AEAT/ENV/R/1086 Issue 1

Revised PM_{10} projections for the UK for PM_{10} objective analysis

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

Contract Number EPG 1/3/146

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Executive Summary

The Air Quality Strategy for England, Wales, Scotland and Northern Ireland currently sets the following objectives for PM_{10} particles, to be achieved by 31 December 2004:

- 50 μgm^{-3} as a 24-hour mean, not to be exceeded more than 35 times a year
- 40 μgm^{-3} as an annual mean, not to be exceeded.

These objectives are consistent with the Stage 1 limit values for PM_{10} included in the first EU Daughter Directive (AQDD), which are to be achieved by 1 January 2005. The 24-hour mean objective and limit value is expected to be the more stringent of the two. Indicative Stage 2 limit values for PM_{10} are also included in the first AQDD at 20 μgm^{-3} as an annual mean and 50 μgm^{-3} as a 24-hour mean, not to be exceeded more than 7 times a year, to be achieved by 1 January 2010.

The Government and devolved administrations recognise that the possible health gains from reducing PM_{10} levels are thought to be greater than those for any other pollutant. They are concerned to set sights beyond the immediate need to comply with the AQDD Stage 1 limit values. The Government and devolved administrations have therefore undertaken to assess the prospects of whether the AQS objectives for PM_{10} can be strengthened (DETR et al, 2000). An analysis of the costs and benefits of different measures to reduce ambient PM_{10} concentrations forms an important part of this PM_{10} objective analysis.

A consultation document on proposals for air quality objectives for particles, benzene, carbon monoxide and polycyclic aromatic hydrocarbons has been published (DEFRA et al, 2001a) along with an economic analysis to inform the review of the Air Quality Strategy objectives for particles (DEFRA, et al, 2001b). A series of reports detailing the air quality modelling (Stedman, et al 2001b, Stedman et al, 2001c), cost analysis (AEA Technology, 2001) and health benefits analyses (Stedman et al, 2001d) supporting the review have also been published.

Projections of PM_{10} concentrations for 2010 were presented in the consultation documents for both a baseline scenario (current policies) and an illustrative package of possible additional measures scenario along with estimates of the costs and likely benefits of the package of additional measures. Cost, modelling and benefits analyses were carried out in parallel, which raised several technical issues, which could not be addressed without disruption to the publication timetable. The Department of Transport Local Government and the Regions also consulted on draft revised emissions factors for road vehicles (Barlow et al, 2001) on a similar timescale as the AQS consultation. A final set of revised emission factors has been published following this consultation. This change in emission factors is important because it has the effect of both increasing the predicted ambient PM_{10} concentrations in 2010 and increasing the effectiveness of the possible measures to reduce emissions from road traffic sources. Additional air quality modelling and benefits calculations have therefore been carried out to address these modelling and emission factor issues and further sensitivity analyses have also been completed. This document provides a description of the revisions to the models and a comprehensive summary of the new modelling methods and results.

The impact of this illustrative package of measures on site-specific projections of PM_{10} concentrations is described. For example, by 2010, using 1999 meteorology, the baseline scenario suggests that 10 of the 16 sites analysed would exceed the indicative Stage 2 limit value of 20 μgm^{-3} as an annual mean. The application of the package of additional measures reduces the annual mean PM_{10} concentrations to below this level at all but 3 of the sites. The biggest reduction in annual mean PM_{10} concentrations resulting from the illustrative scenario is at Marylebone Road (3.2 μgm^{-3}) – illustrating the targeted nature of the package of measures on locations with elevated pollution levels. Reductions at urban background sites are typically of the order of 1-2 μgm^{-3}. By 2015 further reductions occur beyond that delivered in 2010, for both the baseline and illustrative scenario.

Maps of background PM_{10} concentrations have been calculated for both the baseline and illustrative additional measures scenarios. Across the UK the illustrative package of measures would be expected to reduce the population weighted annual mean PM_{10} concentration in 2010 by 0.897 μgm^{-3}, gravimetric.

Maps of roadside PM_{10} concentrations have also been calculated. Roadside PM_{10} concentrations are predicted to be much lower in 2010 than in the base years 1996-1999. Exceedences of 20 μgm^{-3}, gravimetric are however still expected to be common at the roadside for the baseline scenario, especially for the 1996 base year in England. The illustrative package of possible additional measures is predicted to have a significant impact on the number of road links with estimated annual mean PM_{10} concentrations in excess of 20 μgm^{-3}, gravimetric, particularly in Outer London and the Rest of England. The number of exceedences of 23 and 25 μgm^{-3}, gravimetric are also predicted to be considerably reduced. The number of exceedences of the various threshold concentrations for the baseline scenario in 2015 is considerably reduced compared with 2010, largely as a result of the continued decline in road traffic exhaust emissions. Once again the illustrative package of measures is seen to significantly reduce the number of road links exceeding the thresholds.

The illustrative package of possible additional measures includes measures to reduce emissions from both traffic and stationary sources of PM_{10}. PM_{10} concentrations have also been estimated for two components of this scenario considered separately. Considering the site specific and mapped background and roadside projections together it is clear that greater reductions in background concentrations are predicted for the stationary source measures than for the traffic measures. Ambient concentrations are, however, greater at roadside locations and measures to reduce emissions from road traffic are clearly more directly targeted at reducing these concentrations. The traffic measures would therefore be more effective at reducing roadside concentrations than the stationary source measures, particularly in London.

Contents

1 Introduction

1.1 POLICY CONTEXT

The Air Quality Strategy for England, Wales, Scotland and Northern Ireland (AQS, DETR et al, 2000) currently sets the following objectives for PM_{10} particles, to be achieved by 31 December 2004:

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The Government and devolved administrations recognise that the possible health gains from reducing PM_{10} levels are thought to be greater than those for any other pollutant. They are concerned to set sights beyond the immediate need to comply with the AQDD Stage 1 limit values. The Government and devolved administrations have therefore undertaken to assess the prospects of whether the AQS objectives for PM_{10} can be strengthened (DETR et al, 2000). An analysis of the costs and benefits of different measures to reduce ambient PM_{10} concentrations forms an important part of this PM_{10} objective analysis.

A consultation document on proposals for air quality objectives for particles, benzene, carbon monoxide and polycyclic aromatic hydrocarbons has been published (DEFRA et al, 2001a) along with an economic analysis to inform the review of the Air Quality Strategy objectives for particles (DEFRA, et al, 2001b). A series of reports detailing the air quality modelling (Stedman, et al 2001b, Stedman et al, 2001c), cost analysis (AEA Technology, 2001) and health benefits analyses (Stedman et al, 2001d) supporting the review have also been published.

1.2 PURPOSE OF THIS REPORT

Projections of PM_{10} concentrations for 2010 were presented in the consultation documents for both a baseline scenario (current policies) and an illustrative package of possible additional measures scenario along with estimates of the costs and likely benefits of the package of additional measures. Cost, modelling and benefits analyses were carried out in parallel, which raised several technical issues, which could not be addressed without disruption to the publication timetable. The Department of Transport Local Government and the Regions also consulted on draft revised emissions factors for road vehicles (Barlow at al, 2001) on a similar timescale as the AQS consultation. A final set of revised emission factors has been published following this consultation. This change in emission factors is important because it has the effect of both increasing the predicted ambient PM_{10} concentrations in 2010 and increasing the effectiveness of the possible measures to reduce emissions from road traffic sources. This was demonstrated in the consultation documents by applying the draft revised emission factors as a

sensitivity analysis within the site-specific air quality modelling (DEFRA et al, 2001a, Stedman et al, 2001b). Additional air quality modelling and benefits calculations have therefore been carried out to address these modelling and emission factor issues and further sensitivity analyses have also been completed.

This document provides a description of the revisions to the models and a comprehensive summary of the new modelling methods and results. The NO_x and NO_2 modelling results included in the baseline and additional measures reports which accompanied the consulation documents (Stedman et al, 2001b and 2001c) have not been revised at this stage. This document therefore provides the technical information to support the revised air quality modelling results included in the recently published Addendum to the AQS (DEFRA et al, 2003) resulting from the AQS consultation.

This report describes the methods that have been used to calculate site specific projections of PM_{10} concentrations in 2010 from measurements at automatic monitoring network sites for the period from 1996 to 1999. These site-specific projections provide a valuable tool for the rapid assessment of the impact of a range of policy measures on ambient PM_{10} concentrations. The site-specific projections also have the advantage of not including the uncertainties associated with the empirical or dispersion modelling of concentrations.

This report also describes the methods that have been used to calculate maps of PM_{10} concentrations for the base years 1996 to 1999 and projections for 2010. Maps have been calculated of background concentrations for the whole of the UK at a 1 km x 1 km square resolution and for roadside concentrations at a total of 7180 individual built-up major road links (A roads and motorways). The maps of background concentrations are required for the assessment of the health and non-health benefits of policy measures to reduce PM_{10} concentrations. The maps of roadside concentrations can be used to assess the impact of policies on the number of road links with estimated concentrations exceeding threshold concentrations, such as existing or proposed AQS objectives or limit values.

Projections have been calculated for the 2010, as this is the most likely year for which a more stringent AQS PM_{10} objective would apply. The indicative stage 2 limit values for PM_{10} of the first AQDD are also to be achieved by 1 January 2010. 2010 is also the timeframe of the Ten Year Plan for Transport (DETR 2000a), which set out the Government's strategy to tackle congestion and pollution and deliver better integrated, high quality, transport systems over the next decade.

The analyses of PM_{10} concentrations described here are very similar to those published in the consultation documents and are based on the methods described in the AQS (DETR et al, 2000) and supporting technical reports (Stedman et al, 1998a). These methods have been updated to incorporate more recent ambient air monitoring results, understanding of atmospheric chemistry and emissions estimates and projections. The revisions to the models and emission factors are detailed in section 2.2. A comparison of the modelling results for the revised models with those published in the consultation documents is presented in section 2.5

This report describes projections of PM_{10} concentrations from the base years 1996 to 1999 to 2010 for a 'baseline' scenario, which represents our best estimate of the impact of current national and international policies on concentrations of these pollutants. Section 3 gives details of this scenario. Projections for alternative scenarios incorporating the impact of additional policy measures to reduce PM_{10} have also been calculated in order to assess the costs and

benefits of these measures in comparison with the baseline. Projections for these additional measures scenarios are presented in section 4 along with details of the measures represented. Analyses of the health benefits (Stedman et al, 2001d) and non-health benefits (Watkiss et al, 2001) of the additional measures were also published and supported "An Economic Analysis of the Air Quality Strategy Objectives for Particles" (DEFRA et al, 2001b) along with an examination of the costs of possible measures to reduce PM_{10} emissions and concentrations (AEA Technology, 2001). Revised analyses of the health benefits (Stedman et al, 2002) of the additional measures accompany this report in supporting the Addendum to the AQS (DEFRA, et al, 2003).

2 Revisions since the publication of the consultation documents

2.1 INTRODUCTION

This report describes the modelling methods and the results of the air quality modelling analyses carried out using the revised models and emission factors to support the publication of the Addendum to the AQS. The modelling methods are very similar to those reported in the consultation documents and full descriptions are provided here for ease of reference. Section 2.2 describes the principle changes to the models from those described in the consultation documents. Section 2.3 provides a summary of the information that has not been revised. The additional sensitivity analyses carried out in support of the Addendum to the AQS are described in section 2.4 and a summary of the differences between the key modelling results from this study and those presented in the consultation documents is provided in section 2.5.

This section will be of particular interest to those familiar with the consultation documents. Other may wish to omit section 2 and focus attention on section 3 to 8.

2.2 REVISIONS TO THE BASELINE AND ADDITIONAL MEASURES PROJECTIONS

The main revisions to the models are summarised in Table 2.1 and discussed in detail below.

Table 2.1 Revisions to the models

Update	Influences
2001 consulation emission factors for road traffic instead of 1999 NAEI emission factors	Baseline mapping, Additional measures mapping, Effectiveness of measures
Incorporate point source modelling into baseline for maps and site specific projections	Baseline mapping, Additional measures mapping, Minor changes to effectiveness of measures
Ensure modelling fully consistent with cost curve (cost curve was changed after the modelling was completed)	Additional measures mapping, Minor changes to effectiveness of measures
Normalise area type traffic emission projection maps to national totals	Minor changes to Baseline mapping
Take European primary out of the base year maps (and include it in the 'other' fraction)	Baseline mapping, Additional measures mapping, Effectiveness of measures

2001 consultation emission factors for road traffic

Revised hot exhaust emission factors for road traffic were published for consultation shortly after the publication of the PM_{10} review consultation. A site-specific sensitivity analysis of the effect of the use of the revised emission factors was included in the consultation documents. The site–specific and mapped analyses presented here have been revised to incorporate these revised emission factors. The analysis presented here is based on the draft revised emission factors published in 2001 and was carried out prior the publication of the final revisions to the emission factors in early 2002. One of the key emission inventory inputs to the analysis is the percentage of UK urban traffic PM_{10} in 2000 still remaining in 2010. This is 53% for the original emission factors, 58% for the 2001 draft revised emission factors and 57% for the final revised emission factors. The change from the original to the draft revised emission factors is therefore greater than the subsequent change to the final revised emission factors.

Analyses carried out in support of future reviews of the AQS will, of course, incorporate the final revised emission factors or further updates as appropriate.

Point sources

The contribution from individual point source emissions was not explicitly included in the baseline mapping in the consultation documents. It was important, however, to assess the benefits of measures that reduce point source emissions in terms of reductions in concentrations. The reductions in PM_{10} emissions from point sources implied by the illustrative package of measures were modelled using ADMS. Emissions from individual plant were modelled for the Iron and Steel and Refineries sectors. Emission from the Other Industry Combustion, Cement, Aluminium, Lime and Other Industry Large Processes sectors were modelled using a dispersion matrix approach, with emissions assumed to be from 1 km square volume sources of height 50 m. We ensured that the reductions in primary PM_{10} in each grid square do not exceed the baseline primary concentration.

The contribution from individual point source emissions to ambient PM_{10} concentrations have been modelled using ADMS and included in the new baseline mapping described here. The reductions in PM_{10} emissions from point sources implied by the illustrative package of measures can then be directly applied to calculate the maps for the illustrative scenario. This issue was discussed in the additional measures report (Stedman et al, 2001c).

Consistency with cost curves

The illustrative package of measures modelled in the consultation documents included a reduction in emissions of 0.2 ktonnes from coke production in the iron and steel industry and of 1.7 ktonnes in the cement industry. The cost curve analysis does not include any change in emission from coke production and includes a reduction for the cement industry of 2.4 ktonnes. These differences reflect revisions to the cost curve that were made after the completion of the air quality modelling. The overall change in estimated UK population-weighted mean concentration for this revision to the illustrative scenario was estimated to be approximately 0.003 μgm^{-3}. The illustrative scenario used within the air quality modelling presented here is fully consistent with cost curve in the consultation documents. This issue was discussed in the IGCB report (DEFRA et al, 2001b).

Area type traffic emission projections

For England and Wales the network model in the NRTF framework divides the country into 11 different 'area types'. Traffic data for road links in Scotland were also assigned to area types 4 to 11. In addition to projections of UK total emissions the NAEI also provides projections of emissions for each individual area type in England, Scotland and Wales. These were incorporated into the road link and area emissions maps for 2010 in the consultation documents for both the baseline and additional measures scenarios. This involved applying area type specific emissions projections to a UK map assigning each road link and grid square to an area type. A reality check has since been applied to the emissions maps for the base years and 2010 to ensure that the total of UK emissions obtained by summing the values in all the grid squares is consistent with the top down calculations of UK total emissions. The errors introduced by this dissagregation of the traffic emission projections were found to be very small (less than 1% for the baseline scenario and less than 2% for the illustrative scenario in 2010). The maps of road traffic emission projections for 2010 and 2015 used here have been adjusted to ensure consistency with projections of UK total emissions.

Treatment of European contribution to Primary PM_{10}

The treatment of contribution from European primary PM_{10} to ambient PM_{10} in projections presented in the consultation documents was slightly different for the site-specific and mapped projections. It was considered as a separate component in the maps (and assumed to decline in line UK total emissions between the base year and 2010) but not specifically accounted for in the site-specific projections. It is likely, however, that this component will not show as steep a decline as UK emissions. It is reasonable to assume that this component will not be completely assigned to any of the primary, secondary or other components within the receptor model. We have therefore not included a mapped component from European primary in the work presented here as discussed in the baseline report (Stedman et al, 2001b). We have assumed that the majority of this component is likely to have been assigned as other in the receptor model and therefore held constant to 2010.

Dispersion Coefficients

The re-calculation of emissions grids for road traffic and the revised treatment of European primary PM_{10} necessitated the re-calibration of the dispersion coefficients used to calculate the mapped background primary PM_{10} from the emissions estimates. This provided an opportunity to revise the dispersion matrices used to calculate the background primary PM_{10}. Traffic emissions are dispersed from a volume source with a height of 10 m and emissions from stationary sources are now dispersed from a volume source with a height of 30 m, as recommended in the baseline report (Stedman et al, 2001b).

The coefficients used to derive the roadside increment of PM_{10} concentration from road link emissions were also re-examined. The coefficient used in the consultation documents was calibrated using 1999 annual mean measured concentrations from the limited number of roadside PM_{10} monitoring sites. The value of this coefficient was strongly influenced by the measured annual mean at Marylebone Road in 1999, which was influenced by local building activities. The coefficient used in the analyses presented here was derived from the 1998 annual mean at this site and 1999 annual means at other sites, with road link emissions adjusted accordingly. This leads to a reduction of in the value of this coefficient of 20%.

2.3 INFORMATION IN THE CONSULATION DOCUMENTS THAT HAS NOT BEEN REVISED

The technology and activity assumption underlying the baseline and illustrative additional measures scenarios unchanged are unchanged from the consultation documents and full descriptions are provided here for ease of reference. The revision of the emission factors for traffic has lead to a change in the emission from traffic for both scenarios.

The costs of the illustrative package of possible policy measures to reduce PM_{10} in 2010 was discussed in detail by AEA Technology (2001) and DEFRA et al (2001b) and remains applicable to the scenario used for the revised modelling. Analyses of the health and non-health benefits of the possible package of measures have been recalculated for the revised air quality modelling results presented here by Stedman et al (2002) and Watkiss et al (2002).

The modelling of NO_2 and SO_2 concentrations included in the consultation reports (Stedman et al, 2001b, 2001c) has not been repeated at this stage because the main focus of the recent review has been on PM_{10}. The changes would not be expected to have any impact on predicted SO_2 concentrations but NO_2 projections calculated using the using the revised emission factors would be expected to show a greater impact of the measures on what would be expected to be somewhat higher baseline concentrations.

2.4 ADDITIONAL SENSITIVITY ANALYSES

All of the sensitivity analyses listed in section 8 have been recalculated for the revised models and emission factors. The sensitivity analyses carried out in addition to those in the consultation documents are described in this section.

Coarse particles

One area of uncertainty not addressed in the consultation relates to the APEG receptor modelling, in terms of the assignment to primary, secondary and other, largely coarse, particles. This is important because the other stays flat while the primary and secondary decline. The other component is calculated as the residual from the regression analysis to determine the primary and secondary contributions. This method would be very unlikely to provide an underestimate, but it is possible it could overestimate the other (coarse) particle contribution.

