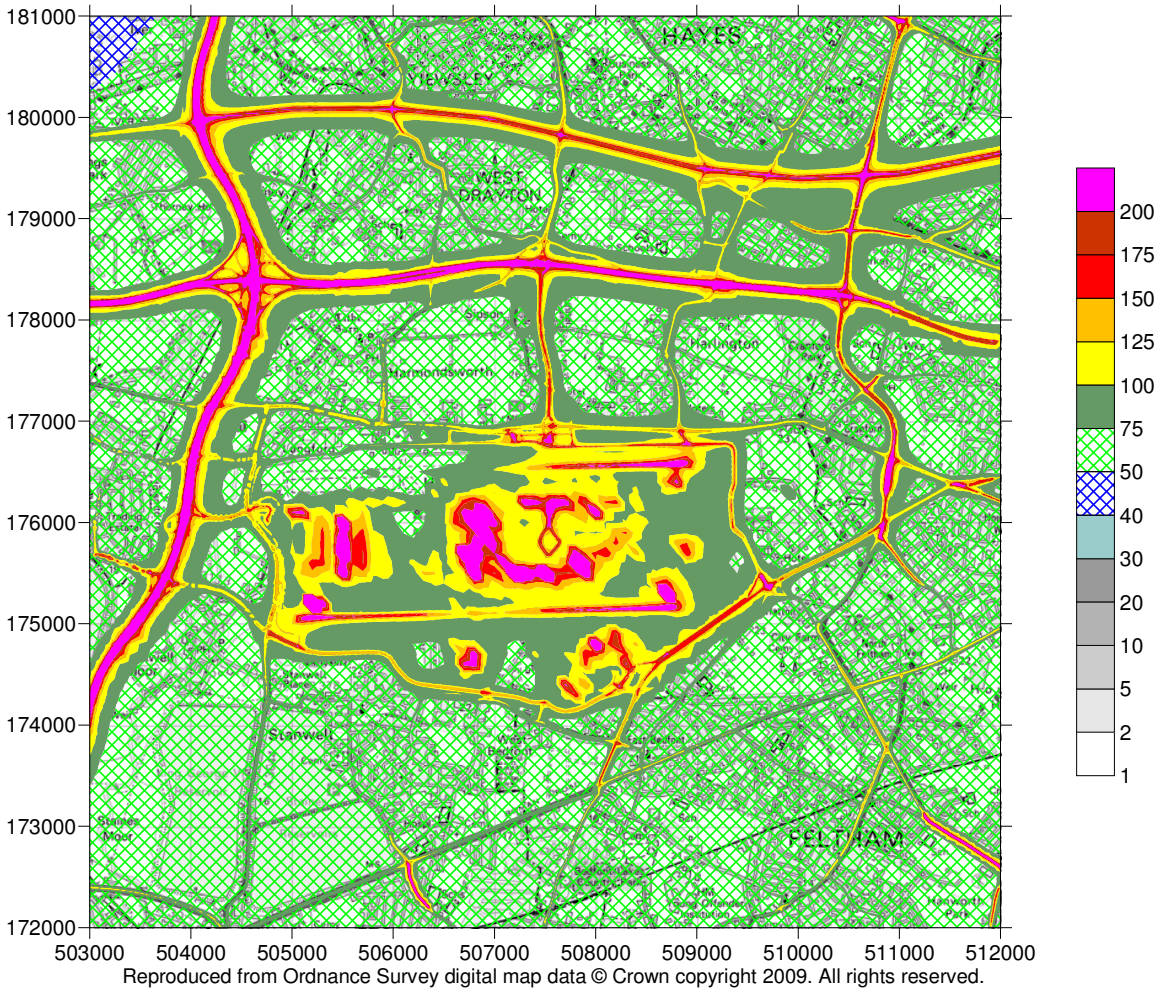


Table 3.30 Modelled total period-mean NO_x concentration (µg/m^3) in 2008/9 (with scaled road network contribution)