The assumed other concentration in the model is 9.9 μgm^{-3}, gravimetric, in good agreement with measured values of PM_{10} - $PM_{2.5}$ at Bloomsbury. PM_{10}- $PM_{2.5}$ will however include some (approximately 20%) of the secondary PM_{10} so you might expect the other value to be lower than PM_{10} - $PM_{2.5}$, but it isn't because we may have included some sources in other that are not coarse particles. The reasonably good agreement between the site-specific projections for the early 1990s and 2000 from the base years 1996 to 1999 also indicates that we have probably got the split between primary, secondary and coarse about right. Overall the 9.9 ugm-3 gravimetric for other is a good estimate for the standard model and any sensitivity analysis should examine the impact of a lower number on predicted concentrations. We have carried out an additional sensitivity analysis for the site specific PM_{10} projections in 2010 for an alternative model in which the other contribution is set to 8 μgm^{-3} gravimemtric (rather less than PM_{10}- $PM_{2.5}$ at Bloomsbury but more than PM_{10}- $PM_{2.5}$ at Rochester and Harwell). The 1.9 μgm^{-3} left over in the base year measurement is then split equally between primary and secondary PM_{10}.

Spatial variation in sulphate to nitrate base year ratios across the UK

A constant nitrate to sulphate ratio across the UK was assumed in the projections presented in the consultation documents. This ratio was derived as the average value from the receptor modelling. Measurements of both sulphate and nitrate at 12 rural sites during 2000 indicate that there is some spatial variation in this ratio, with the highest observed ratio in southeast England (more nitrate). It is not clear at present to what extent this gradient in nitrate concentrations would be expected to be observed in the TEOM measurement of PM_{10}. This issue was discussed in the baseline report (Stedman et al, 2001b) and a sensitivity analysis incorporating the measured gradient is presented here.

Spatial variation in sulphate and nitrate temporal trends across the UK

Single, UK-wide values for the trends in sulphate and nitrate concentrations between 1997 and 2010 were assumed in the projections presented in the consultation documents. The UK mean factor from HARM for sulphate in 2010 is a reduction to 50% of 1997 concentration, with extremes of 47% in the East Midlands and 53% in Scotland. The UK mean factor from HARM for nitrate in 2010 is a reduction to 70% of 1997 concentration, with extremes of 67% in the NI and 71% in South East. This small spatial variation in trends across the UK was not considered in the projections in the consultation documents. As indicated in the baseline report (Stedman et al, 2001b) this has been considered alongside the spatial variation in nitrate to sulphate ratios in the sensitivity analyses presented here.

$PM_{2.5}$ benefits

The analysis of the long-term health benefits associated with the measures to reduce ambient PM_{10} concentrations illustrated in the IGCB report (DEFRA et al, 2001b) have been derived

from associations between ambient concentrations of $PM_{2.5}$ and life expectancy. The simplifying assumption has been made in this analysis that the reductions in $PM_{2.5}$ resulting from these measures are the same as the calculated reductions in PM_{10}, with both expressed in μgm^{-3}, gravimetric. It is recognised that some of the primary PM_{10} emissions abated would be in the coarse fraction. The proportion of ambient PM_{10} concentrations reduced by the package of measures represented by $PM_{2.5}$ would however, be greater than implied by the mass fraction of primary $PM_{2.5}$ emissions abated for the following reasons:

• the particle sources with the greatest impact on population weighted annual mean background concentrations are also those with the highest percentage of primary emissions in the fine fraction, such as emissions from road traffic combustion;
• the bulk of the reductions in ambient concentrations due to reductions in secondary particle concentrations will be in the fine fraction;
• the TEOM to gravimetric conversion factor of 1.3 used here has been derived from a comparison ambient PM_{10} concentrations measured at monitoring sites in the UK and we have applied this factor to the marginal change in ambient concentrations for an illustrative package of measures predicted by the air quality models. A specific conversion factor for this change in concentration would be likely to be higher than 1.3 because the more volatile components of PM_{10} are over-represented in the modelled reduction in concentrations. It is also likely that a TEOM to gravimetric conversion factor for $PM_{2.5}$ would be systematically higher than for PM_{10}.

While there is some uncertainty associated with the assumption that the change in $PM_{2.5}$ concentration will be the same as the change in PM_{10} concentration, it is likely that if appropriate scaling factors were known, then the errors introduced by this assumption would tend to cancel out. In the absence of more detailed information and in the knowledge that a health impact of particles within the coarse fraction cannot be ruled out, we consider that the relatively simple and transparent approach of equating reductions in ambient PM_{10} and $PM_{2.5}$ concentrations adopted in the consultation documents and again here represents a reasonable approach. A 'worst case' additional sensitivity analysis is included in the new analyses presented here in which the 1.3 TEOM to gravimetric conversion factor is applied directly to the reductions in ambient $PM_{2.5}$ concentrations implied by the illustrative package of measures.

2.5 KEY RESULTS: COMPARISON WITH RESULTS IN THE CONSULTATION DOCUMENTS

This section provides a short summary of the key results from the new analysis and a comparison with the results presented in the consultation documents. The revised projections do not substantially change the main findings of the PM_{10} review. There is however a considerable increase of 66% in the benefits associated with the road traffic measures, with the increased effectiveness of these measures continuing well beyond 2010. Key statistics are tabulated in Table 2.2.

Site-specific projections

Baseline PM_{10} concentrations in 2010 are on average 0.5 μgm^{-3}, gravimetric higher than for the analyses in the consultation documents at background sites and 0.5 μgm^{-3}, gravimetric higher at roadside sites. This reflects the revisions to the emission factors for traffic, updates to the traffic emissions maps and the explicit modelling of point sources within the baseline. PM_{10} concentrations for the illustrative scenario in 2010 are on average 0.4 μgm^{-3}, gravimetric higher

than for the analyses in the consultation documents at background sites and 0.2 μgm^{-3}, gravimetric higher at roadside sites.

Maps of background concentrations

The illustrative package of measures is estimated to reduce the population weighted annual mean background PM_{10} concentration by 0.897 μgm^{-3}, gravimetric, 19% more than the 0.751 μgm^{-3}, gravimetric change for the analyses presented in the consultation documents. The main reason for this increase is the revisions to the emission factors for traffic. The explicit modelling of point source emissions within the baseline modelling also results in a small increase. The change in population weighted annual mean background PM_{10} concentration in 2010 relative to the analyses presented in the consultation documents is –0.114 μgm^{-3}, gravimetric for the baseline scenario and –0.241 μgm^{-3}, gravimetric for the illustrative scenario.The stationary source measures alone deliver a reduction in population weighted mean concentration of 0.620 μgm^{-3}, gravimetric (6% higher than the previous estimate of 0.584 μgm^{-3}, gravimetric) and the traffic measures alone deliver a reduction of 0.277 μgm^{-3}, gravimetric (66% higher than the previous estimate of 0.167 μgm^{-3}, gravimetric). The health benefits of the illustrative package of additional measures have been re-calculated to take account of the revised modelling results and scale linearly with the changes in population weighted mean concentrations.

Maps of roadside concentrations

The number of exceedences of various threshold concentrations at roadside locations is lower in the new analyses than those presented in the consultation documents. This is due to a combination of the revisions to the baseline background maps and the coefficient for the roadside increment, which tend to reduce the number of exceedences, while the new emission factors for traffic tend to increase the number of exceedences. The percentage of UK built-up road links exceeding threshold concentrations for the baseline scenario in 2010 for the 1999 base year is 31% above 20, 5% above 23 and 1% above 25 μgm^{-3}, gravimetric (compared with 34%, 7% and 2% for the analyses presented in the consultation documents). Percentages of UK built-up road links exceeding threshold concentrations for the illustrative scenario in 2010 are 13% above 20, 1% above 23 and less than 1 % above 25 μgm^{-3}, gravimetric (compared with 19%, 1% and less than 1%). The relative effectiveness of the stationary and traffic source components of the illustrative scenario at reducing roadside PM_{10} concentrations in 2010 is similar to that for the analyses presented in the consultation documents but the effectiveness of the traffic measures is somewhat increased.

Additional sensitivity analyses

Additional sensitivity analyses have also been carried out for the modelling presented here. A lower coarse particle concentration of 8 μgm^{-3}, gravimetric would reduce baseline PM_{10} concentrations in 2010 by 0.8 μgm^{-3}, gravimetric and increase the effectiveness of the illustrative package of measures by 0.1 μgm^{-3}, gravimetric. Allowing the sulphate to nitrate ratio and the temporal trends in sulphate and nitrate concentrations to vary across the UK was found to have very little influence on the predicted PM_{10} concentration in 2010. If the health benefits are restricted to those resulting from changes in $PM_{2.5}$ concentrations alone, the minimum possible long-term health benefits resulting from the illustrative package of additional measures would be 70% of the central estimate. It is likely that this figure would underestimate the benefits since the use of a 1.3 TEOM to gravimetric conversion factor for $PM_{2.5}$ is likely to be inappropriate.

The sensitivity analyses presented in the consultation documents have also been recalculated using the revised models and the results obtained are very similar. The only differences are the slightly higher impact on the baseline of the use of a 1.4 TEOM to gravimetric conversion factor (+1.6 instead of +1.5 μgm^{-3}, gravimetric) and the alternative traffic projections for Northern Ireland (+0.4 instead of +0.3 μgm^{-3}, gravimetric).

Table 2.2 Comparison of key statistics for the new analysis and those published in the consultation documents.

PM_{10} projections for 2010	**baseline (μgm^{-3}, gravimetric)**	**illustrative package of measures (μgm^{-3}, gravimetric)**
Site specific projections, change relative to consultation documents	+0.5 background +0.5 roadside	+0.4 background +0.2 roadside
Site specific projections, effect of illustrative package of measures (consultation documents)	NA	-1.4 (-1.4) background -2.1 (-1.9) background
Mapped population weighted mean background concentration (consultation documents)	18.195 (18.309)	17.299 (17.558)
Mapped population weighted mean background concentration change relative to consultation documents	-0.114	-0.259
Mapped population weighted mean background concentration, effect of illustrative package of measures (consultation documents)	NA	-0.897 (-0.751)
Mapped roadside concentrations, percentage of road links thresholds for the 1999 base year (consultation documents)	20 μgm^{-3}: 31% (34%) 23 μgm^{-3}: 5% (7%) 25 μgm^{-3}: 1% (2%)	20 μgm^{-3}: 13% (19%) 23 μgm^{-3}: 1% (1%) 25 μgm^{-3}: <1% (<1%)

3 Baseline emissions projections

3.1 INTRODUCTION

The activity statistics and technology assumptions for the emission projections used here are identical to those described in the consultation documents (DEFRA et al, 2001a, Stedman at al 2001b). The emission factors for hot exhaust emissions from traffic have been revised, as discussed in section 2.2. A description of the baseline emissions projections was given in the consultation documents and is included here for easy reference.

Emission inventory maps for 1998 at a 1 km x 1 km from the National Atmospheric Emissions Inventory (NAEI) have been used throughout the work presented here (Goodwin et al, 2000). Maps of area emissions for the following sectors have been calculated:

- Domestic
- Services (emissions from heating plant in commercial and public buildings etc.)
- Industry
- Road Transport
- Off road vehicles
- Shipping
- Rail
- Other

UK totals for these sectors for 1996 and 1997 have been published by the NAEI (Goodwin et al, 2000) in addition to totals for 1998. Emissions maps for 1996 and 1997 have been calculated by scaling the 1998 maps by the changes in UK total emissions for each sector. Emissions maps for 1999 and 2010 have been calculated by scaling the 1998 emissions according to projections of emissions available from the NAEI. The emissions projections for road traffic and non-road traffic sources are described in this section. Projections of secondary PM_{10} concentrations are also described.

3.2 ROAD TRAFFIC EMISSIONS

Projections of emissions from road traffic sources are available from the NAEI. Information on methodology and emission factors is given in Goodwin et al (2000) and Murrells (2000) although the specific emissions projections used here have been calculated since the publication of these reports and have made use of revised emission factors. These projections have been calculated from a combination of road traffic activity projections and knowledge of the expected emissions characteristics of the vehicle fleet in each year. Projections have been calculated from a base year of 1999 and appropriate scaling factors have been used to calculate maps of emissions for the years 1996 to 1999 and 2010 from a combination of these projections and a map of emissions for 1998. Emissions estimates for A-roads and motorways are available for individual road links for 1998 and the emissions projections have similarly been used to calculate individual road link emissions estimates for the other years.

The following projections of traffic activity (in terms of vehicle km travelled) were used:

- England: Traffic projections were provided by the DETR from the National Road Traffic Forecast (NRTF), incorporating the impact of the Ten Year Plan for Transport 'Plan' scenario (DETR, 2000b). The impact of the Plan on vehicle km is assumed to apply fully in 2010, with a linear increase in impact from zero in 2005.
- Scotland: Traffic projections were provided by the Scottish Executive from the Central Scotland Transport Model (CSTM3) and were extrapolated to the rest of Scotland. Projections were provided for a central growth, current policies scenario.
- Wales: Traffic projections were provided by the DETR from the NRTF (1997) The Ten Year Plan for transport has been assumed to also apply in Wales.
- Northern Ireland: Traffic projections were provided by the Northern Ireland Roads service.

For England and Wales the network model in the NRTF framework divides the country into 11 different 'area types' and these are listed in Table 3.1. Traffic data for road links in Scotland were also assigned to area types 4 to 11. In addition to projections of UK total emissions the NAEI can also provide projections of emissions for each individual area type in England, Scotland and Wales and these have been incorporated into the road link and area emissions maps for 2010.

Table 3.1 National Road Traffic Forecast area types for the Ten Year Plan for Transport

Area Type	Description
1	Central London
2	Inner London
3	Outer London
4	Inner Conurbantions
5	Outer Conurbations
6	Other urban areas > 25 km^2 area
7	Urban areas 15 - 25 km^2 area
8	Urban areas 10 - 15 km^2 area
9	Urban areas 5 - 10 km^2 area
10	Urban areas < 5 km^2 area
11	Rural areas

The following assumptions on a number of fleet, fuel and technology related policies were also made to calculate the baseline projections of emissions from the NAEI 1999 road traffic emissions inventory.

Future diesel penetration trends in the new car market

Diesel penetration in the new car market was around 14% in 1999. The trend in percentage of diesel car sales of total new car sales listed in Table 3.2 has been assumed in the baseline scenario. Diesel penetration is expected to increase over the next few years due to the introduction of better performing diesel models and improving consumer perception of diesels. Some increase in diesel penetration is also expected as a result of the EU CO_2 from Cars voluntary agreements.

Table 3.2 Diesel penetration of new car market (%)

Year	2001	2002	2003	2004	2005	2006	2007	2008+
Diesel penetration of new car market (%)	16	17	18	19	20	21	22	22

Early introduction of cleaner fuel specifications

The baseline takes into account the early introduction – as a result of fuel duty incentives - of Ultra Low Sulphur Diesel (ULSD) and Ultra Low Sulphur Petrol (ULSP), the maximum sulphur content of which is below 50ppm. In the case of ULSP, future market penetration is assumed to be 100% in 2001 and subsequent years. ULSD has accounted for around 100% of the diesel market since the end of 1999. These fuel standards will be mandatory from 1 January 2005.

Early introduction of petrol Euro IV standards

It is likely that there will be significant entry of vehicles meeting Euro IV standards into the fleet before 2005, especially for petrol cars. This is primarily due to the introduction by other European Member States of tax incentives for Euro IV vehicles. This development has already led to a wide range of Euro IV compliant models on the market in the UK – over 50 models, according to the January 2001 edition of the VCA's *New Car Fuel Consumption and emissions figures* booklet - as it is more often cost-effective to develop one single power-train for the entire European market. The proportion of new petrol cars meeting Euro IV standards is expected to increase gradually over the next five years, and the uptake listed in Table 3.3 has been assumed in the baseline. The baseline assumes no early introduction of Euro IV for petrol light goods vehicles.

Table 3.3 Proportion of Euro IV cars in the new petrol car market

Year	2000	2001	2002	2003	2004	2005
Proportion of Euro IV cars in the new petrol car market	0%	20%	40%	60%	80%	100%

Fitting of particulate traps to light duty diesel vehicles

Some new diesel light duty vehicles can be expected to meet Euro IV PM_{10} standards before 2005, especially through the fitting of a particulate trap. There are currently no diesel cars on sale which meet the required Euro IV standards. However, it is likely manufacturers will fit many Euro IV diesels with traps as standard before the mandatory date for Euro IV, in order to improve the emission performance of diesel vehicles. For example, Peugeot and Citroen have already fitted particulate traps to some of their new models. In view of this, the trend listed in Table 3.4 has been assumed. The baseline assumes that there is no uptake of particulate traps for diesel light goods vehicles.

Table 3.4 Proportion of new diesel cars with particulate traps

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005+**
Proportion of new diesel cars with particulate traps	0%	5%	10%	15%	20%	25%

Fitting of particulate traps to heavy duty diesel vehicles

Particulate traps for heavy duty diesel vehicles have been feasible for at least the last five years, and their fitting has been encouraged since 1998 through the VED reduced pollution concession. Several large commercial fleet operators such as London Transport have consequently voluntarily fitted particulate traps to their fleets, and the NAEI takes account of such developments based on discussions with the bus industry. Before 2000, the NAEI takes account of the fitting of oxidation cats on buses and the early use of ULSD - again based on discussions with the bus industry. There is no official data on the number of vehicles fitted with particulate traps, but trap manufacturers estimate that there are currently at least 4,000 heavy-duty vehicles fitted with traps in the UK.

The number of heavy duty vehicles fitted with particulate traps is expected to increase by 2005, although it is difficult to estimate the ingress of this technology into the fleet. Euro IV standards are not expected to mandate the use of particulate traps for heavy-duty vehicles. Most growth in heavy-duty vehicles fitted with particulate traps is therefore likely to be from retrofitting of nearly new vehicles. The emission modelling for the baseline assumes the number of heavy-duty vehicles fitted with particulate traps set out in Table 3.5 (split equally between buses and lorries).

Table 3.5 Number of heavy duty vehicles retrofitted with particulate traps

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005+**
Cumulative number of heavy duty vehicles retrofitted with particulate traps	4000	6000	8000	10000	12000	14000
Cumulative % of the heavy duty vehicles in the fleet retrofitted with particle traps.	0.8%	1.2%	1.6%	2.0%	2.3%	2.7%
Proportion of these vehicles which would have met Euro II standards – the remainder complying as Euro III.	100%	90%	75%	60%	45%	30%

Emissions projections for road traffic sources are listed in Table 3.6.

Table 3.6. Projections UK total urban road traffic PM_{10} emissions (ktonnes per year)

Year	PM_{10}
1990	22.26
1991	22.34
1992	21.45
1993	20.84
1994	20.70
1995	19.13
1996	17.98
1997	15.95
1998	14.64
1999	13.65
2000	12.19
2001	12.16
2002	11.96
2003	11.69
2004	11.35
2005	10.93
2006	10.21
2007	9.36
2008	8.51
2009	7.74
2010	7.09
2015	5.44
2020	5.41

3.3 NON-ROAD TRAFFIC EMISSIONS

Projections of non-road transport emissions of PM_{10} have been calculated by the National Atmospheric Emissions Inventory based on the 1998 emissions estimates and activity drivers for the central growth/high fuel price scenario in Energy Paper 68, provided by the Department of Trade and Industry (DTI, 2000). These estimates therefore incorporate an assumed growth in economic activity of about 2.5% per year and the continuation of current trends towards greater use of natural gas and cleaner technologies (DTI, 2000). Emissions from the railways sector have been recalculated within the ambient concentration modelling to take into account the impact of the Ten Year Plan for Transport (DETR, 2000a).

Estimates of emissions for the years 1990 to 1998 for non-traffic sources are based on the NAEI emission inventory for the 1998 base year. This is the base year from which projections for future years have been calculated. Historical emission estimates are also available from the NAEI inventory for the 1999 base year but have not been incorporated into the models described in this report. This avoids any discontinuities in activity drivers caused by the use of 'real' activity data for 1999 and activity data for 2000 that has been projected from a 1998 base year. The historical emission data presented in the technical annex (DEFRA at al. 2001) are taken from the 1999 NAEI inventory and are therefore not exactly the same as the data presented here. Projections for 2000 and beyond are identical. UK total emissions have been split into 9 sectors within the baseline models of ambient concentrations. A more detailed

breakdown of emissions is given in the technical annex. Both historical and projected emission from road traffic sources listed in Table 2.6 have been calculated from a 1999 base year within the NAEI and are identical to the data included in the technical annex (DEFRA et al 2001).

Emissions projections for non-road traffic sources are listed in Table 3.7. Projected emissions are directly available for 2010; emissions for 1999 have been calculated by linear interpolation between 1998 and 2000. Emissions for the years 2001 to 2004 and 2006 to 2009 have been calculated by linear interpolation between 2000, 2005 and 2010.

Table 3.7. Projections UK Total PM_{10} emissions for non-road traffic sources (ktonnes per year)

Year	Power Stations and refineries	Domestic	Services	Industry	Off road	Shipping	Aircraft	Rail	Other
1990	73.63	47.63	7.80	38.81	8.19	1.35	0.12	0.88	3.40
1991	73.41	50.98	7.72	39.91	8.19	1.41	0.12	0.88	3.19
1992	69.44	46.02	7.34	41.19	8.19	1.35	0.13	0.89	2.96
1993	58.78	47.26	6.99	40.18	8.19	1.33	0.13	0.90	2.45
1994	52.72	37.73	6.72	39.24	8.19	1.23	0.13	0.90	2.72
1995	41.13	27.65	6.14	36.35	8.19	1.19	0.14	0.91	2.08
1996	38.23	30.38	6.31	35.43	8.11	1.29	0.15	0.85	2.18
1997	26.52	27.86	6.17	32.83	8.03	1.24	0.15	0.79	1.71
1998	27.16	26.38	5.34	31.52	7.95	1.16	0.16	0.73	1.58
1999	20.14	21.96	5.67	29.10	7.71	1.17	0.17	0.75	1.68
2000	13.13	17.55	6.00	26.69	7.48	1.18	0.17	0.77	1.79
2001	13.46	16.74	5.94	26.79	7.21	1.18	0.18	0.79	1.81
2002	13.80	15.93	5.88	26.89	6.94	1.18	0.19	0.81	1.84
2003	14.13	15.12	5.82	27.00	6.58	1.18	0.19	0.82	1.87
2004	14.46	14.31	5.76	27.10	6.22	1.18	0.20	0.84	1.89
2005	14.79	13.50	5.70	27.20	5.81	1.18	0.20	0.85	1.92
2006	14.05	13.08	5.69	27.47	5.39	1.18	0.21	0.94	1.95
2007	13.30	12.66	5.68	27.73	5.02	1.17	0.22	1.03	1.98
2008	12.56	12.25	5.67	28.00	4.73	1.17	0.22	1.12	2.01
2009	11.82	11.83	5.65	28.27	4.52	1.17	0.23	1.21	2.04
2010	11.08	11.41	5.64	28.53	4.38	1.17	0.24	1.33	2.07
2015	9.17	10.17	5.58	30.00	4.38	1.16	0.27	0.95	2.22
2020	8.60	9.34	5.45	31.36	2.31	1.16	0.30	0.95	2.38

3.4 SECONDARY PARTICLES

Secondary particle concentrations for 2010 and other years have been predicted on the basis of a combination of measurements and modelling results. For simplicity secondary PM_{10} has been assumed to consist of sulphates and nitrates. Secondary organic aerosol has not been considered in the baseline projections but has been considered in the sensitivity analyses presented in section 8. Measurements of sulphate at a network of eight rural sites have been made since 1987. Measurements of total inorganic nitrate (nitrate particles + nitric acid) were made at two rural sites between 1990 and 1999. The trend in nitrate particle concentrations over this period has been assumed to be the same as the trend in total inorganic nitrate concentrations.

Figure 3.1 shows the network mean of annual mean sulphate particle concentrations for the years 1987 to 1999. The overall decline in concentrations is clear and there is also considerable year to year variation in concentrations due to variations in meteorological conditions form. A best fit line has been calculated and we have assumed that this fit line represents an average trend in concentrations due to changes in UK, European and other sources of SO_2 contributing to sulphate measured in the UK, with changes due to meteorological variability removed. Figure 3.2 shows a similar plot for nitrate.

Modelled sulphate and nitrate fields for the UK are available for 1997 and 2010 from both the EMEP model (at 150 x 150 km spatial resolution) and the HARM model (at 10 x 10 km spatial resolution) (Warren et al, 2000, Metcalfe et al, 2001). In both cases these models have been run using 10-year average meteorology for both 1997 and 2010. The calculated values for 2010 incorporate the emissions reductions set out within the 'Gothenburg Protocol' to Abate Acidification, Eutrophication and Ground-level Ozone and those proposed within the EU National Emission Ceilings Directive. Both of these models have been designed to predict acid deposition and are known to over-predict the absolute values of ambient sulphate and nitrate particle concentrations. We have therefore chosen to scale measured concentrations in the years 1996 to 1999 by the ratios of modelled concentrations in 1997 and 2010 from the EMEP model in order to predict sulphate and nitrate concentrations in 2010. The EMEP model results indicate a reduction in UK average sulphate by 2010 to 53% of 1997 levels and a reduction in nitrate to 67% of 1997 levels. These results are broadly confirmed by the results from HARM, which show a reduction of sulphate to 50% and nitrate to 70% of 1997 levels by 2010.

There are a number of ways in which the measured and modelled concentrations could be combined to provide estimates for 2010, particularly because the year to year variability in measured concentrations caused by variations in meteorology has been excluded from the modelled values by the use of average meteorology. Figures 3.1 and 3.2 illustrate the approach that we have adopted. We have used the ratios of the modelled concentrations in 2010 to those in 1997 to calculate a prediction for concentrations in 2010 from the best-fit line values for 1997. This prediction for 2010 therefore represents our best estimate of concentration in 2010 for average meteorology. We have also assumed a linear decline in concentrations from 1997 to 2010. Predictions of secondary particle concentrations for individual base years were then calculated by scaling the measured concentrations in that year according the ratio of the best fit concentration in that year and the average meteorology prediction for 2010. An alternative, more pessimistic interpretation of the possible trends from 1998 and 1999 to 2010 is discussed in section 8. In this way we have incorporated the individual base year meteorology into the prediction for 2010 for secondary particles. This is consistent with the method adopted for primary concentrations, where the incorporation of base year meteorology into the predictions

for 2010 is implicit in the scaling of measured concentrations by changes in emissions. Secondary PM_{10} concentrations have been assumed to remain at 2010 levels in subsequent years.

4 Illustrative additional measures scenario

4.1 INTRODUCTION - POSSIBLE ADDITIONAL POLICY MEASURES

The illustrative package of possible additional policy measures described here is identical to that adopted in the consultation documents (DEFRA et al, 2001a, 2001b, Stedman et al, 2001c) and the description is reproduced here for ease of reference. The effectiveness of the road traffic measures is greater for the revised emission factors used in this current study. The illustrative scenario for stationary sources adopted for the air quality modelling is now fully consistent with that described in the second IGCB report (DEFRA et al, 2001b), as discussed in section 2.2.

The full package of possible additional policy measures includes:

- Traffic measures as follows: Particulate traps on new diesel vehicles from 2006 + sulphur free fuels (<10ppm S) from 2005 and £90m 'area-targeted' retrofit programme (2001-2004). This represents a reduction from the UK total traffic PM_{10} emission in the baseline scenario in 2010 from 16.8 to 13.0 ktonnes.
- A full package of stationary source measures. Measures have been applied to the following sectors: Cement, Iron and Steel, Refineries, Lime Production, Aluminium production, Domestic Solid Fuel Combustion, Public Services, Other Industry (Large Processes), Other Industry (Combustion), Other Industry (Small Processes). This represents a reduction from the UK total stationary PM_{10} emission in 2010 from 79.2 to 48.2 ktonnes relative to the baseline.
- While the measures for quarries are included in these totals they have been considered separately from the stationary source measures described above in the modelling and benefits analyses. The measures represent a reduction in 2010 from the UK annual PM_{10} emission total from 12.1 to 2.5 ktonnes.

The possible additional measures are described in more detail in the paragraphs below.

4.2 ROAD TRANSPORT MEASURES

The road transport measures that have been assessed in the are primarily aimed at technological measures to reduce PM_{10} emissions from diesel vehicles – the predominant source of PM_{10} emission from road transport over the medium term. For some of the scenarios the date of introduction of a measure has been allowed to vary to allow the impact of emission reductions in particular years to be estimated.

The scenarios set out below are not necessary mutually exclusive, and were ordered as follows:

- **S1**: the fitting of particulate traps to all new light duty and heavy duty diesel vehicles, potentially through a combination of regulatory and fiscal measures (from 2006)
- **S2**: early introduction of sulphur free diesel (<10ppm), potentially through a combination of regulatory and fiscal measures (from 2005)
- **S3**: short term retrofitting programmes for older diesel vehicles (between 2001 and 2004) targeted in a particular conurbation

4.2.1 S1: Fitting of particulate traps to all new diesel vehicles

Light duty diesel vehicles

Under this scenario, all new light duty diesel vehicles are fitted with particulate filters, which some manufacturers are already introducing to selected new diesel car models. This could be achieved through the development of tighter European emission standards (beyond Euro IV standards), which set an emission performance which will effectively mandate particulate filters (or equivalent emission abatement technology). Potential fiscal measures could also be used to encourage their early introduction.

It is assumed for the modelling that all new diesel cars and light vans will be fitted with particulate traps by either 2006 or 2008 - having the two dates allows a sensitivity analysis on the resulting emission reduction to be carried out. In terms of emission performance, a light duty vehicle with a particulate trap is assumed to achieve a 90% reduction relative to Euro II.

Heavy duty diesel vehicles

Although some heavy duty vehicles have already been fitted with particulate traps, their widespread application will almost certainly require the development of tighter European vehicle emission standards. This would require standards beyond existing Euro IV for new heavy duty diesel vehicles which would set a particle emission performance which will effectively mandate particulate traps (or equivalent emission abatement technology). Potential fiscal measures could be also used to encourage their early introduction.

It is assumed for the modelling that all new heavy duty vehicles will be fitted with particulate traps by either 2006 or 2008 - having the two dates allows a sensitivity analysis to be carried out. In terms of emission performance, a heavy duty vehicle fitted with a particulate trap is assumed to achieve a 90% reduction relative to Euro II. It should be noted that the modelling already assumes a 85% reduction relative to Euro II for the already stringent Euro IV particle emission limit value. This emission limit value is likely to be achieved through improved engine technology, which should significantly reduce PM_{10} emissions, but any development of tighter emission standards beyond Euro IV is expected to focus on the reduction of ultra-fine particles, which probably require particulate traps.

4.2.2 S2: Sulphur free diesel

This scenario assumes the widespread introduction of 'sulphur free' (<10ppm) diesel through a combination of regulatory standards and fiscal measures. The Commission has recently proposed that 10ppm sulphur diesel should be mandatory across the European Union in 2011, and widely available in Member States by 2005. Fuel duty incentives can be used to encourage its early introduction.

The modelling assumes that 10 ppm sulphur diesel will account for a 100% of the DERV market by 2005. The modelling uses the Commission's assumptions about the emission reductions from 10ppm fuels relative to 2005 fuel (with a sulphur content of 50ppm). Table 4.1 sets out the emission reduction relative to vehicle type and Euro standard. The timing on the introduction of S free petrol is assumed to be the same as for diesel.

Table 4.1 Emission reductions for 10 ppm sulphur fuels relative to 2005 fuels (50ppm S)

Vehicle type		Emission reduction for 10ppm sulphur fuels		
		NO_x	HC	PM
Euro I/II/III LDVs	Petrol	10%	10%	0%
	Diesel	0%	0%	5%
Euro IV LDVs	Petrol	0%	0%	0%
	Diesel	0%	0%	0%
Euro I/II/III HDVs	Diesel	0%	0%	5%
Euro IV/+ HDVs	Diesel	0%	0%	0%

As the table indicates, the Commission has assumed in its modelling that there would be no additional reduction in emissions for Euro IV vehicles. This modelling also assumes that there is no emission reduction from vehicles fitted with a particulate trap and pre-Euro I vehicles.

4.2.3 S3: Retrofitting programme

The Department of Transport, Local Government and the Regions already has two retrofitting programmes to reduce emissions from existing diesel vehicles over the period 2001-2004: the original Clean Up programme and a dedicated HGV retrofitting programme (from the £100million haulage modernisation fund announced in the 2000 Pre-Budget Report). As the details of these retrofitting programmes were not finalised until recently, these programmes have not been included in the baseline case.

There are three distinct elements of this retrofitting scenario which were modelled, in total, in the following order:

- the existing £30m Clean Up programme
- the £30m dedicated HGV retrofitting programme
- a further £30m funding for the Clean Up programme

We have illustrated the maximum impact of the retrofit scenario by assuming that all of the conversions would take place in one city, that city being London. We have assumed that the retrofitting is spread over the years 2001 – 2003 in the proportion 25%, 33%, and 42 %. The modelling makes the following assumptions about the retrofitting technologies used, annual mileage of the vehicles retrofitted, emission reductions achievable, and the number of vehicles retrofitted.

Technologies

The technologies considered were: fitting trucks and buses with particulate traps or oxidation catalysts; fitting taxis with oxidation catalysts; converting taxis to run on LPG; converting trucks to run on CNG; and re-engining pre-Euro I trucks and buses.

Annual mileage

- Taxis – assumed that all mileage will be in central and inner London. Assume annual distance travelled is 40,000km, all of which is in London.
- Buses – assumed annual distance travelled is 38,500km, all of which is in London.
- Trucks – assumed that the typical annual distance travelled is 60,000km of which one third ie: 20,000km is in London.

Emission scaling factors

The following emission benefits from retrofitting have been assumed:

- Particulate traps – the fitting of a trap reduces particulate emissions by 90% over Euro II standards;
- Taxi oxidation catalysts – a 25% reduction in particulate emissions from Euro I;
- Truck oxidation catalysts – a 25% reduction in particulate emissions from Euro I;
- Converting taxis to LPG – conversion improves taxi from Euro I diesel to Euro III petrol standards;
- Converting trucks to CNG – conversion takes Euro I/II truck to the level of particulate emissions from a truck fitted with a particulate trap;
- Converting buses to CNG - conversion takes pre-Euro I bus to Euro III diesel for NO_x and to the level of particulate emissions from a bus fitted with a particulate trap;
- Re-engining buses and trucks - this takes pre-Euro I vehicle to Euro II.

Scenarios

The numbers of each vehicle type, retrofitted for the £90 million spend scenario, are listed in Table 4.2.

Table 4.2 The £90 million retrofit scenario

Vehicle Type, and retrofit option applied	Numbers of vehicles
London	
Taxi LPG	600
Taxi oxidation cat	10000
Truck oxidation cat	1500
Truck CRT see split in following table	27000
Bus CRT see split in following table	10000
Truck CNG see split in following table	500
Bus CNG	100
Bus re-engining	60
Truck re-engining see split in following table	60
Outside London	
Ignore taxi catalyst and LPG retrofits and assume additional number of bus trap retrofits Bus CRT (50% Euro I, 50% Euro II)	1200

Certain types of retrofits and conversions are spread out between different classes of heavy duty vehicles differently each year, as shown in Table 4.3 below.

Table 4.3 The Distribution of the Numbers of Retrofits and Conversions between Vehicle Types

Technology	Vehicle type	Euro standard converted/retro fitted	Distribution of the number of retrofits/conversions between vehicle types		
			2001	2002	2003
Truck CRT	Rigid HGV	Euro I	25%	30%	35%
		Euro II	25%	30%	35%
	Artic HGV	Euro I	25%	12%	6%
		Euro II	25%	28%	24%
Bus CRT		Euro I	50%	40%	30%
		Euro II	50%	60%	70%
Truck CNG	Rigid HGV	Euro I	25%	25%	25%
		Euro II	25%	25%	25%
	Artic HGV	Euro I	25%	25%	25%
		Euro II	25%	25%	25%
Truck re-engine	Rigid		50%	50%	50%
	Artic		50%	50%	50%

This highly area-focused and intense retrofit and conversion programme (i.e. in London) implies that by 2003 a very high proportion of Euro I heavy duty vehicles running in the area having been retrofitted or converted (>90%). A high proportion of Euro II heavy duty vehicles in the area would also have been retrofitted (>25% rigid HGVs, >70% buses).

4.3 STATIONARY SOURCE MEASURES

This section describes the main stationary sources that were considered and summarises the techniques available for emissions reduction. Not all the stationary sources of primary PM_{10} were assessed. Offshore sources of primary particles were not included in the analysis as the impact on mainland concentrations is likely to be limited. Other sectors such as construction, which could make a more significant contribution, were not included in the analysis due to a lack of information on emission factors and abatement costs.

Sectors that were assessed include domestic combustion, quarrying, industrial combustion, public and commercial buildings, petroleum refineries, the iron and steel industry, cement production, lime production and non ferrous metals.

For power stations, the market structure in the electricity supply industry (ESI) is already changing irrespective of any measures to reduce PM_{10} emissions, with generating capacity from coal-fired plants being progressively substituted by gas-fired plants, particularly by combined cycle gas turbine (CCGT) plants. By 2010 the UK ESI is projected to consist mainly of CCGT stations with a small amount of FGD coal and a small residual nuclear component. Under the baseline scenario emissions will be considerable reduced in absolute and relative terms. Consequently, for the purposes of the analysis it was assumed that no emissions abatement above the baseline scenario is feasible in the case of power stations.

4.3.1 Domestic Combustion

The major source of particulate emission is the combustion of solid fuel (comprising coal, anthracite, smokeless solid fuel, coke and wood) for space and water heating. Domestic combustion of natural gas also seems to contribute to a good proportion of PM_{10} emissions from the domestic sector. This might be surprising at first, as the emission factor for gas is very small In fact, the large total emissions from this source is due to the large number of households that burn gas.