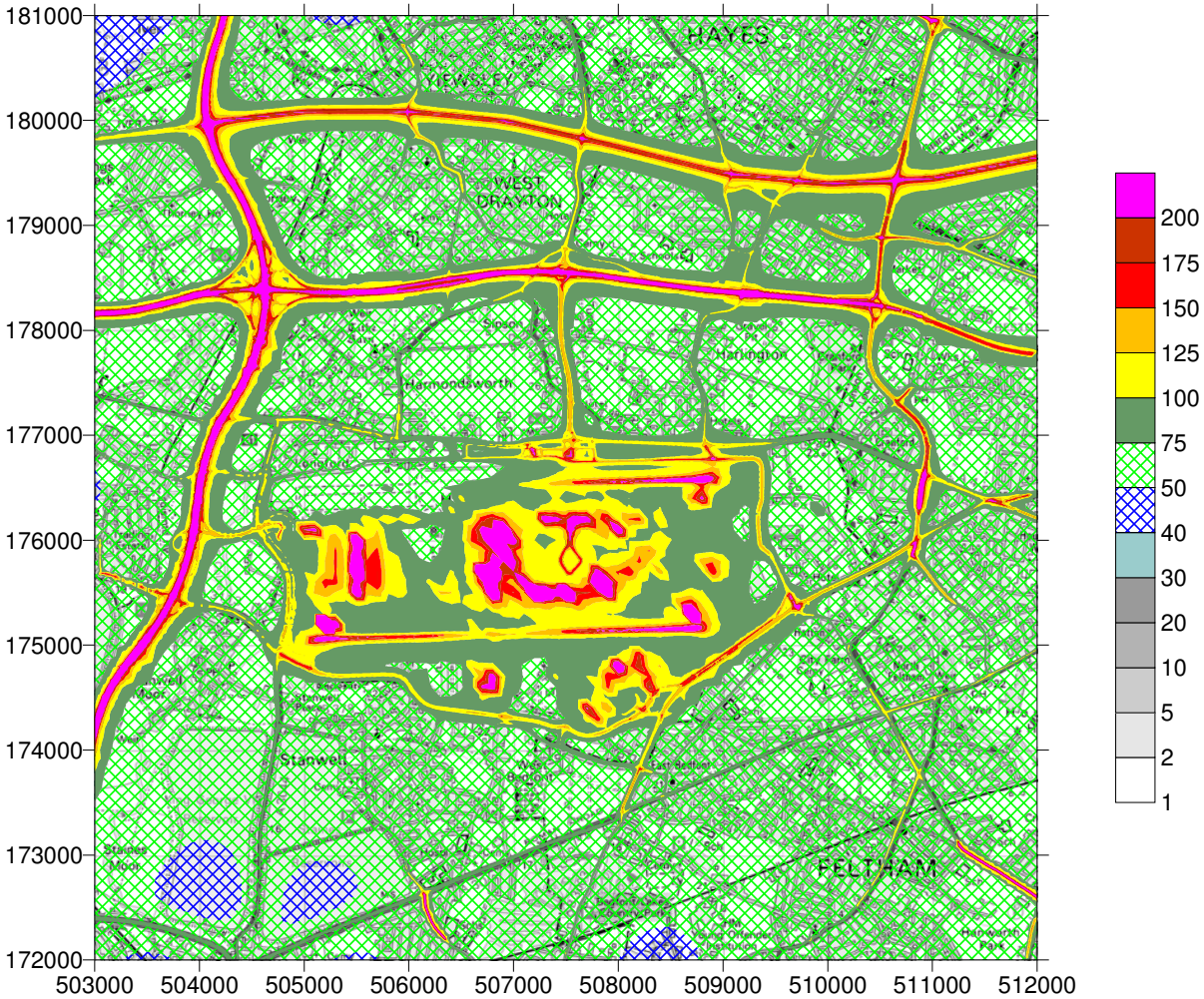


Table 3.31 Modelled total period-mean NO_x concentration (µg/m^3) in 2008/9 (with non-scaled road network contribution)

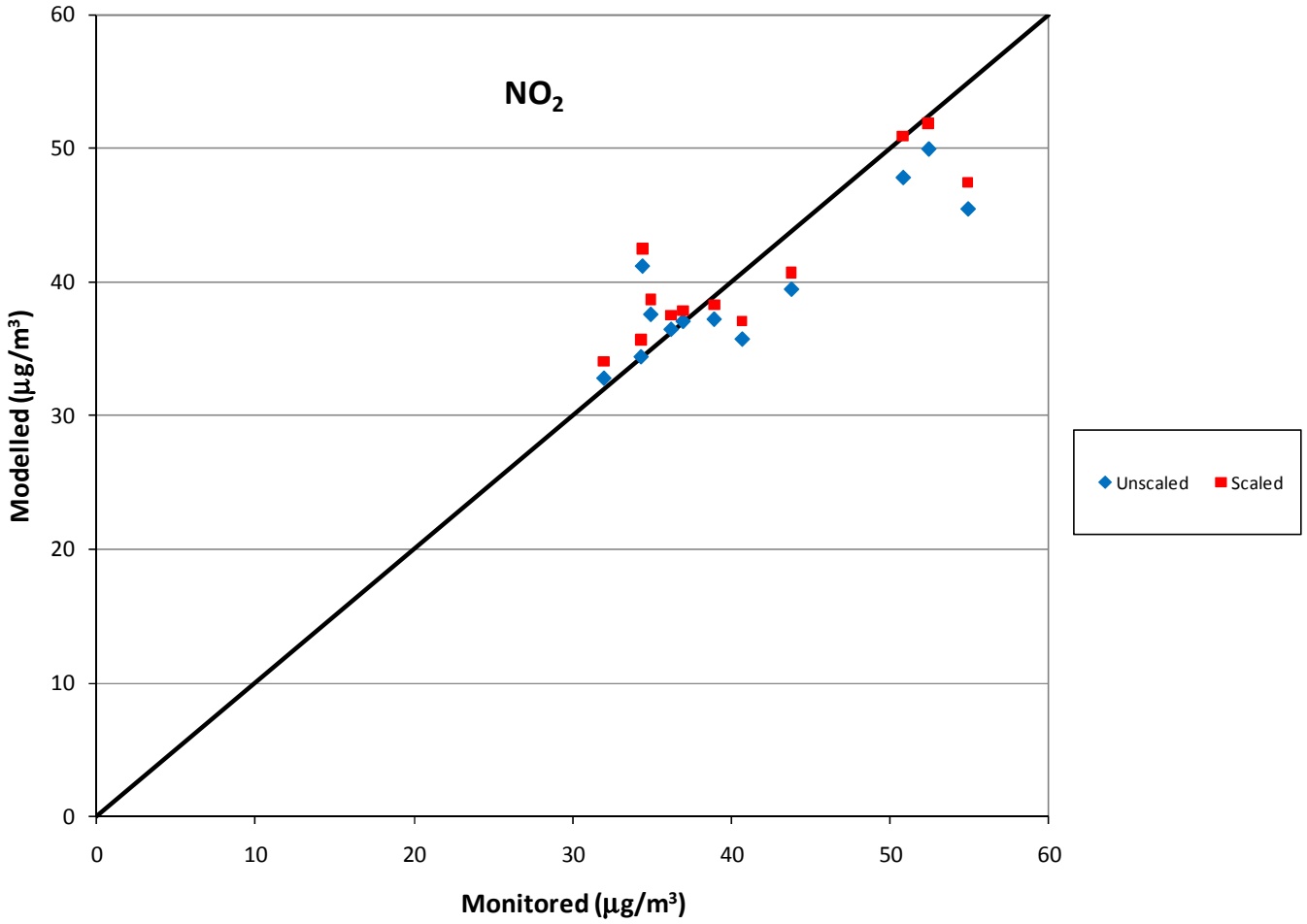


Fig 3.32 Scatter plot of modelled and measured period-mean NO_2 concentrations, before and after applying road-network NO_x scaling factor

Table 3.33 Modelled total period-mean NO_2 concentration (µg/m^3) in 2008/9 (using scaled road-network NO_x contribution)

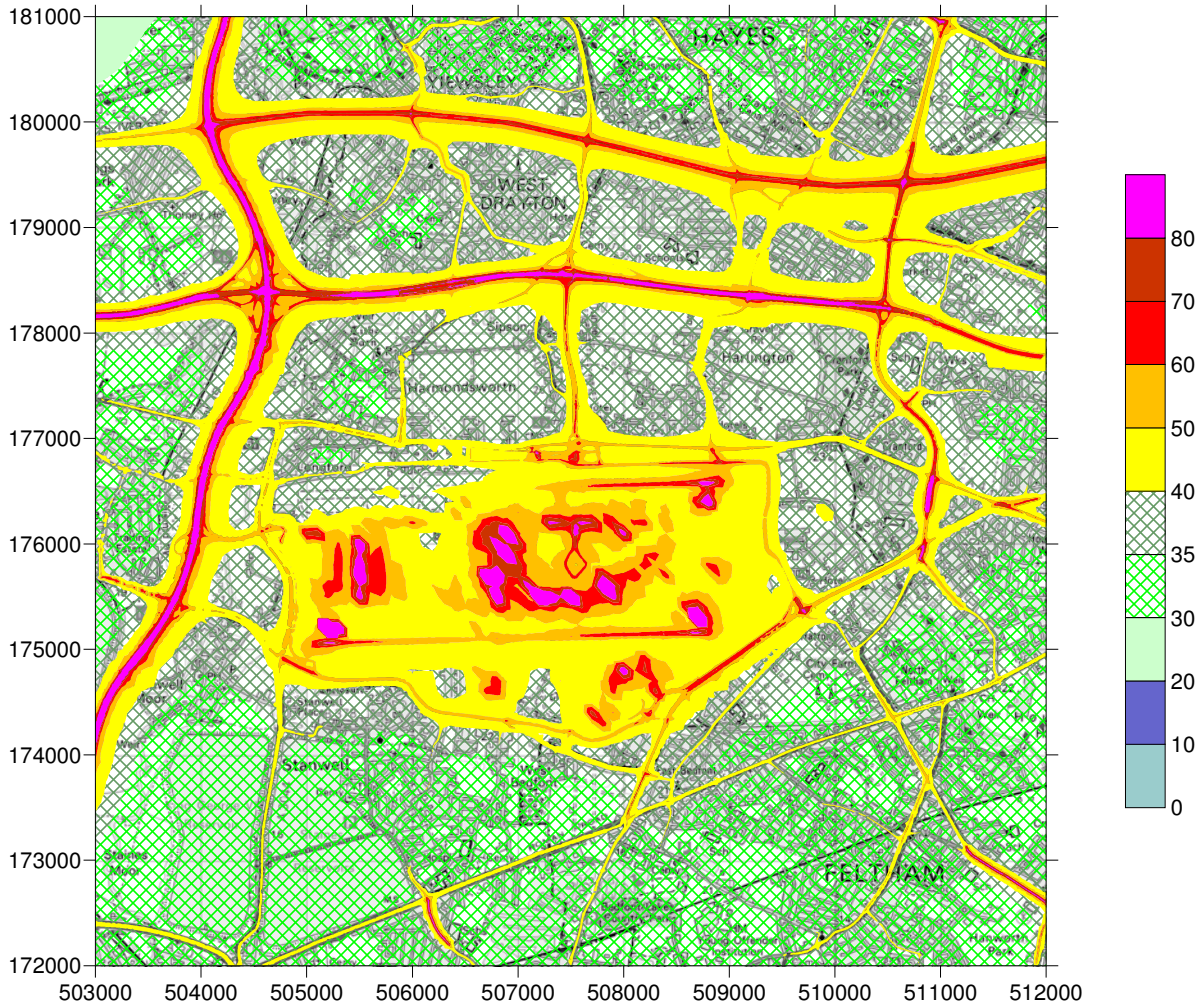


Table 3.34 Modelled total period-mean NO_2 concentration (µg/m^3) in 2008/9 (using non-scaled road-network NO_x contribution)

Fig 3.35 Modelled period-mean NO_2 concentrations: orange 36-40 µg/m^3; red 40-44 µg/m^3; purple >44 µg/m^3