The additional PM_{10} emission abatement measures that were considered from the burning of coal and anthracite consisted of:

- Replacing open grates with enclosed appliances.
- Switching to smokeless solid fuel
- Switching to gas

2.48 Emissions from the burning of all fuels can be reduced by the use of energy saving measures such as insulation and double-glazing. These techniques were not included in the analysis since they already have significant uptakes in the UK housing stock, their effect is quite small and energy-saving measures are usually undertaken for other reasons. Closed appliances, in theory, as well as emitting less PM_{10} per kg of coal burned, are also more fuel-efficient and could therefore lead to a reduction in fuel use. In practice the increased thermal efficiency is likely to increase the level of heating rather than to decrease the rate of fuel consumption (AEA Technology, 2001). Moreover, according to recent evidence (BRE 1998), enclosed solid fuel

appliances (i.e., "central heating" and "stoves") already account for approximately 75% of all solid fuel burning appliances; the remaining 25% of solid fuel is burned in open fires. This means that the technique can at most be applied to 25% of these emissions.

4.3.2 Quarrying

The estimation of PM_{10} emissions from this sector is subject to considerable uncertainty. In particular, there are no emission factors for different types of quarries and for the different operations carried on in a quarry. There is also little information about the size distribution of emissions from quarries, although it is reasonable to assume that the majority of emissions from quarries will be in the coarse size fraction.

For the purposes of the analysis it was assumed that all types of quarry are the same and that only the following types of operations are carried out on site: Mineral extraction; Crushing & Screening; Haulage and Conveyors. In the absence of more detailed information, it was also assumed that the total emissions from a quarry are divided equally among these operations. The available emission reduction measures include (Ove Arup, 1995):

- "good practice" measures (e.g. minimise drop heights)
- speed restrictions;
- water sprays;
- enclose and extraction and filtration systems;
- chemical dust suppressants
- improved road design.

It was assumed that in some cases the measures would not be applicable as additional measures, either because they have already been designed into operations, or because the impacts would be considered too small for action to be taken. An applicability of 50% was assumed in view of these factors and of the uncertainty associated with the diverse nature of the quarrying industry.

4.3.3 Industrial Combustion and Processes

This sector is made up of combustion, large and small processes. Process and space heating at industrial sites is usually generated in boilers of a wide range of sizes burning either natural gas, oil or coal. The combustion of solid and liquid fuels produces the largest emissions of particles, although coal-fired boilers are becoming increasingly rare in industry. Current regulations specify an emission limit that is easily attainable with a well-maintained boiler. Therefore, it was assumed for the purpose of the analysis that emissions from this source are currently unabated.

The abatement options that are in principle available in this sector include:

- fuel switching from coal and oil to gas
- use of ceramic filters
- use of fabric filters

The replacement of coal-fired boilers with gas-fired boiler is a process that is likely to happen anyway in the course of time as existing plants reach the end of their working lives. Oil fired boilers can be converted to gas simply by replacing the burner. In itself, this operation is relatively cheap, but it is particularly difficult to estimate the cost of establishing a new gas supply, which is very site specific and can vary from zero up to a very large amount. Because of the large uncertainties involved, and because only a small proportion of the emission from these

sources is likely to be from coal or oil fired boilers anyway, the fuel switching option was not included in the analysis.

In practice, ceramic filters or fabric filters are likely to be the technology of choice if this sector is required to implement additional emission reduction measures. The choice between this two different technologies is likely to be based on the assessment of variation in cost-effectiveness according to differences in flow rate, particle load, filter specification (e.g. with respect to the fabric used), etc. between plant. A detailed assessment of the rate of adoption of ceramic vs. fabric filters was not attempted; instead it was assumed that firms would choose between two notional abatement options, a low cost and a high cost option. In terms of applicability, it was assumed that each of the two options would be implemented in 30% of the sector plants.

The small processes sector includes a wide range of processes; the emissions from which are likely to be amongst the least well characterised in the inventory. It is likely that the applicability of emission reduction measures would be less than 100% and an applicability of 60% has been assumed. It is also likely that a roughly 50% of these emissions will be in the coarse size fraction.

4.3.4 Public and commercial buildings

The oil, coal or gas fired boilers that typically provide space heating and hot water for public and commercial buildings are not usually subject to abatement, and are therefore a source of particulate emissions, although the latter are likely to be significant only for oil and coal fired boilers. The emission data show that in the public sector there is very little oil burned but a significant amount of coal, particularly in schools. This situation is likely to be different in the private sector, although no data are available to confirm this.

The abatement options that are in principle available in this sector include:

- fuel switching from coal and oil to gas
- use of ceramic filters

Fuel switching is likely to happen in the course of time, as old coal fired plants are replaced. Accelerating this process is thought to provide a negligible contribution to PM_{10} abatement. Ceramic filters were therefore identified as the preferred option for abatement of PM_{10} emissions in this sector. However, an applicability of 75% was assumed as emissions from some plants would be too low to warrant abatement or the plants would have too limited a remaining life to warrant the expense. Also, for some plant it would not be physically possible to install abatement devices.

4.3.5 Petroleum Refineries

The largest single source of particulate emissions from oil refineries is the fluid catalytic cracking unit (FCCU), which converts the heavier fractions of crude oil into gasoline. Currently only one FCCU in the UK is fitted with an electrostatic precipitator. The other FCCUs usually have two cyclones in series to remove particles from exhaust gases, but this does not remove all the particles, especially the smaller ones. The rest of the particulate emissions come from the many combustion plants, including the central boiler (typically fired using heavy oil) and various fired process heaters. These are sometimes fitted with electrostatic precipitators.

For every process, further emission abatement could be achieved through the following options:

- adopting wet flue gas scrubbing;
- fitting additional electrostatic precipitators;
- switching to gas in combustion processes.

As far as PM_{10} control is concerned, the first two measures have to be considered as alternatives. Indeed, it would not be reasonable to add wet scrubbing to control particles on top of an ESP (there are plants with both but for purposes of multi-pollutant controls). By contrast, switching to gas in combustion processes can be implemented in addition to one of the other measures. However, gas supply at certain UK refinery sites is likely to be insufficient to allow fuel switching.

4.3.6 Iron and Steel Industry

The different industrial process/installations in this sector include:

- Coke production
- Sinter production
- Blast Furnaces for the production of pig iron
- Basic oxygen furnaces for the production of steel
- Electric arc furnaces for the production of carbon and alloy steels

A wide range of abatement techniques are currently being applied across these industrial processes, ranging from good operational practice and conventional smoke-capture systems to gas-cleaning devices and modern electrostatic precipitators (EPs). Nonetheless, for some sources it would be possible to achieve further reductions in emissions at relatively low marginal costs by fitting relatively standard devices (e.g., fabric filters, EPs and cyclones). It is noted that the choice of the best technology for the UK is affected by the abatement technology already in place. For instance, modern EPs are currently fitted at all the existing UK sinter plants; therefore the only option available for achieving further emission reduction is to fit fabric filters in addition to the existing EPs.

4.3.7 Cement Production

Emissions of PM_{10} take place at several stages of the cement manufacturing process; the main source of particulate matter is from the kiln and clinker cooler exhaust stacks. Also, fugitive emissions of particulate matter can arise from materials handling and transfer operations, as well as from raw milling dry process facilities, and finish milling operations.

For every process, further emission abatement could be achieved through the following options:

- Fitting electrostatic precipitators (EPs);
- Fitting fabric filters
- Fitting EPs and fabric filters in series

4.3.8 Lime production

The lime making process involves heating crushed, aggregate-sized limestone to temperatures between 900 and 1200°C. Emissions from the blasting and crushing are part of quarry

operations and not lime making emissions and are therefore discussed in the above section on quarrying. As far as lime production from aggregate limestone is concerned, the kiln is the most important source of particle emissions, followed by the hydrator. In addition, fugitive emissions can occur from almost any part of the process.

Modern lime works are equipped with electrostatic precipitators that remove at least 98 % of the particulate matter from exhaust gases. Other possible control devices include multiple cyclones, wet scrubbers, and baghouses. Further emission reductions could be obtained by:

- fitting EPs and fabric filters on rotary kilns;
- fitting fabric filters on other kilns;
- adopting wet scrubbers in lime hydrators

4.3.9 Non ferrous metals

The non ferrous metal industry (in particular aluminium production) accounted for 0.5% of overall UK primary emissions in 1998. Under the baseline scenario their contribution is expected to increase slightly both in absolute terms (to 1.19 Kte/year) and in percentage terms (to 1%) by 20101. The main abatement options in this sector that were considered in the analysis included electrostatic precipitators and fabric filters.

4.4 THE IMPACT OF THE POSSIBLE ADDITIONAL POLICY MEASURES ON UK ANNUAL PM_{10} EMISSIONS

The impact on UK annual PM_{10} emissions of both the illustrative package of possible transport, and stationary source measures and its individual components are set out in the proceeding tables. Table 4.4 shows the illustrative scenario. The total impact of this package is to reduce annual UK emissions by 35.2 ktonnes in 2010 (i.e. by 35%), by 37.9 ktonnes in 2015 (i.e. by 40%) and by 39.1 ktonnes in 2020 (i.e. by 41%). The total impact of the package as modelled (excluding the quarry measures) is to reduce annual UK emissions by 25.6 ktonnes in 2010 (i.e. by 25%), by 28.3 ktonnes in 2015 (i.e. by 30%) and by 30.3 ktonnes in 2020 (i.e. by 32%).

Table 4.4 Annual UK PM_{10} emissions, with whole package of possible additional measures, 2010 to 2020, (ktonnes)

Source	2010	2010 illustrative scenario	2015	2015 illustrative scenario	2020	2020 illustrative scenario
Public Power	**7.2**	7.2	**5.1**	5.1	**4.4**	4.4
Petroleum Refining Plants	**3.8**	0.2	**4.1**	0.3	**4.2**	0.3
Other Comb. & Trans.	**3.9**	3.9	**4.3**	4.3	**4.6**	4.6
Residential Plant	**11.4**	8.7	**10.2**	7.5	**9.3**	6.7
Comm., Public & Agri. Comb	**5.6**	3.9	**5.6**	3.9	**5.5**	3.7
Iron_&_Steel Combustion	**1.9**	0.0	**2.2**	0.0	**2.5**	0.0
Other Comb. in Industry	**11.2**	4.1	**11.4**	4.1	**11.6**	4.2
Processes in Industry	**11.5**	6.7	**12.1**	7.1	**12.7**	7.6
Construction	**4.6**	4.6	**5.0**	5.0	**5.5**	5.5
Quarrying	**12.1**	2.5	**10.1**	0.5	**8.8**	0.0
Road Transport Combustion	**16.8**	13.0	**12.7**	6.9	**12.4**	5.5
Road Transport Brake & Tyre Wear	**5.8**	5.8	**6.3**	6.3	**6.7**	6.7
Off-Road Sources	**2.0**	2.0	**2.2**	2.2	**2.3**	2.3
Military	**0.3**	0.3	**0.3**	0.3	**0.3**	0.3
Railways	**0.3**	0.3	**0.3**	0.3	**0.3**	0.3
Shipping	**1.2**	1.2	**1.2**	1.2	**1.2**	1.2
Civil Aircraft	**0.2**	0.2	**0.3**	0.3	**0.3**	0.3
Waste Incineration	**1.8**	1.8	**1.9**	1.9	**2.1**	2.1
Animal Wastes	**n/a**	n/a	**n/a**	n/a	**n/a**	n/a
Non Livestock Agricult.	**n/a**	n/a	**n/a**	n/a	**n/a**	n/a
TOTAL	**101.8**	**66.6**	**95.1**	**57.1**	**94.5**	**55.5**

It should be noted that tonnage reductions in stationary source emissions in 2015 and 2020 are assumed to be the same as in 2010. The decline in quarry emission in the baseline leads to a reduction that is bigger than the total in 2020, so the emissions are set to zero in 2010. Since quarry emissions are not explicitly included in the modelling this does not influence the model results.

The impact of the individual policy measures on annual UK PM_{10} emissions in future years have been calculated separately and set out in Table 4.5.

Table 4.5 Annual UK PM_{10} Emission reductions from individual measures in 2010, 2015,and 2020 ktonnes

Source	2010	2015	2020
Petroleum Refining Plants	-3.61	-3.80	-3.93
Residential Plant	-2.67	-2.67	-2.67
Comm., Public & Agri. Comb	-1.72	-1.72	-1.72
Iron_&_Steel Combustion	-1.84	-2.18	-2.43
Other Comb. in Industry			
Other Industry Combustion	-2.30	-2.33	-2.35
Iron and Steel Sinter plant	-1.70	-1.72	-1.75
Cement	-2.37	-2.37	-2.37
Lime Production	-0.81	-0.87	-0.93
Total Other Comb. in Industry	**-7.18**	**-7.29**	**-7.40**
Processes in Industry			
Other industry Small processes	-2.64	-2.64	-2.64
Other Industry Large processes	-1.03	-1.13	-1.23
Iron and Steel Basic oxygen Furnace	-0.41	-0.42	-0.43
Aluminium Production	-0.75	-0.78	-0.82
Total processes in industry	**-4.83**	**-4.97**	**-5.12**
Quarrying	-9.60	-9.60	-8.80
Total Road Transport Combustion	**-3.76**	**-5.71**	**-7.05**
Total	**-35.2**	**-37.9**	**-39.1**
Total (excluding quarry measures)*	**-25.6**	**-28.3**	**-30.3**

* air quality modelling, cost and benefits analyses calculated for this scenario in both here and in the consultation documents.

Projections of emissions for road traffic have been calculated for the baseline and additional measures scenario transport scenarios. The impact of each individual measure on annual UK traffic emissions has not been assessed for the revised emission factors. An analysis using the old emission factors was carried out for the consultation documents and found that of the traffic measures, particulate traps have the greatest impact on road traffic emissions. The impact of sulphur free fuels is less. The impact of the retrofit programme when targeted in one area (i.e. London) is very small on a national scale, but is more significant in the area itself. The effect on emissions in London in 2010 and beyond is relatively modest but is greater in the early to mid 2000s when it will play a valuable role in reducing road traffic emissions ahead of the achievement date for the current mandatory EC Stage 1 limit value for PM_{10}.

4.5 THE IMPACT OF THE POSSIBLE ADDITIONAL POLICY MEASURES ON UK ANNUAL NO_x AND SO_2 EMISSIONS

The majority of the measures are not expected to have significant impacts on the UK emissions of NOx or SO_2 in 2010. The traffic measures have been estimated to reduce UK NOx emissions by approximately 49 ktonnes on the 2010 baseline and have no significant effect on SO_2. The impact of the traffic measures within the illustrative package of measures on ambient NO_2 concentrations was assessed in the consultation documents (DEFRA, et al 2001a, Stedman, et al 2001c). This analysis used the old emission factors, which indicated a reduction in UK NOx emissions of approximately 23 ktonnes and analysis based on the revised emission

factors would be expected to show a correspondingly greater impact of the measures on what would be expected to be somewhat higher baseline concentrations. Projection of NO_2 concentrations for the illustrative scenario in 2010 have not been recalculated for the revised emissions factors because the main focus of the recent review has been on PM_{10}.

Measures to reduce domestic PM_{10} emissions (by fuel switching) have been assumed to have no significant effect on NOx and to reduce UK SO_2 emissions by approximately 7 ktonnes. Measures to reduce refinery PM_{10} emissions (by fuel switching) have been assumed to reduce UK NOx emissions by approximately 16 ktonnes and to reduce UK SO_2 emissions by approximately 64 ktonnes.

The impact of these reductions on ambient secondary PM_{10} concentrations has been included in the PM_{10} modelling. The methods that have been used to project secondary PM_{10} on the basis of a combination of measurement data and model results are described in section 3.4. We have assumed that 30% of the sulphate particle concentration in the UK in 2010 is of UK source origin, with the remainder being from other sources. Similarly we have assumed that UK sources contribute 45% of UK nitrate concentrations. The resulting scaling factors for estimating secondary PM_{10} concentrations in 2010 from base year values are listed in Table 4.6. These factors have been applied throughout the UK. Beyond 2010 concentrations of secondary particles have been assumed to remain at 2010 levels, and the reductions in secondary PM_{10} concentrations implied by the illustrative package of measures have similarly been held constant after 2010.

Table 4.6 Secondary PM_{10} reduction factors for 2010 (base year concentration = 1)

Base year	**1996**	**1997**	**1998**	**1999**
Baseline	0.565	0.574	0.631	0.677
Illustrative package of measures	0.553	0.558	0.615	0.662

5 Site specific projections of PM_{10} concentrations

5.1 TEOM AND GRAVIMETRIC MEASUREMENTS

The reference method for the AQDD limit values and AQS objectives for PM_{10} is the use of a gravimetric instrument. The analyses presented here is based on TEOM (Tapered Element Oscillating Microbalance) instruments, which are currently widely used with in the UK national monitoring networks. We have applied a scaling factor of 1.3 to all data before comparing with the limit value, as suggested by APEG (1999), and recommended as an interim measure by the EC Working Group set up to address the issue of scaling automatic PM measurements in advance of Member States undertaking their own detailed inter-comparisons with the Directive Reference Method.. All PM_{10} concentration data reported within this study are given in units of μgm^{-3}, gravimetric, meaning that TEOM data has been scaled to give a representation of concentrations as measured by a gravimentic, or equivalent instrument. In addition, a sensitivity analysis has been undertaken using a factor of 1.4 (see Section 8). This is at present the highest factor measured in the UK inter-comparison exercise between TEOM analysers and EC Directive Reference Method measurements.

5.2 THE APEG RECEPTOR MODEL: SOURCE APPORTIONMENT FOR BACKGROUND SITES

The method for the site specific projections presented here is very similar to that adopted for the analyses reported in the consultation documents (DEFRA, et al 2001a, Stedman et al, 2001b, 2001c) but the model now includes an explicit treatment of the contributions to primary PM_{10} concentrations from point sources.

The site-specific projections are based on the receptor modelling methods that we developed within the framework of the Airborne Particles Expert Group (APEG, 1999, Stedman et al, 1998). A regression analysis has been carried out to divide measured daily average PM_{10} concentrations (as measured by TEOM or equivalent monitor) into three components:

- primary combustion PM_{10} (from co-located NO_x measurements)
- secondary PM_{10} (from rural sulphate measurements)
- 'other' PM_{10} (the residual)

The regression analysis was carried out for a calendar year of monitoring data for each site to determine the coefficients A and B:

[measured PM_{10} (mg m^{-3}, TEOM)] = A [measured NO_x (mg m^{-3}, as NO_2)] + B [measured sulphate (mg m^{-3})] + C (mg m^{-3}, TEOM)

These coefficients can then be used to divide the measured concentration into the three components and the contributions from each component to the annual mean concentration can be calculated. This analysis has been completed for the years 1996 to 1999 inclusive at a range of UK national network monitoring sites. Two key outputs from the model are a UK average concentration of 'other' particles and the coefficient, B, relating measured sulphate concentrations to secondary PM_{10} concentrations. Values of this coefficient are listed in Table 5.1 for the base years that have been studied.

Table 5.1 Empirically derived factors relating measured sulphate to secondary PM_{10} concentrations

1996	2.66
1997	2.03
1998	2.60
1999	2.91

If all of the measured secondary PM_{10} were ammonium sulphate, then this coefficient would be approximately 1.3. The remaining secondary PM_{10} was assumed to be nitrate. The increase in the value of this coefficient from 1996 to 1999 illustrates a more rapid decline in sulphate concentrations in recent years, compared with nitrate concentrations.

5.3 SOURCE APPORTIONMENT FOR ROADSIDE SITES

Site-specific projections for roadside monitoring sites have also been calculated. Daily averages of measured PM_{10} at a nearby background monitoring site have been subtracted from the concentrations measured at roadside monitoring sites in order to determine the roadside increment of daily PM_{10}. A regression analysis was then carried out to determine the coefficients *A*, *B* and *R*. The coefficients derived from the regression of daily concentrations can then be used to divide the measured concentration into the contributions from primary, secondary, coarse and roadside increment. The contributions from each component to the annual mean concentration can then be calculated

[measured PM_{10} (mg m^{-3}, TEOM)] = A [measured background NO_x (mg m^{-3}, as NO_2)] + B [measured sulphate (mg m^{-3})] + R [measured roadside increment of NO_x (mg m^{-3}, as NO_2)] + C (mg m^{-3}, TEOM)

It is not possible to determine the split of the roadside increment between traffic exhaust emissions and re-suspended dusts from current network measurements. Analyses of PM_{10} and $PM_{2.5}$ monitoring data presented in the APEG report (APEG 1999) suggested that re-suspended component could be 50% of the total. It is likely that this is an overestimate because exhaust emission may include some particles of diameter greater than 2.5 μm. We have assumed that re-suspended dust does not contribute to the roadside increment of PM_{10} concentrations in our baseline projections. An alternative scenario in which 25% of the roadside increment in 1997 is assumed to be from re-suspended dust has been examined as a sensitivity analysis.

5.4 SOURCE APPORTIONMENT OF THE PRIMARY PM_{10} COMPONENT

The concentration footprints of the major point sources were calculated using the Gaussian plume dispersion model ADMS (provided by Cambridge Environmental Research Consultants) and subtracted from the primary particle component to leave the contribution from area sources only.

Maps of primary PM_{10} emissions for 1998 from the NAEI (Goodwin et al, 2000) were used to determine the sectors contributing to local primary combustion PM_{10} at each monitoring site location. Local sources were summed within a 35 km x 35 km area centred on the monitoring site location. An ADMS based dispersion matrix was applied to weight emissions from individual grid cells according to distance and direction from the site location. This dispersion matrix determines the contribution to ambient concentrations at the monitoring site from unit emissions in each of the 1 km x 1 km squares within the 35 km x 35 km area. Road traffic emissions dispersed from volume sources of height 10 m and emissions from stationary sources dispersed from volume sources of height 30 m. This dispersion matrix approach was also used to calculate the maps and is described in section 6.

5.5 SITE-SPECIFIC PROJECTIONS OF PM_{10} CONCENTRATIONS FOR OTHER YEARS

Each component of the primary PM_{10} contribution was then projected from the measurements in 1996, 1997, 1998 and 1999 to provide estimates of concentrations in 2010 by scaling the contributions to the base year concentrations by the changes in UK emissions for each sector over this period.

Secondary particle concentrations in the base years 1996 to 1999 were derived from maps of rural measurements of sulphate (at 8 sites) using the factors listed in Table 5.1. Concentrations of sulphate and nitrate in future years were derived as described in section 3.3. We assumed that there will be no change in coarse ('other') particle concentrations.

Figure 5.1 and 5.2 show examples of site-specific projections of annual mean PM_{10} concentrations for the London Bloomsbury and Belfast Centre sites. It is clear that there is good agreement between the projections for the years 1992 to 1999 and the measured values for these years. The projections track both the year to year variability in concentrations due to changes in the meteorology that influences secondary particle concentrations and the changes in concentrations due to reductions in emissions. The projections based on 1996 and 1997 monitoring data are higher than the projections based on 1998 and 1999 data. Secondary particle episodes made an important contribution to the high concentrations measured in 1996 (Stedman 1997, 1998) and primary pollutant concentrations were higher in 1997 than in 1996, 1998 and 1999, as discussed above for NO_x. Figures 5.3 and 5.4 show projections for the Bury Roadside and Sutton Roadside monitoring sites.

5.6 ANNUAL MEAN CONCENTRATIONS AND THE NUMBER OF DAYS WITH CONCENTRATIONS ABOVE 50 μgm^{-3}

The analysis described in this report, has focussed on the prediction of annual mean values. Equivalent values of numbers of days exceeding 50 μgm^{-3} (gravimetric) can be calculated. Figure 5.5 illustrates that there is a reasonably robust relationship between annual mean concentrations and number of days per year with concentrations greater than or equal to 50 μgm^{-3}, although it should be noted that there are few data points in the 20 – 25 μgm^{-3} (gravimetric) range. Measured values of the number of days with concentrations greater than or equal to 50 μgm^{-3}, gravimetric are also subject to greater influence from local events such as bonfires, road or other contruction work or more wide spread events such as Saharan dust events than are annual means. Such events are especially important if the number of exceedences due to elevated concentrations from better characterised and controlled sources are relatively infrequent, as is anticipated for much of the country by 2010. The figure also illustrates that the EU Stage 2 annual mean limit value of 20 μgm^{-3} is likely to be more stringent than the 24 hour limit value of 50 μgm^{-3}, not to be exceeded more than 7 times a year. The approximate annual mean equivalents of different numbers of days above 50 μgm^{-3} are listed in Table 4.2 along with the equivalent annual mean concentrations for raw TEOM measurement data.

Table 5.2 The relationship between annual mean and number of days per year with concentrations greater than or equal to 50 μgm^{-3}, gravimetric

Annual mean equivalent μgm^{-3}, gravimentric	Annual mean equivalent μgm^{-3}, TEOM	Number of days with concentration greater than 50μgm^{-3}, gravimetric
28.0	21.5	23
25.0	19.2	14
23.0	17.7	9
*20.0	15.4	3

* EU AQDD indicative stage 2 annual mean limit value for PM_{10}

5.7 MEASURED CONCENTRATIONS 1996 – 1999

Measured annual mean PM_{10} concentrations for the years 1996 to 1999 are listed in Table 5.3 for the sites for which site-specific projections have been calculated. Data from TEOM instruments has been multiplied by a factor of 1.3, as discussed above.

The measured annual mean PM_{10} concentrations show a considerable decline in values from 1996 to 1999. Concentrations at most sites background sites ranged from 30 to 33 μgm^{-3}, gravimetric in 1996 (the concentration at London Bloomsbury was 39 μgm^{-3}, gravimetric) and had declined to between 20 and 26 μgm^{-3}, gravimetric by 1999 (the concentration at London Bloomsbury was 29 μgm^{-3}, gravimetric). The roadside increment in PM_{10} is less in comparison with background values than for NO_x. The site with the highest measured concentrations was London Marylebone Road.

5.8 SITE-SPECIFIC PROJECTIONS FOR 2010, 2015 AND 2020

The projected PM_{10} annual mean concentrations for individual sites, for 2010, 2015 and 2020 for the baseline and illustrative package of possible additional measures scenario, for a range of meteorology, are shown in Tables 5.4, 5.5 and 5.6. For example, by 2010, under 1999 meteorology, the baseline scenario suggests that 10 of the 16 sites analysed would exceed the indicative Stage 2 limit value of 20 μgm^{-3} as an annual mean. The application of the package of additional measures reduces the annual mean PM_{10} concentrations to 20 μgm^{-3} or lower at all but 3 of the sites. The analysis also shows the impact of years characterised by a high secondary particle contribution. In 2010, with 1996 meteorology, 9 out of 10 sites are predicted to exceed under the baseline scenario, falling to 7 sites with the illustrative package of measures scenario. In 2010, under 1999 meteorology the biggest reduction in annual mean PM_{10} concentrations resulting from the illustrative scenario is at Marylebone Road (3.2 μgm^{-3}) – illustrating the targeted nature of the package of measures. The smallest reduction from the additional measures is predicted to occur at the rural site at Rochester (0.4 μgm^{-3}), consistent with the relatively low primary particle contribution at this location. Reductions at urban background sites are typically of the order of 1-2 μgm^{-3}.

By 2015 further reductions occur beyond that delivered in 2010, for both the baseline and illustrative scenario. In this year, for the baseline scenario, for 1999 meteorology, 8 sites are predicted to exceed the EC Stage 2 indicative limit value - falling to 1 site exceeding for the illustrative scenario. The biggest reductions occur at roadside sites - annual mean concentrations at Marylebone Road are 3.6 μgm^{-3} lower (1999 meteorology) that those predicted for the baseline scenario. Reductions of about 1-2 μgm^{-3} occur at urban background sites. The predicted annual mean concentrations in 2015 can also be compared to what would be delivered for the same scenario in 2010. For the illustrative scenario, the largest additional reduction in annual mean concentration occurs at Marylebone Road (2.7 μgm^{-3}).

By 2020 very small additional reductions are expected beyond that already delivered by 2015. In 2020, for 1999 meteorology, 7 sites are predicted to exceed the EC Stage 2 annual mean indicative limit value for the baseline scenario, falling to 1 site for the illustrative scenario. When compared with what would be delivered by the illustrative scenario in 2015 (1999 meteorology) additional reductions in annual mean concentrations are typically only 0.1 – 0.3 μgm^{-3} at urban background sites. This rises to between 0.2-0.7 μgm^{-3} at roadside sites, with the highest additional reduction occurring at Marylebone Road.

Table 5.3 Measured annual mean PM_{10} concentrations 1996 to 1999 (mgm^{-3}, gravimetric)

	measured PM_{10}			
Base year	1996	1997	1998	1999
London Bloomsbury	39.0	35.1	29.9	28.6
Birmingham Centre	32.5	28.6	24.7	23.4
Cardiff Centre	32.5	33.8	28.6	27.3
Edinburgh Centre	24.7	23.4	19.5	19.5
Belfast Centre	31.2	32.5	27.3	26.0
Liverpool Centre	32.5	32.5	28.6	26.0
Rochester	31.2	26.0	22.1	20.8
Newcastle Centre	31.2	27.3	23.4	20.8
Manchester Piccadilly	33.8	31.2	27.3	26.0
Bristol Centre	32.5	31.2	27.3	26.0
Haringey Roadside		33.8	28.6	28.6
Glasgow Roadside		40.3	35.1	27.3
Marylebone Road		50.7	41.6	45.5
Camden Roadside		41.6	32.5	33.8
Sutton Roadside		31.2	27.3	26.0
Bury Roadside		39.0	33.8	31.2

Table 5.4 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario and the illustrative package of measures scenario (pm10aqsef analysis)

	Projected PM_{10} 2010 Baseline				projected PM_{10} 2010 illustrative scenario			
Base year	1996	1997	1998	1999	1996	1997	1998	1999
London Bloomsbury	24.8	23.1	21.6	21.7	23.0	20.9	19.9	20.0
Birmingham Centre	21.9	20.2	18.9	18.8	20.6	18.7	17.7	17.7
Cardiff Centre	22.5	24.0	21.7	21.7	21.0	21.7	20.0	20.0
Edinburgh Centre	17.9	17.4	15.8	16.2	17.0	16.3	15.1	15.5
Belfast Centre	21.2	22.5	20.4	20.6	19.5	20.0	18.6	18.7
Liverpool Centre	22.4	23.1	21.7	20.8	21.1	21.4	20.2	19.5
Rochester	21.9	19.3	17.6	17.3	21.0	18.3	17.1	16.9
Newcastle Centre	21.0	19.3	18.0	17.0	19.7	17.9	16.9	16.2
Manchester Piccadilly	22.3	21.4	20.2	20.2	20.7	19.4	18.6	18.7
Bristol Centre	22.2	22.1	20.7	20.7	20.8	20.2	19.2	19.2
Haringey Roadside		21.7	20.2	21.0		19.8	18.8	19.5
Glasgow Roadside		23.5	22.3	19.0		20.9	20.0	17.5
Marylebone Road		26.6	24.5	27.2		23.3	21.9	24.0
Camden Roadside		24.8	21.6	23.2		22.1	19.9	21.1
Sutton Roadside		20.5	19.6	19.7		19.0	18.4	18.6
Bury Roadside		24.1	23.0	22.4		21.4	20.6	20.2

Table 5.5. Projected annual mean PM_{10} concentrations 2015 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario and the illustrative package of measures scenario (pm10aqsef analysis)

	projected PM_{10} 2015 Baseline				projected PM_{10} 2015 illustrative scenario			
Base year	1996	1997	1998	1999	1996	1997	1998	1999
London Bloomsbury	24.2	22.3	21.0	21.2	22.2	19.9	19.1	19.3
Birmingham Centre	21.4	19.5	18.4	18.4	19.8	17.6	17.0	17.1
Cardiff Centre	22.0	23.2	21.1	21.2	20.3	20.4	19.0	19.1
Edinburgh Centre	17.5	16.9	15.5	16.0	16.5	15.6	14.7	15.2
Belfast Centre	20.7	21.7	19.8	19.9	18.7	18.8	17.7	17.8
Liverpool Centre	21.8	22.2	21.0	20.2	20.3	20.1	19.2	18.7
Rochester	21.7	19.0	17.5	17.3	20.7	17.9	16.9	16.8
Newcastle Centre	20.4	19.3	17.5	16.7	18.8	17.9	16.1	15.8
Manchester Piccadilly	21.6	20.4	19.5	19.5	19.7	18.0	17.5	17.7
Bristol Centre	21.7	21.2	20.0	20.1	19.9	18.8	18.1	18.2
Haringey Roadside		20.7	19.4	20.2		18.5	17.8	18.4
Glasgow Roadside		21.0	20.2	17.4		17.3	17.1	15.3
Marylebone Road		24.3	22.7	24.9		20.6	19.8	21.3
Camden Roadside		23.2	20.6	22.0		20.2	18.6	19.6
Sutton Roadside		19.6	19.0	19.1		17.8	17.6	17.8
Bury Roadside		22.1	21.4	20.9		18.5	18.3	18.0

Table 5.6 Projected annual mean PM_{10} concentrations 2020 from base years 1996 to 1999 (μgm^{-3}, gravimetric) for the baseline scenario and the illustrative package of measures scenario (pm10aqsef analysis)

	projected PM_{10} 2020 Baseline				projected PM_{10} 2020 illustrative scenario			
Base year	1996	1997	1998	1999	1996	1997	1998	1999
London Bloomsbury	24.1	22.2	20.9	21.1	22.0	19.7	19.0	19.2
Birmingham Centre	21.4	19.5	18.4	18.4	19.6	17.4	16.8	16.9
Cardiff Centre	22.0	23.2	21.1	21.2	20.1	20.1	18.7	18.8
Edinburgh Centre	17.5	16.9	15.5	16.0	16.4	15.4	14.6	15.0
Belfast Centre	20.5	21.5	19.7	19.8	18.4	18.4	17.3	17.5
Liverpool Centre	21.8	22.1	20.9	20.2	20.1	19.7	18.9	18.4
Rochester	21.7	19.0	17.5	17.3	20.6	17.8	16.9	16.8
Newcastle Centre	20.4	18.5	17.4	16.7	18.6	16.5	16.0	15.6
Manchester Piccadilly	21.6	20.4	19.4	19.5	19.4	17.7	17.2	17.4
Bristol Centre	21.6	21.2	20.0	20.0	19.7	18.5	17.9	18.0
Haringey Roadside		20.6	19.4	20.1		18.2	17.5	18.2
Glasgow Roadside		20.8	20.1	17.3		16.4	16.3	14.8
Marylebone Road		24.0	22.5	24.6		19.9	19.3	20.6
Camden Roadside		23.1	20.5	21.9		19.8	18.3	19.3
Sutton Roadside		19.5	18.9	19.1		17.5	17.4	17.6
Bury Roadside		22.1	21.4	20.8		17.8	17.8	17.5

6 Maps of PM_{10} concentrations

6.1 METHOD FOR MAPS OF BACKGROUND CONCENTRATIONS

Mapping of PM_{10} concentrations is complex, due to the wide range of different sources and processes contributing to ambient particle concentrations. The knowledge derived from the results of the APEG receptor model studies has been applied to the calculation of maps of estimated annual mean concentrations by Abbott and Stedman (1999). These methods have since been revised and updated to incorporate more up-to-date monitoring information and considerably more detailed emission inventory and projection information (Stedman and Bush, 2000). The models used here are very similar to those adopted for the analyses reported in the consultation documents (DEFRA, et al 2001a, Stedman et al, 2001b, 2001c) but the models now include an explicit treatment of the contributions to primary PM_{10} concentrations from point sources.

The map of PM_{10} concentrations presented here was calculated by adding together a number of different components:

1. The concentration footprints of the major point sources were calculated using the Gaussian plume dispersion model ADMS.
2. The contribution from local primary PM_{10} area emissions has been estimated using 1 km primary PM_{10} emission maps from the NAEI for 1998 and empirical dispersion coefficients calibrated using measurement data.

3. Secondary PM_{10} derived from maps of measured rural sulphate concentrations using the coefficients from the site specific receptor modelling analysis listed in Table 5.1.
4. A constant regional coarse component 9.9 μgm^{-3},gravimetric has also been added. This value was derived from the site specific receptor modelling results as described in section 5.2 and this value is consistent with the intercept of the regression analyses to determine the empirical dispersion coefficients.

The difference, *diff*, between measured ambient PM_{10} concentrations at urban automatic monitoring sites (not roadside, industrial sites or urban or suburban sites that are significantly influenced by emissions from a nearby road) and the underlying concentration field (the sum of the point source primary and secondary) is calculated where automatic monitoring data are available.

diff = measured annual mean urban PM_{10} concentration – (point source primary + secondary)

A regression analysis is then performed to find the coefficient, k_b, for the relationship between *diff* and estimated PM_{10} emissions in the vicinity of the monitoring sites taken from the NAEI (Goodwin et al 2000):

$diff = k_b.emissions$

This coefficient, which is the equivalent of an empirical box model coefficient, can then be used to derive a map of annual mean local primary PM_{10} concentrations, to which the other contributions can be added to calculate a map of total PM_{10}. The intercept of this regression analysis also provides confirmation of the constant concentration of coarse particles.

In earlier work on the estimation of air pollutant concentrations from emission related parameters (Stedman et al, 1997) we have studied the spatial scale at which local emissions seem to influence ambient air quality. We found that estimates of emissions in an area of 25 km^2 centred on a background monitoring site provide the most robust relationships. In subsequent work incorporating improved spatially resolved emission inventories and more extensive monitoring data it became clear that contributions from outside the 25 km^2 area should be included. This is particularly important for large urban areas such as London, where an empirically derived 'out of square' contribution was added for inner London, (Stedman and Bush 2000). This has been addressed in the current work by including contributions to ambient concentrations from emissions in an area of 1225 km^2, with the contribution weighted by distance and direction from the central receptor. We have adapted an ADMS based approach described by Abbott and Vincent (1999) and others. The ADMS dispersion model was used to calculate the contribution to concentrations at a central receptor point from a 35 x 35 km hypothetical grid of 1 x 1 km cells of unit emissions, grouped into blocks of 5 x 5 km. This level of spatial resolution was chosen to retain consistency with earlier work and avoid discontinuities in predicted concentrations at the borders of 1 x 1 km cells. Long period average meteorological data from Heathrow was used. The weighted sum of emissions around each monitoring site location was calculated and compared with *diff* to derived the empirical dispersion coefficient k_b.

This revised method therefore implicitly includes a contribution from 'out of square' emissions but the calibration of dispersion coefficients by automatic monitoring data is retained.