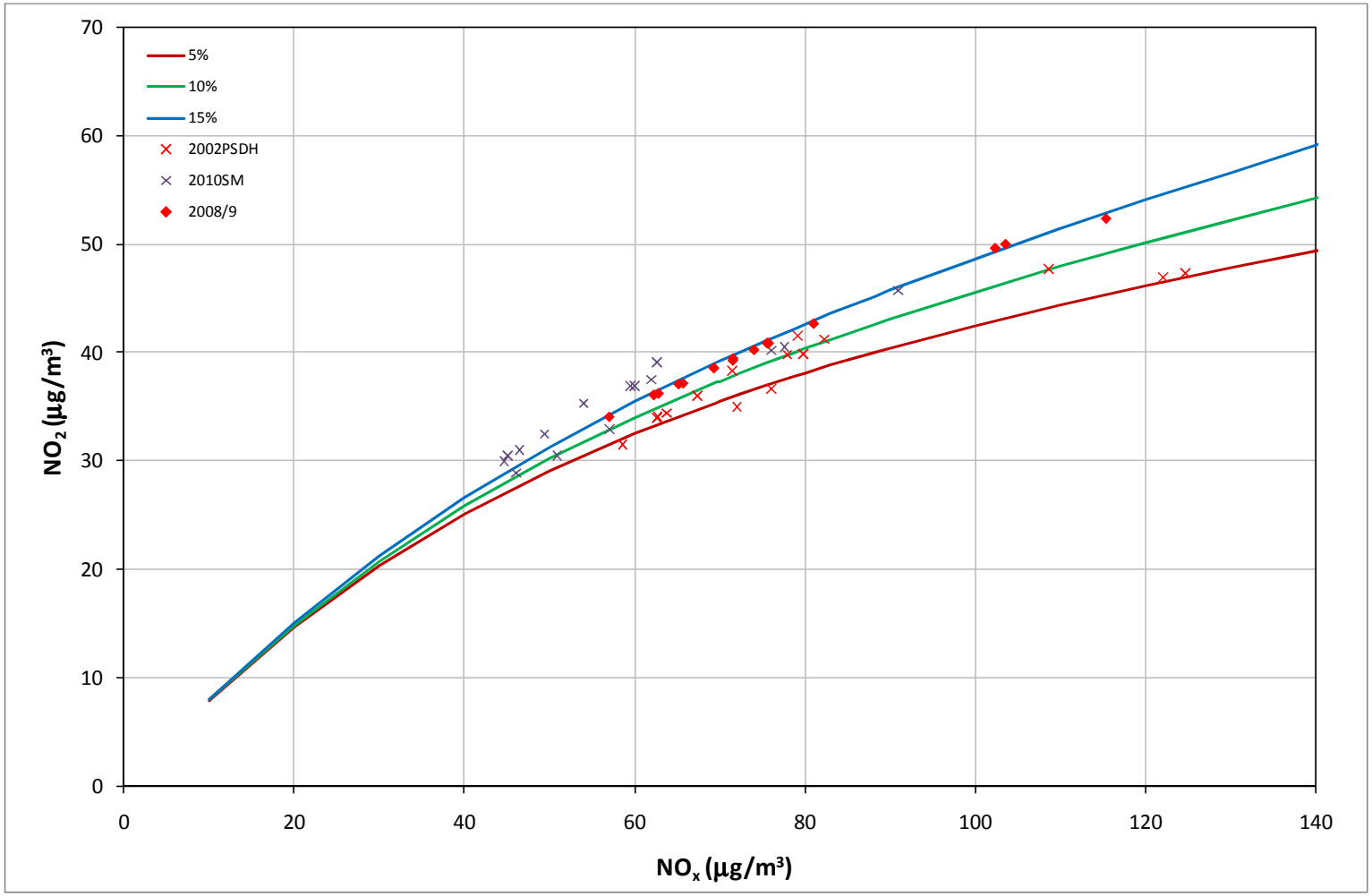
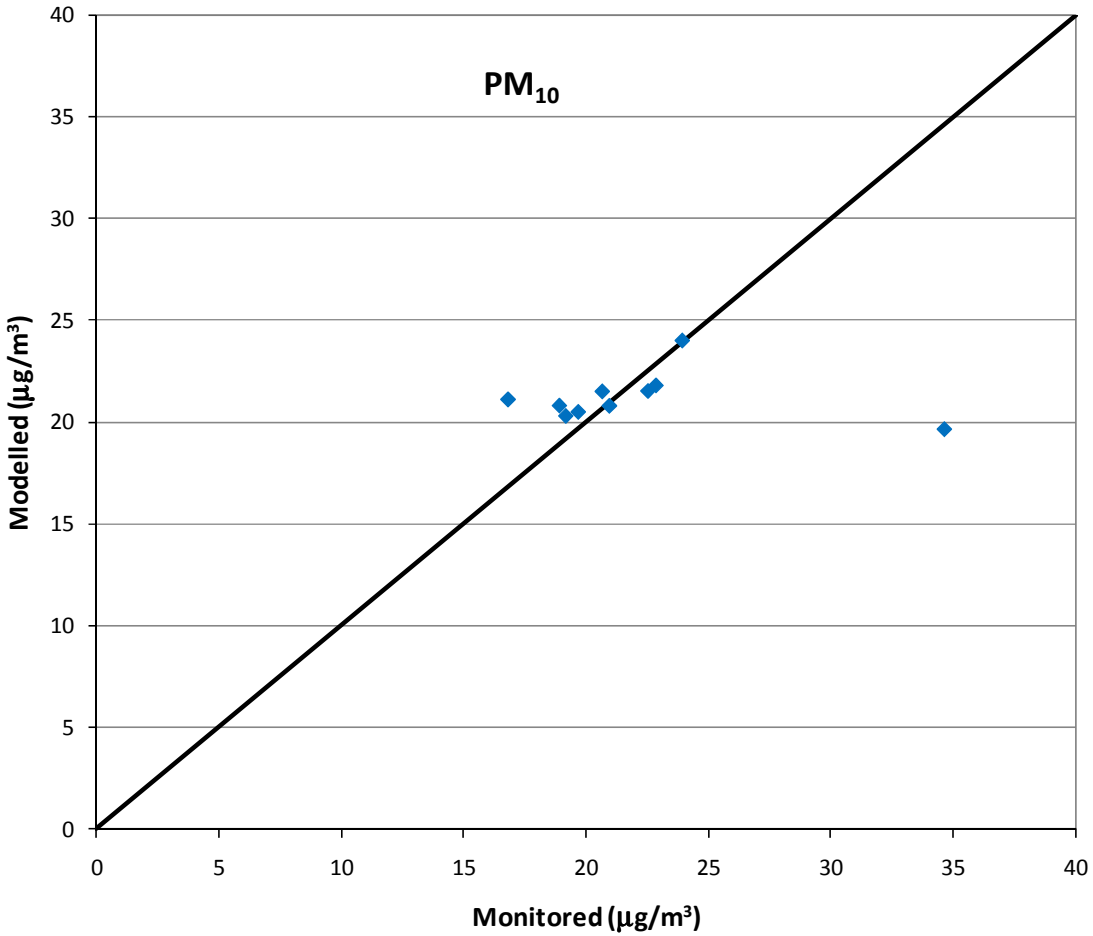


Fig 3.36 Comparison of NO_2/NO_x ratios. Solid curves are given by the Jenkin methodology for fixed values of A (primary NO_2 fraction) and B-33.5 ppb.