Area emissions maps were calculated from each of the base years 1996 to 1999 as described in section 2 and empirical dispersion coefficients were calculated for each year by comparing these emissions with automatic monitoring results. The meteorological conditions of the base year are therefore included in the dispersion coefficients and this should be the only difference between the coefficients for different years because the year to year changes in emissions have been accounted for.

Coefficients are listed in Table 6.1 for the relationship between the weighted sum of emissions and the local source contribution to ambient annual mean PM_{10} concentration. The highest coefficients were derived for the 1997 base year, which is consistent with the results of the site-specific projections described above. Monitoring sites were found to fall into two groups: those in the large urban centres of Greater London, the West Midlands and Greater Manchester and those in the rest of the UK. The empirical dispersion coefficients were found to be lower in the large urban areas, presumably due to a combination of urban influences on local meteorology. This result has been confirmed by dispersion modelling studies in London recently carried out by Abbott and Vincent (2001), who found considerable differences in modelled concentrations for results derived from meteorological data at Heathrow and London Weather Centre. Figure 6.1 shows the derivation of the regression coefficients for 1999.

Table 6.1 Coefficients used to calculate background annual mean PM_{10} maps (sm^{-1})

Base year	1996	1997	1998	1999
Large urban areas	5.40	7.23	4.79	4.74
Elsewhere in the UK	9.06	13.77	11.23	9.72

6.2 METHOD FOR MAPS OF ROADSIDE CONCENTRATIONS

We have considered that the annual mean concentration of PM_{10} at a roadside location is made up of two parts: the background concentration (as described above) and a roadside increment

roadside concentration = background concentration + roadside increment

The NAEI provides estimates of PM_{10} emissions for a total of 14075 major road links in the UK for 1998 (Goodwin et al, 2000). Figure 6.2 shows a comparison of the roadside increment of annual mean PM_{10} concentrations at roadside or kerbside national automatic monitoring sites with PM_{10} emission estimates for the individual road links alongside which these sites are located. The background PM_{10} component at these roadside monitoring sites was derived from the map described above and the roadside increments were found to be in good agreement with those derived from the results of the APEG receptor model for these sites. The sites chosen for this analysis are those for which emission estimates are available that are in built-up areas.

roadside increment of annual mean PM_{10} (mgm^{-3}) = k_r.PM_{10} emission from road link (kg PM_{10} km^{-1} y^{-1})

A single value of the coefficient was applied for all base years. This value was derived for the 1999 base year (1998 base year at Marylebone Road because of the construction work during 1999) and is given in Table 6.2

Table 6.2 Coefficients used to calculate the roadside increment of annual mean PM_{10} concentration (sm^{-2})

Base year	1996	1997	1998	1999
Coefficient	0.133	0.133	0.133	0.133

Roadside monitoring sites at locations with a more open aspect, such as roads in rural areas, do not conform to this relationship. The PM_{10} emissions from vehicles travelling on these roads are generally more effectively dispersed than the emissions on built-up urban roads. We have therefore restricted our mapping to built-up major roads (7180 A-road and motorway road links), where the relationship is reliable. Built-up motorway road links with speed limits of less than 70 mph were treated in the same as other built-up major road links. Built-up motorway road links with speed limits of 70 mph were treated separately and the roadside increment was set to 0.225 of the value for other built-up major road links. This factor is based on the analysis of the limited amount of monitoring data from sites close to motorways with fast moving traffic, which indicates considerably enhanced dispersion in comparison with other roads in the urban environment.

6.3 COMPARSION OF MAPPED CONCENTRATIONS FOR 1996 – 1999 WITH MEASUREMENTS

Maps of annual mean background PM_{10} concentrations for the years 1996 to 1999 are shown in Figure 6.3. There is a clear south east to north west gradient in rural concentrations due to the reduction in secondary PM_{10} concentrations with increasing distance from precursor source regions. The highest estimated background concentrations are in the centres of the large cities. Areas strongly influenced by emissions from busy motorways are also evident. Scatter plots of estimated and measured concentrations are shown in Figure 6.4. Summary statistics for the comparison between mapped and measured background concentrations of PM_{10} are listed in Table 6.3. There is reasonably good agreement between the mapped and measured concentrations of PM_{10}, considering the complexities of mapping concentrations for this multi-source pollutant. The measurement data presented in these comparisons is the same as was used to calibrate the relationships between measurements and emissions. A separate report describing the verification of the mapping results by comparison with an independent set of measurement data has also been published (Stedman and Handley, 2001).

Table 6.3 Summary statistics for comparison between estimated and measured concentrations of PM_{10} at background sites

	Mean of measurements (μgm^{-3}, garavimetric)	**Mean of model estimates (μgm^{-3}, garavimetric)**	**r^2**	**Number of sites**
PM_{10}, 1996	31.3	30.4	0.37	21
PM_{10}, 1997	28.3	27.4	0.51	34
PM_{10}, 1998	24.8	24.5	0.47	43
PM_{10}, 1999	23.3	23.5	0.57	40

Maps of annual mean PM_{10} concentrations at the roadside of built-up major road links for the years 1996 to 1999 are shown in Figure 6.5. Scatter plots of estimated and measured concentrations are shown in Figure 6.6 (full year annual means are not available for roadside monitoring sites for 1996). Summary statistics for the comparison between mapped and measured background concentrations of PM_{10} are listed in Table 6.4. There is generally good agreement between the mapped and few measured concentrations of PM_{10} at roadside sites but the mapped values are generally somewhat higher than the measured values. The verification of the mapping results by comparison with an independent set of measurement data has also been published (Stedman and Handley, 2001).

Table 6.4 Summary statistics for comparison between estimated and measured concentrations of PM_{10} at roadside sites

	Mean of measurements (μgm^{-3}, garavimetric)	Mean of model estimates (μgm^{-3}, garavimetric)	r^2	Number of sites
PM_{10}, 1996	-	-	-	0
PM_{10}, 1997	39.3	39.5	1.00	4
PM_{10}, 1998	32.5	33.5	0.98	4
PM_{10}, 1999	32.2	32.0	0.99	4

6.4 MAPS OF PROJECTED BACKGROUND CONCENTRATION FOR 2010 AND 2015

Maps of annual mean background PM_{10} concentrations for the 2010 for the baseline and illustrative scenarios for the base years 1996 to 1999 are shown in Figures 6.7 and 6.8. The population weighted annual mean background PM_{10} concentration is a key output from the mapping studies as it is the statistic required for the calculation of the health benefits of reductions in ambient concentrations (Stedman et al (2001d), Stedman et al, 2002, DEFRA et al, 2001b). Population weighted mean concentrations are listed in Table 6.5 for the base years 1996 and 1999 and for 2010 for the baseline and illustrative package of measures scenarios. The difference between the baseline and illustrative scenario in 2010 has also been calculated and is listed in Table 6.6. The largest change in population weighted mean concentration for the illustrative package of measures is in London; the rest of England is similar to the value for the UK as a whole, which is –0.897 (μgm^{-3}, garavimetric).

Table 6.5 Population weighted annual mean background PM_{10} concentrations for the base years 1996 and 1999 and for 2010 for the baseline and illustrative package of measures scenarios (mgm^{-3}, gravimetric) (pm10aqsef maps)

Base year	1996	1997	1998	1999
Base years				
Scotland	21.318	19.249	18.165	17.867
Wales	24.733	21.185	19.963	19.218
Northern Ireland	25.553	24.643	22.590	20.472
Inner London	37.774	33.959	28.320	27.396
Outer London	34.051	29.630	25.799	25.038
Rest of England	27.782	23.745	22.163	21.355
UK	27.896	24.126	22.250	21.451
2010 Baseline				
Scotland	16.085	15.067	14.946	15.168
Wales	18.319	16.515	16.359	16.316
Northern Ireland	17.745	17.272	16.879	16.476
Inner London	24.159	22.417	20.716	21.012
Outer London	22.653	20.516	19.485	19.745
Rest of England	19.795	17.792	17.591	17.627
UK	19.738	17.875	17.552	17.616
2010 Illustrative package of measures				
Scotland	15.608	14.451	14.415	14.688
Wales	17.537	15.586	15.528	15.550
Northern Ireland	17.188	16.530	16.246	15.919
Inner London	22.918	20.947	19.590	19.910
Outer London	21.566	19.211	18.478	18.771
Rest of England	18.935	16.718	16.683	16.796
UK	18.891	16.825	16.673	16.805

Table 6.6 The change in population weighted annual mean background PM_{10} concentrations in 2010 for the baseline and illustrative package of measures scenarios (mgm^{-3}, gravimetric) (pm10aqsef maps)

Base year	1996	1997	1998	1999	mean
Scotland	-0.477	-0.616	-0.531	-0.480	-0.526
Wales	-0.781	-0.929	-0.831	-0.765	-0.827
Northern Ireland	-0.557	-0.742	-0.633	-0.558	-0.622
Inner London	-1.240	-1.470	-1.125	-1.102	-1.235
Outer London	-1.087	-1.304	-1.007	-0.973	-1.093
Rest of England	-0.860	-1.074	-0.907	-0.831	-0.918
UK	-0.847	-1.051	-0.879	-0.811	-0.897

6.5 MAPS OF PROJECTED ROADSIDE CONCENTRATION FOR 2010 AND 2015

Maps of roadside PM_{10} concentrations 2010 for the baseline and illustrative scenarios are shown in Figures 6.9 and 6.10. Table 6.7 lists the number of road links with estimated roadside concentrations PM_{10} greater than or equal to a range of annual mean thresholds for the base years for six geographical areas of the UK. The relationship between annual mean and number of days with concentrations above 50 μgm^{-3} has been described in section 5.5.

The majority of the road links are predicted to have exceeded the illustrative threshold concentrations in the 1996 base year. A smaller proportion of the total number of urban road links exceeded the higher thresholds in Scotland, Wales and Northern Ireland. Roadside concentrations were lower in the 1999 base year, reflecting reductions in both primary and secondary particle concentrations. The modelling results indicate that almost all of the road links in London still had roadside PM_{10} concentrations in excess of 25 μgm^{-3}, gravimetric in 1999.

Table 6.8 lists the number of road links with estimated roadside estimated roadside concentrations PM_{10} greater than or equal to a range of annual mean thresholds in 2010 for the baseline scenario. Baseline projections for primary PM_{10} were calculated by the applying the empirical dispersion coefficients derived for each individual base year to the 2010 emission inventory for the baseline scenario. Projections of secondary particle concentrations were calculated as described in section 3.3.

Roadside PM_{10} concentrations are predicted to be much lower in 2010 than in the base years. Exceedences of 20 μgm^{-3}, gravimetric are however still expected to be common at the roadside for the baseline scenario, especially for the 1996 base year in England. Fewer exceedences of 20 μgm^{-3}, gravimetric are expected in 2010 for the 1999 base year. Exceedences of 25 μgm^{-3}, gravimetric are largely confined to Inner London.

The illustrative package of possible additional measures is predicted to have a significant impact on the number of road links with estimated annual mean PM_{10} concentrations in excess of 20 μgm^{-3}, gravimetric, particularly in Outer London and the Rest of England. Results for the illustrative scenario in 2010 are listed in Table 6.9. The number of exceedences of 23 and 25 μgm^{-3}, gravimetric is also predicted to be considerably reduced.

Projections or 2015 are listed in Tables 6.10 and 6.11. Projections for 2015 are shown for the 1996 and 1999 base years only. The number of exceedences of the various threshold concentrations for the baseline scenario in 2015 is considerably reduced compared with 2010, largely as a result of the continued decline in road traffic exhaust emissions. Once again the illustrative package of measures is seen to significantly reduce the number of road links exceeding the thresholds. Exceedences of 23 μgm^{-3}, gravimetric are removed in all areas except Inner London for the 1999 base year and exceedences of 20 μgm^{-3}, gravimetric are largely confined to Inner London.

Table 6.7 The number of built-up major road links with estimated PM_{10} concentrations greater than or equal to various thresholds for the base years 1996 to 1999 (pm10aqsef maps)

Base year		1996					1997					1998					1999				
Threshold (μgm^{-3}, gravimetric)		28	25	23	20	18	28	25	23	20	18	28	25	23	20	18	28	25	23	20	18
Geographical area	Total																				
Scotland	548	66	199	306	470	510	49	112	207	332	433	7	52	105	269	401	6	12	62	236	386
Wales	282	49	168	235	279	279	14	46	86	195	262	2	18	47	168	240	2	6	21	124	225
Northern Ireland	101	25	38	53	96	99	22	31	38	58	87	16	23	31	52	82	10	14	22	37	59
Inner London	760	760	760	760	760	760	760	760	760	760	760	757	760	760	760	760	277	760	760	760	760
Outer London	789	787	787	787	787	787	781	787	787	787	787	484	784	787	787	787	277	768	787	787	787
Rest of England	4700	3781	4477	4623	4664	4664	1434	3152	3987	4562	4646	399	1804	3282	4458	4635	115	950	2555	4330	4615
Total	7180	5468	6429	6764	7056	7099	3060	4888	5865	6694	6975	1665	3441	5012	6494	6905	1154	2510	4207	6274	6832

Table 6.8 The number of built-up major road links with estimated PM_{10} concentrations greater than or equal to various thresholds in 2010 for the base years 1996 to 1999 for the baseline scenario (pm10aqsef maps)

Base year		1996					1997					1998					1999				
Threshold (μgm^{-3}, gravimetric)		28	25	23	20	18	28	25	23	20	18	28	25	23	20	18	28	25	23	20	18
Geographical area	Total																				
Scotland	548	0	0	2	10	139	0	0	3	25	95	0	0	1	8	68	0	0	1	8	63
Wales	282	2	2	2	42	173	2	2	2	17	58	2	2	2	6	46	2	2	2	5	42
Northern Ireland	101	0	1	5	15	30	1	5	9	18	26	0	1	5	13	23	0	1	4	12	22
Inner London	760	59	610	760	760	760	16	297	636	760	760	0	30	262	757	760	0	44	333	760	760
Outer London	789	2	50	654	787	787	0	4	55	757	787	0	1	11	616	787	0	2	13	694	787
Rest of England	4700	9	37	256	3404	4502	5	22	83	1245	3365	5	14	40	788	3108	5	12	35	708	3222
Total	7180	72	700	1679	5018	6391	24	330	788	2822	5091	7	48	321	2188	4792	7	61	388	2187	4896

Table 6.9 The number of built-up major road links with estimated PM_{10} concentrations greater than or equal to various thresholds in 2010 for the base years 1996 to 1999 for the illustrative additional measures scenario (pm10aqsef maps)

Base year		1996					1997					1998					1999				
Threshold (μgm^{-3}, gravimetric)		28	25	23	20	18	28	25	23	20	18	28	25	23	20	18	28	25	23	20	18
Geographical area	Total																				
Scotland	548	0	0	0	4	47	0	0	0	4	29	0	0	0	3	7	0	0	0	3	7
Wales	282	1	1	2	8	107	0	1	1	2	24	0	1	1	2	14	0	1	1	2	8
Northern Ireland	101	0	1	4	12	21	0	3	6	13	19	0	1	4	12	18	0	0	1	9	17
Inner London	760	1	228	760	760	760	0	29	301	753	760	0	0	25	660	760	0	0	44	709	760
Outer London	789	0	4	135	787	787	0	0	2	375	786	0	0	0	89	781	0	0	0	181	787
Rest of England	4700	0	0	8	1780	4289	0	0	1	130	1618	0	0	0	64	1456	0	0	0	55	1517
Total	7180	2	234	851	3351	6011	0	33	311	1277	3236	0	2	30	830	3036	0	1	47	959	3096

Table 6.10 The number of built-up major road links with estimated PM_{10} concentrations greater than or equal to various thresholds in 2015 for the base years 1996 and 1999 for the baseline scenario (pm10aqsef maps)

Base year		1996					1999				
Threshold (μgm^{-3}, gravimetric)		28	25	23	20	18	28	25	23	20	18
Geographical area	Total										
Scotland	548	0	0	0	8	79	0	0	0	6	32
Wales	282	2	2	2	32	158	2	2	2	3	32
Northern Ireland	101	0	1	4	13	26	0	0	1	9	18
Inner London	760	3	377	750	760	760	0	1	91	752	760
Outer London	789	0	10	338	787	787	0	0	2	410	787
Rest of England	4700	8	20	97	2931	4461	5	11	20	303	2657
Total	7180	13	410	1191	4531	6271	7	14	116	1483	4286

Table 6.11 The number of built-up major road links with estimated PM_{10} concentrations greater than or equal to various thresholds in 2015 for the base years 1996 and 1999 for the illustrative additional measures scenario (pm10aqsef maps)

Base year		1996					1999				
Threshold (μgm^{-3}, gravimetric)		28	25	23	20	18	28	25	23	20	18
Geographical area	Total										
Scotland	548	0	0	0	0	4	0	0	0	0	0
Wales	282	0	1	2	2	63	0	1	1	2	2
Northern Ireland	101	0	0	0	9	18	0	0	0	5	12
Inner London	760	0	2	393	760	760	0	0	0	409	760
Outer London	789	0	0	3	787	787	0	0	0	5	744
Rest of England	4700	0	0	3	808	3960	0	0	0	6	390
Total	7180	0	3	401	2366	5592	0	1	1	427	1908

7 Illustrative calculations of stationary source and road transport measures

7.1 INTRODUCTION

The illustrative package of possible additional measures includes measures to reduce emissions from both traffic and stationary sources of PM_{10}. PM_{10} concentrations in 2010, 2015 and 2020 have also been estimated for two components of this scenario considered separately.

7.2 SITE-SPECIFIC PROJECTIONS

Site specific projections are listed in Tables 7.1 to 7.3 and can be compared with the projections for the baseline and full package of measures scenarios in Tables 5.2, 5.3 and 5.4. Average reductions in concentrations at the background and roadside sites for which projections have been calculated are listed in Table 7.4 for the various scenarios, relative to the baseline. The stationary source measures are predicted to be more effective in reducing concentrations at background sites in 2010, slightly more effective in 2015 but slightly less effective than the

traffic measures in 2020. The traffic measures are predicted to be considerably more effective in reducing concentrations at roadside sites for all of the years examined.