ig 3.37 Scatter plot of modelled and measured period-mean PM_{10} concentration

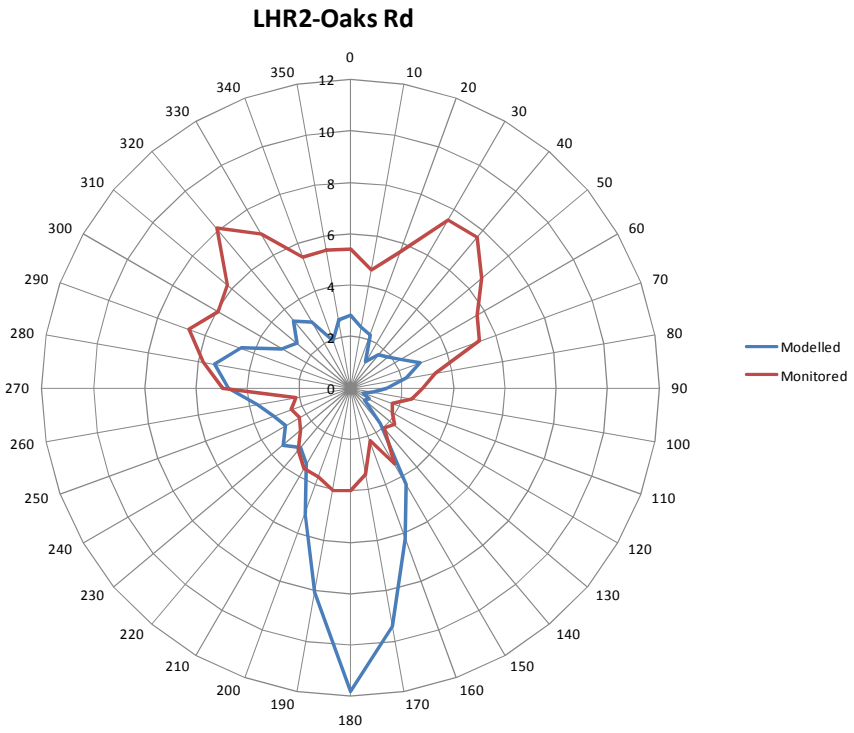


Fig 3.38 The average difference in PM_{10} concentration ($\mu g/m^3$) between LHR2 and Oaks Rd as a function of wind direction

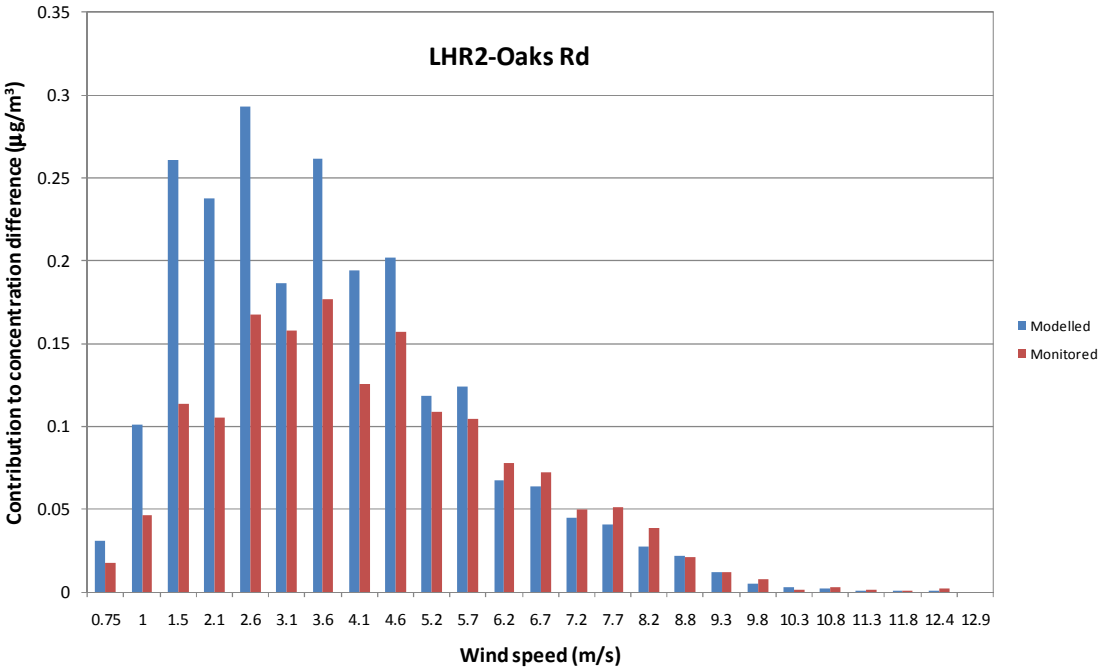


Fig 3.39 LHR2- Oaks Rd PM_{10} concentration difference contribution from wind sectors 150° to 270° inclusive as a function of wind speed

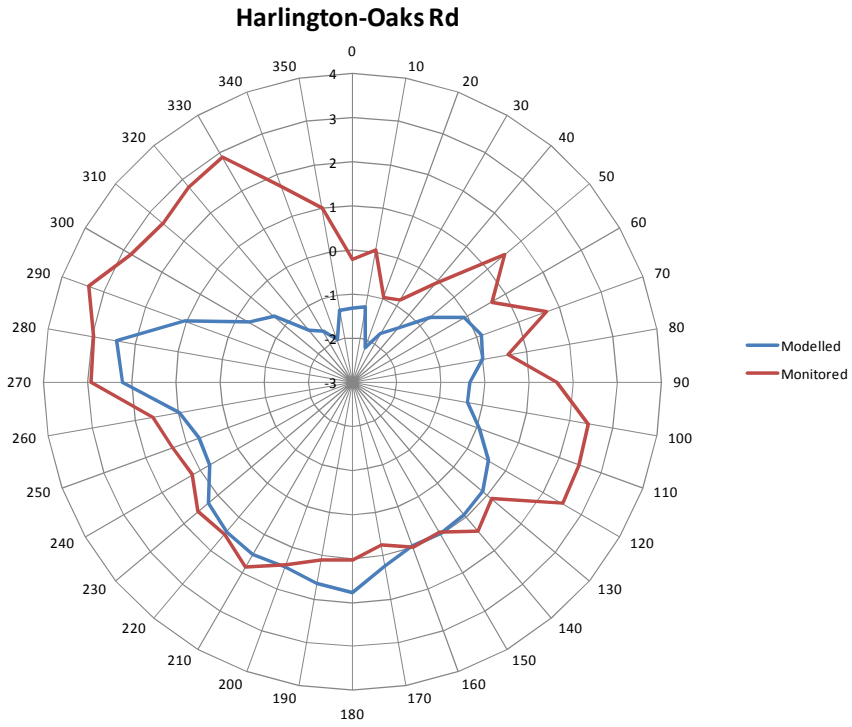


Fig 3.40 The average difference in PM_{10} concentration ($\mu g/m^3$) between Harlington and Oaks Rd as a function of wind direction

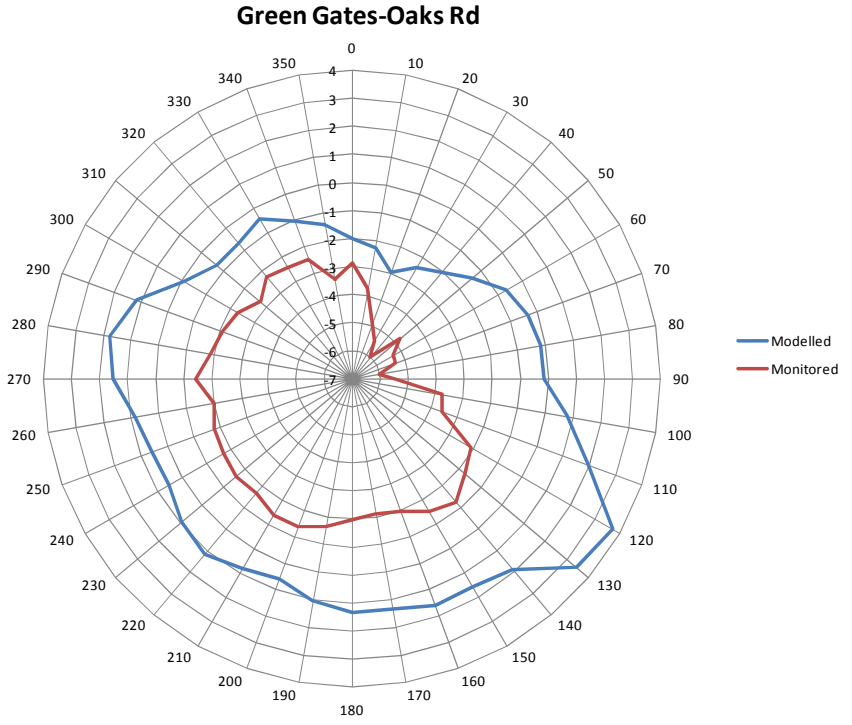


Fig 3.41 The average difference in PM_{10} concentration ($\mu g/m^3$) between Green Gates and Oaks Rd as a function of wind direction

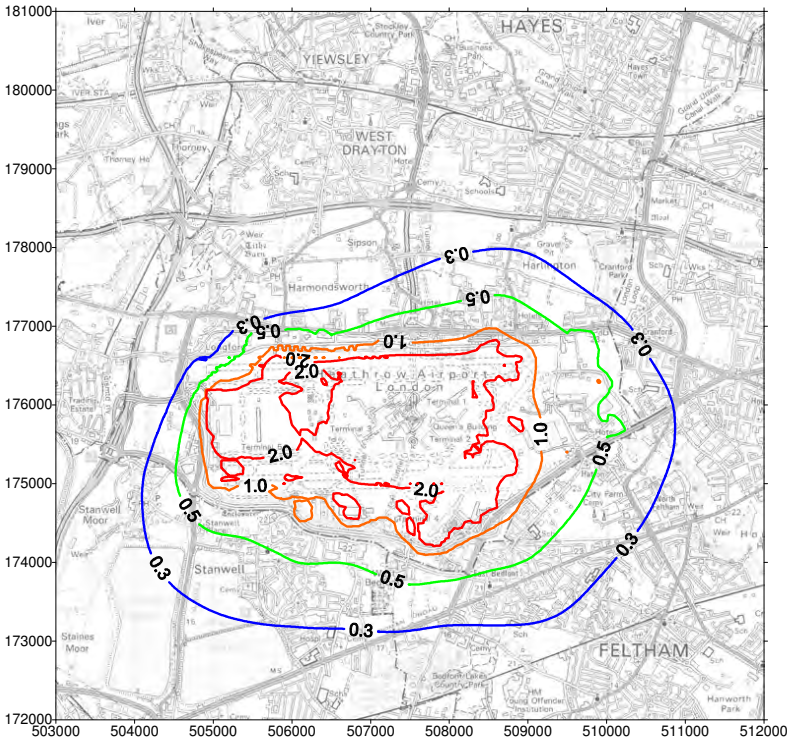


Fig 3.42 Airport contribution to 2008/9 period-mean PM_{10} concentrations: contours shown for 0.3, 0.5, 1.0 and 2.0 µg/m^3

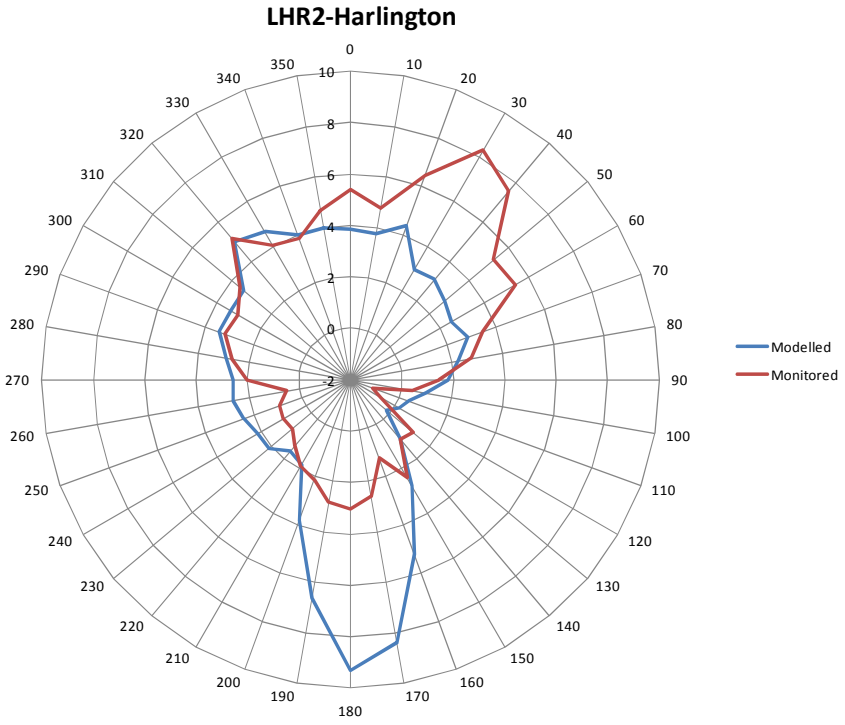


Fig 3.43 The average difference in PM_{10} concentration (µg/m^3) between LHR2 and Harlington as a function of wind direction