Table 7.1 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the stationary source and traffic measures of the illustrative scenario (pm10aqsef analysis)

	projected PM_{10} 2010 Stationary source measures				projected PM_{10} 2010 Traffic measures			
Base year	1996	1997	1998	1999	1996	1997	1998	1999
London Bloomsbury	23.6	21.7	20.4	20.6	24.2	22.4	21.0	21.2
Birmingham Centre	21.1	19.3	18.2	18.1	21.4	19.6	18.4	18.4
Cardiff Centre	21.5	22.6	20.6	20.6	22.0	23.1	21.1	21.1
Edinburgh Centre	17.3	16.7	15.3	15.8	17.5	17.0	15.5	16.0
Belfast Centre	19.9	20.7	19.1	19.2	20.8	21.9	20.0	20.1
Liverpool Centre	21.6	22.1	20.9	20.1	21.9	22.3	21.1	20.3
Rochester	21.3	18.6	17.2	17.0	21.7	19.0	17.5	17.3
Newcastle Centre	20.3	18.5	17.3	16.6	20.4	18.7	17.5	16.7
Manchester Piccadilly	21.4	20.3	19.3	19.3	21.7	20.5	19.5	19.6
Bristol Centre	21.4	21.0	19.8	19.8	21.6	21.2	20.0	20.0
Haringey Roadside		20.8	19.5	20.3		20.7	19.4	20.2
Glasgow Roadside		22.9	21.7	18.8		21.5	20.6	17.7
Marylebone Road		25.4	23.5	26.1		24.6	22.9	25.2
Camden Roadside		23.5	20.8	22.3		23.4	20.7	22.1
Sutton Roadside		19.8	19.1	19.2		19.7	19.0	19.1
Bury Roadside		23.2	22.0	21.5		22.3	21.6	21.0

Table 7.2 Projected annual mean PM_{10} concentrations 2015 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the stationary source and traffic measures of the illustrative scenario (pm10aqsef analysis)

	projected PM_{10} 2015 Stationary source measures				projected PM_{10} 2015 Traffic measures			
Base year	1996	1997	1998	1999	1996	1997	1998	1999
London Bloomsbury	22.9	20.9	19.8	20.0	23.4	21.4	20.3	20.5
Birmingham Centre	20.6	18.6	17.7	17.7	20.6	18.5	17.7	17.7
Cardiff Centre	21.1	21.8	20.0	20.1	21.2	21.8	20.1	20.2
Edinburgh Centre	17.0	16.3	15.1	15.5	17.1	16.3	15.1	15.6
Belfast Centre	19.4	19.8	18.4	18.6	20.0	20.7	19.1	19.2
Liverpool Centre	21.1	21.2	20.2	19.5	21.0	21.1	20.1	19.4
Rochester	21.1	18.3	17.1	16.9	21.3	18.6	17.3	17.2
Newcastle Centre	19.6	18.5	16.8	16.2	19.5	18.7	16.8	16.2
Manchester Piccadilly	20.7	19.3	18.5	18.6	20.6	19.1	18.4	18.5
Bristol Centre	20.8	20.2	19.2	19.2	20.7	19.9	19.0	19.1
Haringey Roadside		19.8	18.7	19.4		19.4	18.5	19.2
Glasgow Roadside		20.4	19.7	17.3		17.9	17.6	15.5
Marylebone Road		23.1	21.7	23.7		21.9	20.8	22.5
Camden Roadside		22.0	19.8	21.0		21.5	19.5	20.6
Sutton Roadside		18.9	18.4	18.6		18.5	18.2	18.4
Bury Roadside		21.2	20.4	20.0		19.4	19.3	18.8

Table 7.3 Projected annual mean PM_{10} concentrations 2020 from base years 1996 to 1999 (μgm^{-3}, gravimetric) for the stationary source and traffic measures of the illustrative scenario (pm10aqsef analysis)

	projected PM_{10} 2020 Stationary source measures				projected PM_{10} 2020 Traffic measures			
Base year	1996	1997	1998	1999	1996	1997	1998	1999
London Bloomsbury	22.9	20.8	19.8	19.9	23.3	21.1	20.1	20.3
Birmingham Centre	20.6	18.6	17.7	17.7	20.4	18.3	17.6	17.6
Cardiff Centre	21.1	21.7	20.0	20.0	21.0	21.5	19.9	19.9
Edinburgh Centre	17.0	16.2	15.1	15.5	16.9	16.1	15.0	15.5
Belfast Centre	19.3	19.7	18.3	18.4	19.7	20.2	18.7	18.9
Liverpool Centre	21.0	21.1	20.1	19.4	20.8	20.7	19.8	19.2
Rochester	21.0	18.3	17.1	16.9	21.3	18.4	17.3	17.2
Newcastle Centre	19.6	17.7	16.8	16.2	19.3	17.3	16.6	16.1
Manchester Piccadilly	20.6	19.3	18.5	18.6	20.4	18.8	18.2	18.3
Bristol Centre	20.8	20.1	19.1	19.2	20.5	19.6	18.7	18.8
Haringey Roadside		19.7	18.7	19.4		19.1	18.2	18.9
Glasgow Roadside		20.2	19.5	17.1		17.0	16.9	15.0
Marylebone Road		22.7	21.4	23.4		21.2	20.3	21.8
Camden Roadside		21.8	19.6	20.9		21.1	19.2	20.2
Sutton Roadside		18.8	18.3	18.5		18.2	18.0	18.2
Bury Roadside		21.1	20.4	19.9		18.8	18.8	18.3

Table 7.4 Summary of changes in annual mean PM_{10} concentrations for the illustrative scenario relative to the baseline from the site specific analysis (μgm^{-3}, gravimetric) (pm10aqsef analysis)

Scenario	Background sites	Roadside sites
2010 (Total Package)	-1.4	-2.1
2010 (Stationary measures)	-0.9	-0.8
2010 (Traffic measures)	-0.5	-1.3
2015 (Total Package)	-1.7	-2.6
2015 (Stationary measures)	-0.9	-0.8
2015 (Traffic measures)	-0.8	-1.8
2020 (Total Package)	-1.9	-2.9
2020 (Stationary measures)	-0.9	-0.8
2020 (Traffic measures)	-1.0	-2.1

7.3 MAPS OF BACKGROUND CONCENTRATIONS

The modelling results in terms of changes in mapped population weighted annual mean background PM_{10} concentrations in 2010 have been broken down in Tables 6.5 and 6.6 by the separating the impacts stationary and road transport measures. The reduction in population weighted annual mean PM_{10} concentration in 2010 is predicted to be greater for the stationary source measures in isolation than for the traffic measures in isolation (the traffic measures are expected to have the biggest impact in inner London, where the change in concentration is almost as great as for the stationary measures).

Table 7.5 The change in population weighted annual mean background PM_{10} concentrations in 2010 for the baseline and stationary source measures within the illustrative scenario (mgm^{-3}, gravimetric) (pm10aqsef maps)

Base year	1996	1997	1998	1999	mean
Scotland	-0.322	-0.396	-0.345	-0.316	-0.345
Wales	-0.641	-0.737	-0.665	-0.619	-0.665
Northern Ireland	-0.443	-0.585	-0.498	-0.439	-0.491
Inner London	-0.644	-0.693	-0.591	-0.576	-0.626
Outer London	-0.635	-0.712	-0.587	-0.566	-0.625
Rest of England	-0.628	-0.753	-0.644	-0.595	-0.655
UK	-0.597	-0.710	-0.607	-0.564	-0.620

Table 7.6 The change in population weighted annual mean background PM_{10} concentrations in 2010 for the baseline and traffic measures within the illustrative scenario (mgm^{-3}, gravimetric) (pm10aqsef maps)

Base year	1996	1997	1998	1999	mean
Scotland	-0.154	-0.220	-0.186	-0.164	-0.181
Wales	-0.141	-0.193	-0.166	-0.146	-0.161
Northern Ireland	-0.114	-0.157	-0.135	-0.118	-0.131
Inner London	-0.597	-0.778	-0.535	-0.527	-0.609
Outer London	-0.453	-0.592	-0.420	-0.408	-0.468
Rest of England	-0.233	-0.321	-0.264	-0.236	-0.263
UK	-0.250	-0.341	-0.272	-0.247	-0.277

7.4 MAPS OF ROADSIDE CONCENTRATIONS

The number of urban road links with estimated concentrations exceeding various thresholds in 2010 have also been calculated for the stationary source and traffic measures components of the illustrative scenario. The results of these illustrative calculations are listed in Table 7.7 and 7.8 and can be compared with the results for the baseline and full illustrative scenario in Tables 6.8 and 6.9. As expected the number of road links exceeding the threshold concentrations for these two parts of the scenario is intermediate between the number of exceedences for the baseline and full illustrative package of measures scenarios.

There are very few exceedences of 20 μgm^{-3} in Scotland, Wales or Northern Ireland for any of the scenarios. The traffic measures are seen to be more effective at reducing the total number of exceedences in London but the stationary source measures are seen to be more effective in the rest of England. Over the UK as a whole the stationary source measures are more effective at reducing the number of exceedences of 20 μgm^{-3}, while the traffic measures are more effective for the higher thresholds. This dependence on threshold is largely due to the large number of predicted exceedences in London, with all or almost all road links with concentrations greater than 20 μgm^{-3} for all scenarios. The percentage of the total number of road links with concentrations greater than or equal to illustrative thresholds for the various scenarios is listed in Table 7.9.

Table 7.7 The number of built-up major road links with estimated PM_{10} concentrations greater than or equal to various thresholds in 2010 for the base years 1996 to 1999 for the illustrative scenario (stationary source measures only) (pm10aqsef maps)

Base year		1996					1997					1998					1999				
Threshold (μgm^{-3}, gravimetric)		28	25	23	20	18	28	25	23	20	18	28	25	23	20	18	28	25	23	20	18
Geographical area	Total																				
Scotland	548	0	0	0	6	83	0	0	1	6	61	0	0	0	6	43	0	0	0	5	35
Wales	282	1	2	2	16	140	0	1	2	5	33	0	1	2	2	26	0	1	2	2	19
Northern Ireland	101	0	1	4	13	23	1	4	6	13	20	0	1	5	12	19	0	1	2	11	18
Inner London	760	28	464	755	760	760	4	174	525	760	760	0	14	149	746	760	0	21	194	756	760
Outer London	789	0	18	385	787	787	0	2	17	671	787	0	0	5	335	787	0	0	5	466	787
Rest of England	4700	0	2	55	2542	4391	0	1	9	468	2482	0	0	4	266	2128	0	0	2	218	2272
Total	7180	29	487	1201	4124	6184	5	182	560	1923	4143	0	16	165	1367	3763	0	23	205	1458	3891

Table 7.8 The number of built-up major road links with estimated PM_{10} concentrations greater than or equal to various thresholds in 2010 for the base years 1996 to 1999 for the illustrative scenario (traffic measures only) (pm10aqsef maps)

Base year		1996					1997					1998					1999				
Threshold (μgm^{-3}, gravimetric)		28	25	23	20	18	28	25	23	20	18	28	25	23	20	18	28	25	23	20	18
Geographical area	Total																				
Scotland	548	0	0	0	8	81	0	0	0	7	60	0	0	0	6	49	0	0	0	6	38
Wales	282	2	2	2	31	158	2	2	2	6	45	2	2	2	3	38	2	2	2	2	31
Northern Ireland	101	0	1	5	13	27	0	5	6	15	24	0	1	5	13	22	0	0	1	11	19
Inner London	760	4	398	752	760	760	0	80	441	760	760	0	1	71	732	760	0	3	113	753	760
Outer London	789	0	10	359	787	787	0	0	7	664	787	0	0	2	302	787	0	0	2	430	787
Rest of England	4700	8	21	104	2931	4457	4	12	30	663	2872	4	11	20	372	2504	4	11	21	306	2657
Total	7180	14	432	1222	4530	6270	6	99	486	2115	4548	6	15	100	1428	4160	6	16	139	1508	4292

Table 7.9 The percentage of urban road links exceeding illustrative threshold concentrations in 2010 for various scenarios for the 1999 base year for the illustrative package of measures scenario (<1 % means less than 1 % but not 0%) (pm10aqsef maps).

Scenario	Threshold (μgm^{-3}, gravimetric)	Baseline	full package of measures	stationary source measures only	traffic measures only
Scotland, Wales and NI	20	3 %	2 %	2 %	2 %
Scotland, Wales and NI	23	1 %	<1 %	<1 %	<1 %
Scotland, Wales and NI	25	<1 %	<1 %	<1 %	<1 %
London	20	94 %	58 %	79 %	76 %
London	23	22 %	3 %	13 %	7 %
London	25	3 %	0 %	1 %	<1 %
Rest of England	20	15 %	1 %	5 %	7 %
Rest of England	23	1 %	0 %	<1 %	<1 %
Rest of England	25	<1 %	0 %	0 %	<1 %

8 Uncertainty and Sensitivity analyses for 2010 Baseline PM_{10} projections

8.1 INTRODUCTION

In assessing the results from any modelling, particularly that involving atmospheric phenomena, it is important to quantify as far as possible the uncertainties in the model output. This is separated into three components in the following discussion.

Firstly there is the possibility that various components of the input data are systematically wrong-for example the relationship between gravimetric and TEOM measurements has been taken as 1.3 (for the reasons discussed); but it may be some other factor (indeed a single factor may not even be appropriate, but there is insufficient evidence yet to analyse this possibility). We have therefore undertaken sensitivity analyses to investigate the likely upper bound of uncertainty in the more important input parameters in the model. Many of the uncertainties, such as the predictions of emission factors for new technologies and the political background to policy decisions are clearly beyond the scope of this report. There are, however, a number of areas where it is relatively easy to assess the sensitivity of the projections to the assumptions that we have made. This is particularly important in areas where the current scientific understanding

of PM_{10} is limited. This section presents the results of a number of sensitivity analyses carried out on the site-specific projections of PM_{10} concentrations in 2010.

Secondly, the concentrations measured in 2010, or any future year, will be critically dependent on the prevailing meteorology. It is impossible to predict this, so we have used a range of 'base year' meteorologies to attempt to span the possible outcomes from this variability.

Thirdly there is the inherent unpredictability atmospheric properties-including air pollutant concentrations. This arise from a series of uncertainties including the stochastic nature of the atmosphere (although this is to some extent minimised by calculating annual average concentrations); the uncertainties in the emission rates and locations of the large number of sources; and the atmospheric processes which produce and remove particles in the atmosphere. An a priori 'bottom-up' analysis of these uncertainties is impossible in any practicable sense. We have attempted to assess this uncertainty by comparing the models predictions for 2000 (based on inputs from earlier years) with those which were actually measured.

8.2 TOTAL PM10

A 1.4 conversion factor

A conversion factor of 1.3 has been applied to the baseline projections of PM_{10} concentrations. This factor is considered as a central estimate and is generally confirmed at locations where TEOM and gravimetric measurements of PM_{10} are co-located. There are indications that the ratio could be closer to 1.4 at some locations and we have therefore recalculated the site-specific projections using this factor. The results of this sensitivity analysis are listed in Table 8.1 and can be compared with the baseline projections listed in Table 5.2. The use of a 1.4 conversion factor leads to a change in projected annual mean PM_{10} concentrations of +1.6 μgm^{-3}, gravimetric at background sites and +1.7 μgm^{-3}, gravimetric at roadside sites.

Table 8.1 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario and a 1.4 TEOM to gravimetric conversion factor (pm10aqsef analysis)

	projected PM_{10} 2010			
Base year	1996	1997	1998	1999
London Bloomsbury	26.7	24.9	23.2	23.4
Birmingham Centre	23.6	21.8	20.3	20.2
Cardiff Centre	24.2	25.8	23.4	23.4
Edinburgh Centre	19.2	18.8	17.0	17.5
Belfast Centre	22.8	24.2	22.0	22.1
Liverpool Centre	24.1	24.9	23.4	22.4
Rochester	23.6	20.7	19.0	18.7
Newcastle Centre	22.6	20.8	19.3	18.3
Manchester Piccadilly	24.1	23.0	21.8	21.8
Bristol Centre	23.9	23.8	22.3	22.2
Haringey Roadside		23.4	21.7	22.6
Glasgow Roadside		25.3	24.0	20.4
Marylebone Road		28.7	26.4	29.3
Camden Roadside		26.7	23.3	25.0
Sutton Roadside		22.1	21.1	21.2
Bury Roadside		26.0	24.7	24.1

Coarse particles

One area of uncertainty not addressed in the consultation relates to the APEG receptor modelling, in terms of the assignment to primary, secondary and other, largely coarse, particles. This is important because the other stays flat while the primary and secondary decline. The other component is calculated as the residual from the regression analysis to determine the primary and secondary contributions. This method would be very unlikely to provide an underestimate, but it is possible it could overestimate the other (coarse) particle contribution.

The assumed other concentration in the model is 9.9 μgm^{-3}, gravimetric, in good agreement with measured values of PM_{10} - $PM_{2.5}$ at Bloomsbury. PM_{10}- $PM_{2.5}$ will however include some (approximately 20%) of the secondary PM_{10} so you might expect the other value to be lower than PM_{10} - $PM_{2.5}$, but it isn't because we may have included some sources in other that are not coarse particles. The reasonably good agreement between the site-specific projections for the early 1990s and 2000 from the base years 1996 to 1999 also indicates that we have probably got the split between primary, secondary and coarse about right. Overall the 9.9 ugm-3 gravimetric for other is a good estimate for the standard model and any sensitivity analysis should examine the impact of a lower number on predicted concentrations. We have carried out an additional sensitivity analysis for the site specific PM_{10} projections in 2010 for an alternative model in which the other contribution is set to 8 μgm^{-3} gravimemtric (rather less than PM_{10}- $PM_{2.5}$ at Bloomsbury but more than PM_{10}- $PM_{2.5}$ at Rochester and Harwell). The 1.9 μgm^{-3} left over in the base year measurement is then split equally between primary and secondary PM_{10}.

The results of this sensitivity analysis are listed in Table 8.2 and can be compared with the baseline projections listed in Table 5.2. This model leads to an change in projected annual mean PM_{10} concentrations of –0.8 μgm^{-3}, gravimetric at background sites and –0.8 μgm^{-3}, gravimetric at roadside sites.

Table 8.2 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (μgm^{-3}, gravimetric) for the baseline scenario and an coarse particle concentration of 8 μgm^{-3}, gravimetric (pm10aqsef analysis)

	projected PM_{10} 2010			
Base year	1996	1997	1998	1999
London Bloomsbury	23.8	22.1	20.7	20.9
Birmingham Centre	21.0	19.3	18.1	18.1
Cardiff Centre	21.7	23.2	21.0	21.2
Edinburgh Centre	16.9	16.6	15.0	15.6
Belfast Centre	20.3	21.7	19.7	19.9
Liverpool Centre	21.5	22.3	21.0	20.2
Rochester	21.1	18.5	16.9	16.7
Newcastle Centre	20.1	18.4	17.2	16.3
Manchester Piccadilly	21.4	20.5	19.4	19.5
Bristol Centre	21.3	21.2	19.9	20.0
Haringey Roadside		20.8	19.3	20.3
Glasgow Roadside		22.6	21.5	18.2
Marylebone Road		25.6	23.6	26.4
Camden Roadside		23.8	20.8	22.4
Sutton Roadside		19.6	18.8	19.0
Bury Roadside		23.3	22.2	21.7

8.3 PRIMARY PM10

Assumptions on re-suspended dusts and the roadside increment in concentrations

It is not possible to determine the split of the roadside increment in PM_{10} concentrations between traffic exhaust emissions and re-suspended dusts from current network measurements. The receptor model, can however, be used to determine the magnitude of the roadside increment. Analyses of PM_{10} and $PM_{2.5}$ monitoring data presented in the APEG report (APEG 1999) suggested that re-suspended component could be 50% of the total. It is likely that this is an overestimate because exhaust emission may include some particles of diameter greater than 2.5 μm. We have assumed that re-suspended dust does not contribute to the roadside increment of PM_{10} concentrations in our baseline projections. Projections for an alternative scenario in which 25% of the roadside increment in 1997 is assumed to be from re-suspended dust are listed in Table 8.3. This component of the roadside increment has been held constant from the base year to 2010. The average change in projected annual mean PM_{10} in 2010 at roadside sites is +1.6 μgm^{-3}, gravimetric as an average over projections for the three base years, compared with the 2010 baseline.

Table 8.3 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario and 25% of 1997 roadside increment assumed to be re-suspended dust (pm10aqsef analysis)

	projected PM_{10} 2010			
Base year	1996	1997	1998	1999
Haringey Roadside	22.6	21.0	21.8	
Glasgow Roadside	26.3	24.4	20.9	
Marylebone Road	30.1	27.2	30.4	
Camden Roadside	26.2	22.8	24.4	
Sutton Roadside	21.2	20.1	20.1	
Bury Roadside	25.9	24.0	23.5	

Alternative traffic projections for Northern Ireland

Two alternative projections are available for road traffic activity in Northern Ireland. The NRTF for 1997 implies a growth in vehicle km from 1997 to 2010 of about 25%. Projections provided by the Northern Ireland Roads Service suggest a growth in vehicle km over the same period of about 40%. This projection has been extrapolated from current trends and does not therefore include the impact of any specific policies or network constraints. In consultation with the Northern Ireland Roads Service we therefore used the NRTF projections to derive our baseline projections for Northern Ireland. Table 8.4 shows the effect of the higher traffic growth assumption. The average change in annual mean PM_{10} at Belfast Centre in 2010 for this scenario is 0.4 μgm^{-3}, gravimetric.

Table 8.4 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario and higher traffic growth in Northern Ireland (pm10aqsef analysis)

	projected PM_{10} 2010			
Base year	1996	1997	1998	1999
Belfast Centre	21.6	23.0	20.8	20.9

8.4 SECONDARY PM10

More pessimistic projections of secondary PM_{10} from 1998 and 1999 base years

We have assumed a linear decline in concentrations secondary PM_{10} from 1997 to 2010. Predictions of secondary particle concentrations for individual base years were calculated by scaling the measured concentrations in that year according the ratio of the best fit concentration in that year and the average meteorology prediction for 2010. The assumption in the baseline projections is that the low measured secondary PM_{10} concentrations in 1998 and 1999 were due to a combination of meteorological conditions leading to low concentrations and a long term trend due to reductions in precursor emissions. An alternative, more pessimistic interpretation of the possible trends from 1998 and 1999 to 2010 is that the low measured concentrations in 1998 and 1999 resulted from a combination of a steeper than expected reduction in emissions and more 'typical' meteorology. Such an assumption is more pessimistic than the baseline assumptions since it considers that the reduction in concentrations between 1998 and 1999 and 2010 will be less. The site-specific projections of PM_{10} presented in Table 8.5 have been

calculated by extrapolating the measured sulphate and nitrate concentrations in 1998 and 1999 directly to the predicted concentrations in 2010 for average meteorology. The average change in projected annual mean PM_{10} in 2010 at background sites is +0.3 μgm^{-3}, gravimetric as an average over projections for the four base years, compared with the 2010 baseline.

Table 8.5 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (μgm^{-3}, gravimetric) for the baseline scenario and a more pessimistic assumption for secondary PM_{10} in 1998 and 1999 base years (pm10aqsef analysis)

	projected PM_{10} 2010			
Base year	1996	1997	1998	1999
London Bloomsbury	24.8	23.1	22.1	22.4
Birmingham Centre	21.9	20.2	19.3	19.4
Cardiff Centre	22.5	24.0	22.1	22.3
Edinburgh Centre	17.9	17.4	16.1	16.7
Belfast Centre	21.2	22.5	20.8	21.0
Liverpool Centre	22.4	23.1	22.1	21.3
Rochester	21.9	19.3	18.2	18.1
Newcastle Centre	21.0	19.3	18.3	17.6
Manchester Piccadilly	22.3	21.4	20.6	20.8
Bristol Centre	22.2	22.1	21.1	21.2
Haringey Roadside		21.7	20.8	21.8
Glasgow Roadside		23.5	22.6	19.4
Marylebone Road		26.6	25.1	28.0
Camden Roadside		24.8	22.2	24.0
Sutton Roadside		20.5	20.2	20.5
Bury Roadside		24.1	23.4	22.9

More pessimistic assumption on secondary organic aerosol

We have assumed that the secondary component of PM_{10} consists of sulphates and nitrates only and have projected concentrations to 2010 on this basis in our baseline projections. Preliminary modelling work on the formation of secondary organic aerosol during photochemical episodes indicates that up to 15% of the total mass of secondary PM_{10}, could consist of secondary organic aerosol and that the bulk of this aerosol is of natural origin. This is likely to be an upper limit on the amount of secondary organic aerosol and would not be expected to show a significant decline between the base years and 2010. The projections listed in Table 8.6 have been calculated on the basis of 15% of the secondary PM_{10} in the base years being present as secondary organic aerosol. The average change in projected annual mean PM_{10} in 2010 at background sites is +0.2 μgm^{-3}, gravimetric as an average over projections for the four base years, compared with the 2010 baseline.

Table 8.6 Projected annual mean PM_{10} concentrations 2010 from base years 1996 to 1999 (mgm^{-3}, gravimetric) for the baseline scenario and 15% of base year secondary PM_{10} assumed to be secondary organic aerosol (pm10aqsef analysis)

	projected PM_{10} 2010			
Base year	1996	1997	1998	1999
London Bloomsbury	25.3	23.4	21.8	21.9
Birmingham Centre	22.3	20.5	19.1	18.9
Cardiff Centre	22.9	24.2	21.9	21.9
Edinburgh Centre	18.1	17.6	15.9	16.4
Belfast Centre	21.5	22.7	20.6	20.7
Liverpool Centre	22.7	23.3	21.9	21.0
Rochester	22.4	19.6	17.9	17.5
Newcastle Centre	21.4	19.5	18.1	17.2
Manchester Piccadilly	22.7	21.6	20.4	20.4
Bristol Centre	22.6	22.3	20.9	20.8
Haringey Roadside		22.0	20.4	21.2
Glasgow Roadside		23.6	22.4	19.1
Marylebone Road		26.9	24.8	27.4
Camden Roadside		25.0	21.9	23.4
Sutton Roadside		20.8	19.9	19.9
Bury Roadside		24.3	23.2	22.5

Spatial variation in sulphate to nitrate base year ratios across the UK

A constant nitrate to sulphate ratio across the UK was assumed in the projections presented in the consultation documents. This ratio was derived as the average value from the receptor modelling. Measurements of both sulphate and nitrate at 12 rural sites during 2000 indicate that there is some spatial variation in this ratio, with the highest observed ratio in south east England (more nitrate). It is not clear at present to what extent this gradient in nitrate concentrations would be expected to be observed in the TEOM measurement of PM_{10}. This issue was discussed in the baseline report (Stedman et al, 2001b) and a sensitivity analysis is presented in Table 8.7. Nitrate concentration in 1999 have been derived from a map of sulphate concentrations in 1999 scaled by the measured sulphate to nitrate ratios interpolated to provide values for each 20 km grid square in 2000. This assumes that the spatial variation in sulphate to nitrate ratio across the country was the same in 1999 and 2000. This is unlikely to have been the case for the earlier base years such as 1996 and 1997 due to the more rapid decline in sulphate than nitrate concentrations during the late 1990's. These considerations along with the uncertainties surrounding the sensitivity of TEOM measurements to nitrate concentrations mean that it is only appropriate to use the nitrate map as a sensitivity analysis. The change in projected annual mean PM_{10} in 2010 is less than 0.05 μgm^{-3}, gravimetric at all background sites and roadside sites for the 1999 base year, compared with the 2010 baseline. The average change is less than 0.01 μgm^{-3}, gravimetric at background sites and 0.02 μgm^{-3}, gravimetric at roadside sites.

Table 8.7 Projected annual mean PM_{10} concentrations 2010 from base year 1999 (mgm^{-3}, gravimetric) for the baseline scenario with spatially varying sulphate to nitrate ratio (pm10aqsef analysis)

	projected PM_{10} 2010
Base year	1996 1997 1998 1999
London Bloomsbury	21.7
Birmingham Centre	18.9
Cardiff Centre	21.8
Edinburgh Centre	16.2
Belfast Centre	20.5
Liverpool Centre	20.8
Rochester	17.4
Newcastle Centre	17.0
Manchester Piccadilly	20.3
Bristol Centre	20.7
Haringey Roadside	21.1
Glasgow Roadside	18.8
Marylebone Road	27.2
Camden Roadside	23.3
Sutton Roadside	19.8
Bury Roadside	22.5

Spatial variation in sulphate and nitrate temporal trends across the UK

Single, UK-wide values for the trends in sulphate and nitrate concentrations between 1997 and 2010 were assumed in the projections presented in the consultation documents. The UK mean factor from HARM for sulphate in 2010 is a reduction to 50% of 1997 concentration, with extremes of 47% in the East Midlands and 53% in Scotland. The UK mean factor from HARM for nitrate in 2010 is a reduction to 70% of 1997 concentration, with extremes of 67% in the NI and 71% in South East. This small spatial variation in trends across the UK was not considered in the projections in the consultation documents. As indicated in the baseline report (Stedman et al, 2001b) this has been considered alongside the spatial variation in nitrate to sulphate ratios in the sensitivity analyses presented here. Table 8.8 shows the results of this sensitivity analysis for the 1999 base year, in which the base year sulphate to nitrate ratio varies across the UK as do the temporal trends in both sulphate and nitrate. Trends have been applied according to Government Office regions in England, with separate values for Scotland, Wales and Northern Ireland. The values have been normalised to give a UK area average trend consistent with that assumed in the baseline calculations, which were derived from EMEP model results The change in projected annual mean PM_{10} in 2010 is less than 0.04 μgm^{-3}, gravimetric at all background sites and roadside sites for the 1999 base, compared with the 2010 variable nitrate to sulphate ratio baseline. The average change is less than 0.01 μgm^{-3}, gravimetric at background sites and 0.02 μgm^{-3}, gravimetric at roadside sites.

Table 8.8 Projected annual mean PM_{10} concentrations 2010 from base year 1999 (μgm^{-3}, gravimetric) for the baseline scenario with spatially varying sulphate and nitrate temporal trends (pm10aqs analysis)

	projected PM_{10} 2010			
Base year	1996	1997	1998	1999
London Bloomsbury				21.6
Birmingham Centre				18.9
Cardiff Centre				21.8
Edinburgh Centre				16.3
Belfast Centre				20.5
Liverpool Centre				20.7
Rochester				17.4
Newcastle Centre				16.9
Manchester Piccadilly				20.2
Bristol Centre				20.8
Haringey Roadside				21.0
Glasgow Roadside				18.9
Marylebone Road				27.1
Camden Roadside				23.2
Sutton Roadside				19.7
Bury Roadside				22.4

Alternative assumptions on the UK/other sources split in secondary PM_{10}

The UK contribution to sulphate concentrations has been assumed to be 44% in 1997, falling to 30% in 2010. The UK contribution to nitrate concentrations has been assumed to be 48% in 1997, falling to 45% in 2010. These percentages have been calculated as the UK average of EMEP modelling results and are broadly confirmed by the HARM model results of the UK contribution of sulphate declining from 42% to 29% and the UK contribution to nitrate declining from 44% to 42%. It is likely that these of Lagrangian models will overestimate the long-range transported component of secondary particle concentrations because mass cannot be lost due to vertical transport. The split between UK and long-range transported sulphate and nitrate concentrations does not directly affect the baseline projected PM_{10} concentrations in 2010. The marginal impact of changes in sulphate and nitrate due to changes in UK emissions of SO_2 and NO_x would however be greater if the long-range transported component is assumed to be smaller. Site-specific projections for the illustrative package of measures in 2010 for the standard model have been compared with projections from an alternative model, in which a 75% UK contribution to sulphate and nitrate concentrations in 1997 has been assumed, declining to 60% in 2010. This change was found to increase the impact of the illustrative package of measures by 0.1 μgm^{-3}, gravimetric.

8.5 $PM_{2.5}$ BENEFITS

The analysis of the long-term health benefits associated with the measures to reduce ambient PM_{10} concentrations illustrated in the IGCB report (DEFRA et al, 2001b) have been derived from associations between ambient concentrations of $PM_{2.5}$ and life expectancy. The simplifying assumption has been made in this analysis that the reductions in $PM_{2.5}$ resulting from these measures are the same as the calculated reductions in PM_{10}, with both expressed in μgm^{-3}, gravimetric. It is recognised that some of the primary PM_{10} emissions abated would be in the

coarse fraction. The proportion of ambient PM_{10} concentrations reduced by the package of measures represented by $PM_{2.5}$ would however, be greater than implied by the mass fraction of primary $PM_{2.5}$ emissions abated for the following reasons:

• the particle sources with the greatest impact on population weighted annual mean background concentrations are also those with the highest percentage of primary emissions in the fine fraction, such as emissions from road traffic combustion;
• the bulk of the reductions in ambient concentrations due to reductions in secondary particle concentrations will be in the fine fraction;
• the TEOM to gravimetric conversion factor of 1.3 used here has been derived from a comparison ambient total PM_{10} concentrations measured at monitoring sites in the UK and we have applied this factor to the marginal change in ambient concentrations for an illustrative package of measures predicted by the air quality models. A specific conversion factor for this change in concentration would be likely to be higher than 1.3 because the more volatile components of PM_{10} are over-represented in the modelled reduction in concentrations. It is also likely that a TEOM to gravimetric conversion factor for $PM_{2.5}$ would be systematically higher than for PM_{10} because the more volatile components are generally found in the $PM_{2.5}$ fraction, rather than the $PM_{2.5}$ to PM_{10} fraction.

While there is some uncertainty associated with the assumption that the change in $PM_{2.5}$ concentration will be the same as the change in PM_{10} concentration, it is likely that if appropriate scaling factors were known, then the errors introduced by this assumption would tend to cancel out. In the absence of more detailed information and in the knowledge that a health impact of particles within the coarse fraction cannot be ruled out, we consider that the relatively simple and transparent approach of equating reductions in ambient PM_{10} and $PM_{2.5}$ concentrations adopted in the consultation documents and again here represents a reasonable approach. A 'worst case' sensitivity analysis in which the 1.3 TEOM to gravimetric conversion factor is applied directly to the reductions in ambient $PM_{2.5}$ concentrations implied by the illustrative package of measures has been calculated. This results in a reduction in the long-term health benefits to 70% of the value presented in the health benefits section. The short-term health benefits are unaffected as these are derived from dose response functions relating to PM_{10}.

8.6 SUMMARY OF SENSITIVITY ANALYSES

Table 8.9 summarises the results of these sensitivity analyses in terms of impact on baseline concentration in 2010 and/or impact on the effectiveness of the illustrative package of measures (and therefore the implied health benefits in terms of changes in population-weighted mean background concentrations). The site-specific analysis is primarily based on city centre locations. Mean concentration in 2010 (averaged over the 4 base years) are about 21 μgm^{-3}, gravimetric at background sites and 23 μgm^{-3}, gravimetric at roadside sites. The population weighted mean background concentration in 2010 (averaged over the 4 base years) is 18 μgm^{-3}, so the impact of these sensitivity analyses on the population weighted mean background concentration will be somewhat smaller than listed in the table. No change means either no change at all or very small impact.

Table 8.9 Summary of sensitivity analyses (2010 site-specific projections)

Sensitivity analysis	Impact on baseline (μgm^{-3}, gravimetric)	Impact on effectiveness of measures (μgm^{-3}, gravimetric) for the illustrative package of measures
1.4 instead of 1.3 TEOM factor	+1.6	- 0.1 (measures more effective)
Coarse fraction is 8 μgm^{-3} instead of 10 μgm^{-3}	-0.8	- 0.1 (measures more effective)
25% of roadside increment is resuspended	No change background + 1.6 roadside	No effect on population weighted mean + 0.2 (out of total of 1.9) roadside (traffic measures less effective)
Alternative traffic projections for NI	+0.4 (NI only)	Small increase in effectiveness in NI
More pessimistic secondary for 1998 and 1999 base years	+0.3	No change
More pessimistic secondary organic aerosol	+0.2	No change
Sulphate to nitrate ratio varies across the UK	No change	No change
Change in secondary concentration with time varies across the country	No change	No change
UK/imported source split for secondary	No change	-0.1 population weighted mean (measures more effective)
Health benefits arise from minimum change in $PM_{2.5}$ only*	N/A	Benefits reduced to 70% of central scenario

* from mapping analysis

We have examined the sensitivity of the predicted baseline concentrations in 2010 to the likely upper bound of uncertainty in the more important input parameters in the model. The parameter that causes the largest increase in predicted concentration is the TEOM to gravimetric conversion. A more pessimistic assumption on the contribution to the roadside increment of concentrations from re-suspended dusts would also cause an increase in predicted roadside concentrations. The other sensitivity analyses lead to increases in concentrations in the range from 0 to 0.3 μgm^{-3}, gravimetric, except for a lower coarse particle concentration, which leads to a decrease in baseline concentrations of 0.8 μgm^{-3}, gravimetric.

Several of the parameters have no influence on the effectiveness of the illustrative package of possible measures and others only have an effect on roadside concentrations. The 2001 emission factors, a 1.4 TEOM to gravimetric conversion factor and an assumption that UK emission contribute more to secondary concentrations than assumed in the baseline all lead to increases in effectiveness of the measures of between 0.1 and 0.2 μgm^{-3}, gravimetric for this site specific analysis. A more pessimistic assumption on the contribution to the roadside increment of concentrations from re-suspended dusts would cause a decrease in the predicted effectiveness of the illustrative package of measures.

8.7 DIFFERENT BASE YEAR METEOROLOGIES

As has already been noted the meteorological conditions can play an extremely important role in determining particle concentrations in the atmosphere, in three important ways. Firstly, extended periods of low wind speeds can reduce dispersion and lead to a build-up of high concentrations of all pollutants including particles, especially 'primary' particles from nearby sources. Secondly, in the UK, easterly air flows increase the contribution from secondary particles formed from sulphur and nitrogen emissions in Europe, so a year like 1996 when the incidence of such flows was much higher than normal, can lead to elevated particle levels in the UK. Thirdly low temperatures (or, increasingly, high temperatures) can lead to increased energy demand for heating (or for air conditioning) which increase emissions.

Table 5.4 for example shows the effect of different base year meteorologies on predicted concentrations in 2010 in the baseline and illustrative additional measures scenarios. The variation in predicted concentrations is, overall, greater than for the sensitivity analyses discussed in the previous section. This variation amounts to a spread of some 3 μgm^{-3}, gravimetric at the higher concentration sites. There is only a limited amount of data for roadside sites, but here the effect would be expected to be proportionally smaller, since the 'imported European' particles would make a proportionally smaller contribution than they would to a nearby urban background site.

8.8 OVERALL UNCERTAINTY

As noted above the overall uncertainty of the model has been assessed by calculating the concentrations for 2000 by using only the earlier years' data, and then comparing with the eventual measurements. The meteorological uncertainty discussed in the previous paragraph has also been incorporated in this process so that this should give a reasonably good estimate of the overall uncertainty of the model predictions. The plot of the modelled concentrations against those measured, for 2000, is shown in Figure 8.1 below. 55% of the predicted annual mean concentrations for 2000 are within 2 μgm^{-3} of the measured value and 90% are within 5 μgm^{-3}. The majority of the estimates showing the greatest difference from measured concentrations are due to known influences such as local construction emissions or unusual meteorological conditions leading to elevated secondary particle concentrations. Overall the correlation coefficient (r^2) between the measured and predicted values for 2000 is 0.68.

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