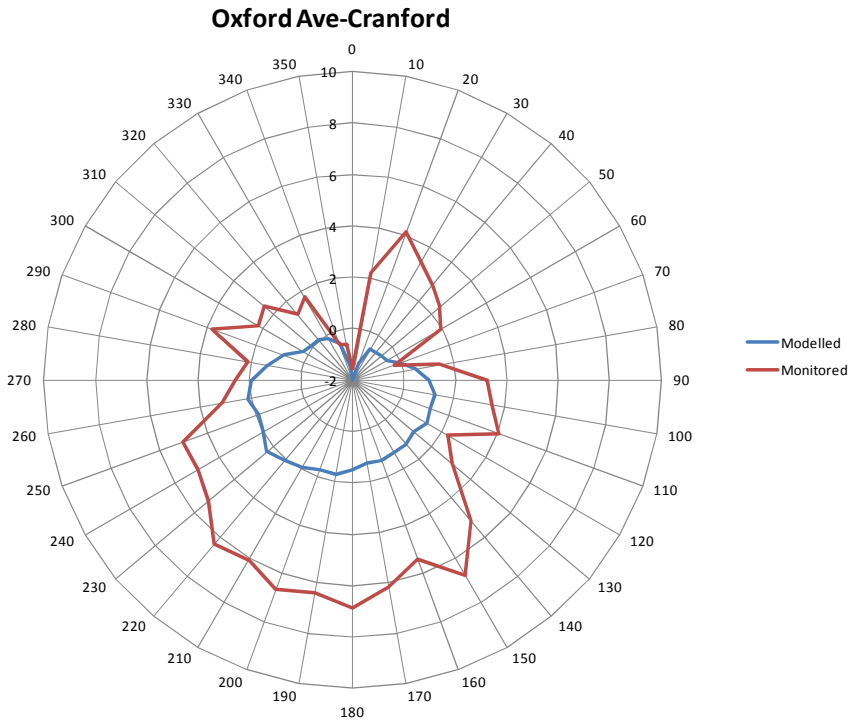


Fig 3.44 The average difference in PM_{10} concentration ($\mu g/m^3$) between Oxford Ave and Cranford as a function of wind direction

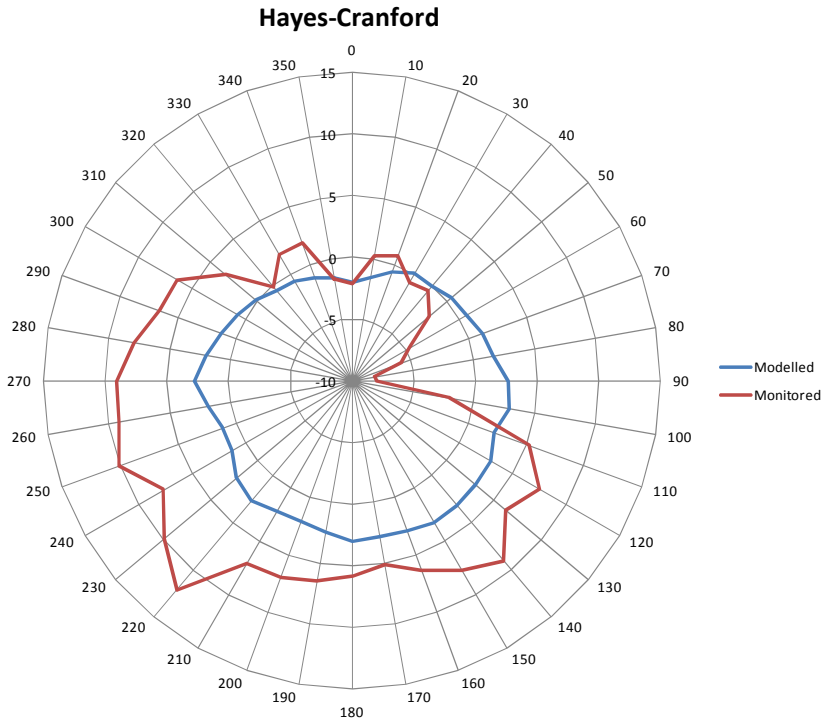


Fig 3.45 The average difference in PM_{10} concentration ($\mu g/m^3$) between Hayes and Cranford as a function of wind direction

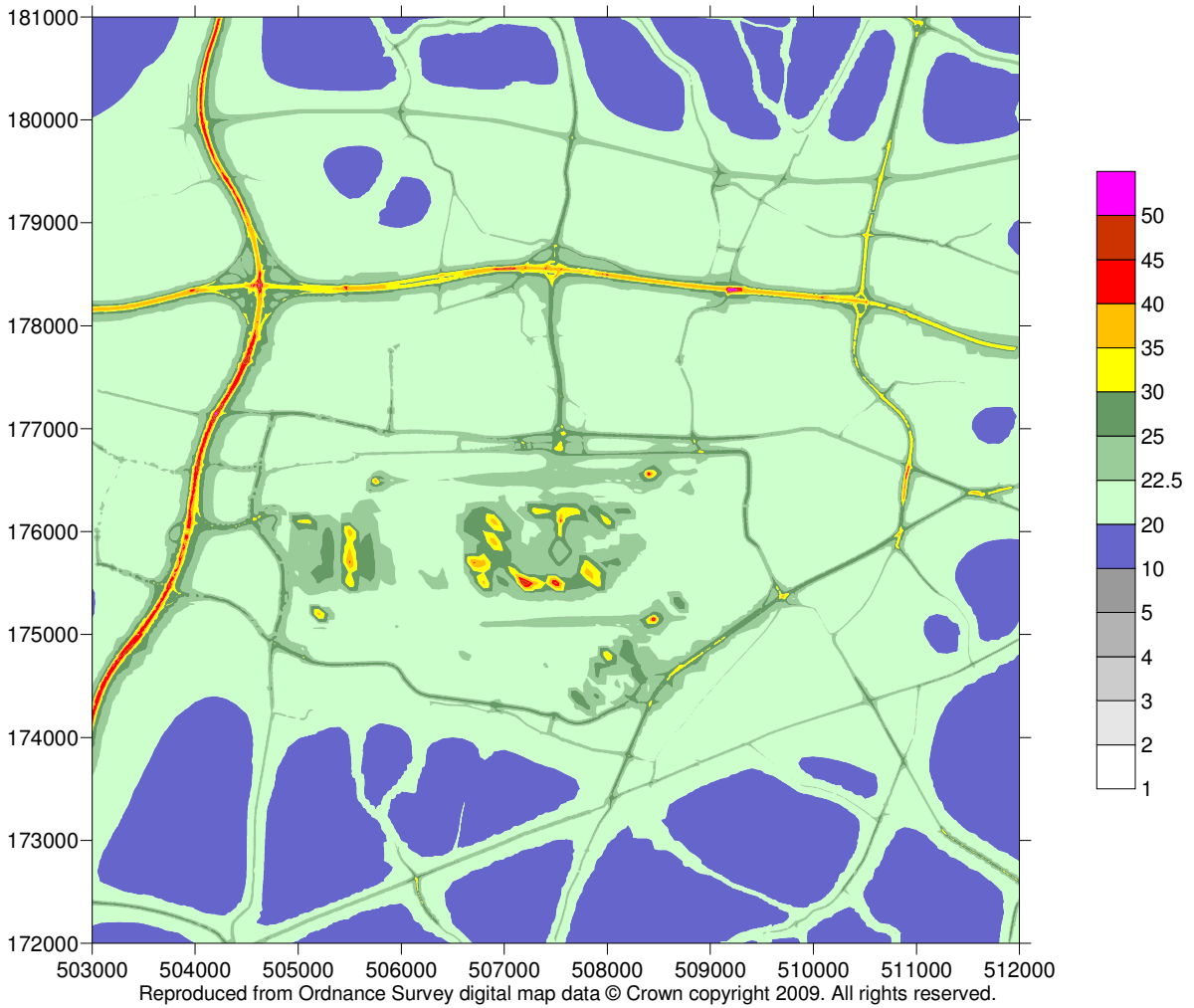


Fig 3.46 Modelled total (all hours) period-mean PM_{10} concentrations for 2008/9

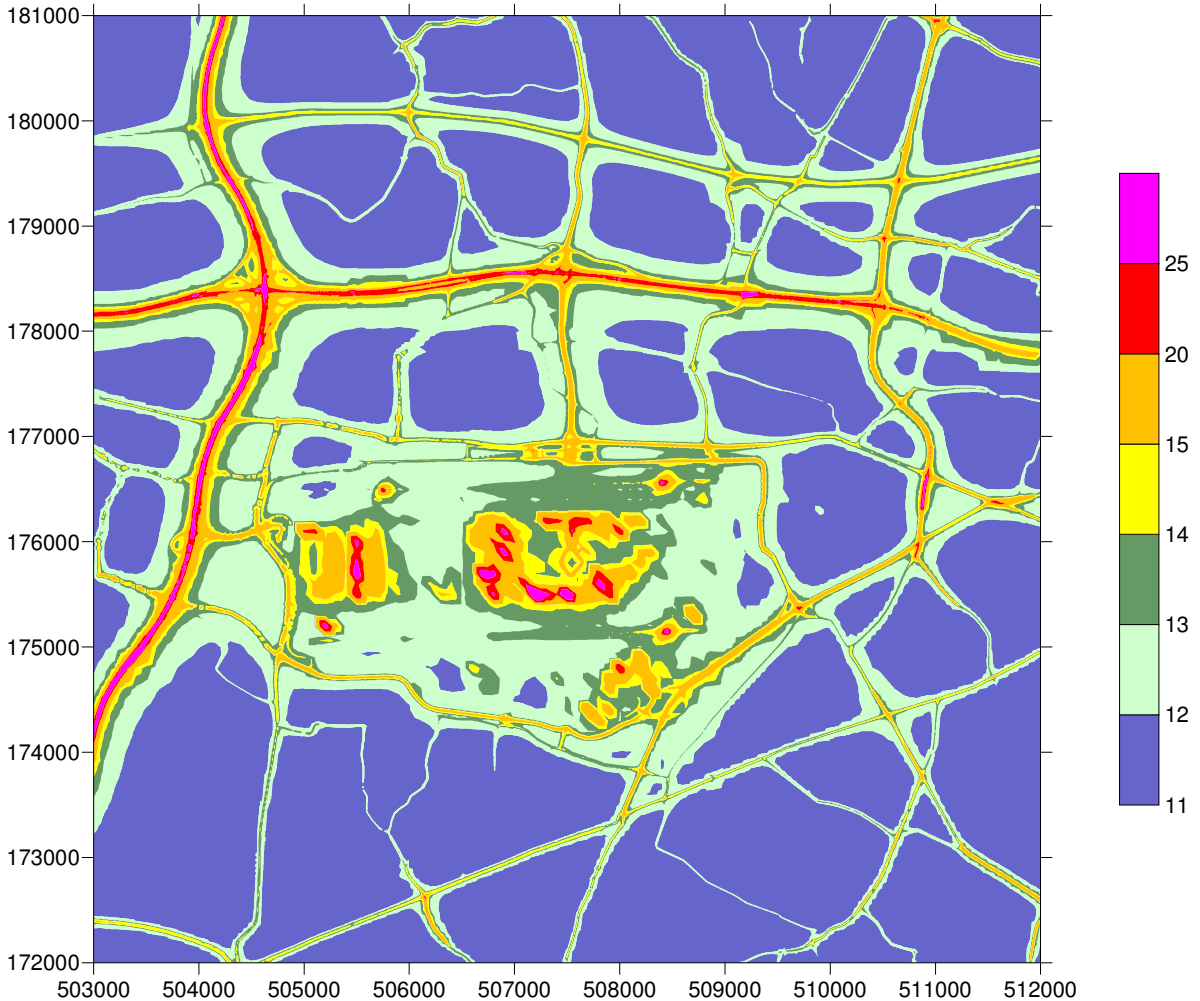


Fig 3.47 Modelled total (all hours) period-mean $PM_{2.5}$ concentration for 2008/9

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