AEAT/ENV/R/1162 Issue 1

Quantification of the health effects of air pollution in the UK for revised 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 2001a Stedman et al, 2001b cost analysis (AEA Technology, 2001) and health benefits analyses (Stedman et al, 2001c 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. This report examines the health benefits of additional measures that could be put in place to reduce particle levels further than the levels predicted from currently agreed policies for his revised air quality modelling

As a result of the publication of a Committee on the Medical Effects of Air Pollutants statement, this report includes quantification of the possible effects of long term exposure to particles on mortality in addition to the short term effects of air pollution on deaths brought forward and respiratory hospital admissions considered in earlier work. This has had a major impact on this analysis for several reasons. It has necessitated the use of a much longer time horizon for the analysis (101 years from 2010), and, although the additional quantified effects are potentially much greater than before, there is also more uncertainty. This has been dealt with by using a range of estimates from the possibility of no long-term effects to estimates 6 or even 9-fold higher than the preferred estimate.

The modelled exposure to PM_{10} has been combined with population statistics, baseline rates of mortality and hospital admissions and dose response functions in order to estimate the short term health benefits of an illustrative package of measures to reduce PM_{10} concentrations in 2010. A similar approach has also been adopted to estimate the long term health benefits in terms of life years gained.

The results of the benefits analysis for the reduction in particles resulting from an illustrative package of additional measures (relative to a current policies baseline scenario) are as follows:

- a gain of 332,000 to 607,000 life years for the UK population over the years from 2010 to 2110. This is equivalent to 96,000 to 253,000 life years gained after discounting. The range is due to the different assumptions about the lagtime between exposure and effect (assumed to be somewhere between 0 and 40 years). Discounting takes into account the view that people tend to prefer to receive a benefits sooner rather than later;
- 30,100 fewer respiratory hospital admissions (additional or brought forward) in the UK;
- 4,820 fewer deaths brought forward (2510 after discounting) and 3,690 fewer respiratory hospital admissions (additional or brought forward) due to UK reductions in sulphur dioxide arising from the additional measures to reduce particles.

Results have also been calculated for a range of sensitivity analyses including different population scenarios, different reductions in mortality rates for changes in PM_{10} concentration, the inclusion of cardiovascular hospital admissions and the inclusion of the benefits associated with changes in NO_2 concentrations.

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 2001a, Stedman et al, 2001b), cost analysis (AEA Technology, 2001) and health benefits analyses (Stedman et al, 2001c) 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 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, 2001a). 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.

1.2 PURPOSE OF THIS REPORT

This report examines the health benefits of additional measures that could be put in place to reduce particle levels further than the levels predicted from currently agreed policies. This analysis is based on the revised PM_{10} modelling presented by Stedman et al (2002) and updates the health benefit calculations presented by DEFRA et al (2001b) and Stedman et al (2001c). The results of this assessment form an important component of the analysis of the costs and benefits of measures to reduce PM_{10} concentrations. This document provides additional 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.

2 Overview Of Health Effects Of Particles

2.1 SHORT TERM EFFECTS ON MORTALITY AND RESPIRATORY HOSPITAL ADMISSIONS

Evidence has accumulated in recent years to show that day to day variations in concentrations of airborne particles, measured as PM_{10}, $PM_{2.5,}$ Black Smoke or other measures, are associated with day to day variations in a range of health end-points. These include daily deaths, admissions to hospital for the treatment of both respiratory and cardiovascular diseases and symptoms amongst patients suffering from asthma. In addition to these effects there is evidence from the United States that long term exposure to particulate air pollution is associated with a decrease in life expectancy.

The Department of Health's Committee on the Medical Effects of Air Pollutants (COMEAP) published a report on particles in 1995 (Department of Health, 1995) and examined the quantification of the health effects of particles in 1998 (Department of Health, 1998). In November 2000 COMEAP reviewed further evidence on these effects published since and concluded that the concentration-response function coefficients linking concentrations of particles with effects on health used in 1998 and listed in Table 2.1 remain reasonable summary estimates.

Table 2.1: Dose Response Coefficients

Pollutant	Health Outcome	Dose-response coefficient
PM_{10}	Deaths brought forward (all causes)	+ 0.75% per 10 µg/m^3 (24 hour mean) (95% confidence interval +0.6 to +0.9)
	Respiratory hospital admissions	+ 0.80% per 10 µg/m^3 (24 hour mean) (95% confidence interval +0.5 to +1.1)
Source: COMEAP (1998) EAHEAP (1999)		

The health effects considered are daily deaths and admissions to hospital for the treatment of respiratory diseases. In both cases, the COMEAP report makes it clear that the numbers of events

calculated as related to exposure to air pollution cannot simply interpreted as extra events. Deaths are brought forward and hospital admissions may be either brought forward or caused *de novo*. It is thought that particles worsen the condition of those, particularly the elderly, that are already ill with heart or lung disease. This can lead to a death occurring earlier than would otherwise be the case. However, the extent of advancement of deaths cannot be calculated directly from the type of studies (time-series studies) used to estimate the short-term effects of particles on mortality.

2.2 LONG-TERM EXPOSURE TO PARTICLES AND MORTALITY

Studies in the United States have shown that those living in less polluted cities live longer than those living in more polluted cities. After adjustment for other factors, an association remained between ambient concentrations of fine particles ($PM_{2.5}$) and shorter life expectancy. In its 1998 report (Department of Health, 1998), COMEAP did not recommend that these studies should be used as a basis for quantifying the effects on health of long term exposure to particulate air pollution in the UK. However, it was noted that, had these studies been used, the assessment of the overall impacts of particulate air pollution would have been considerably increased.

Recently, COMEAP have published a further report on the long-term effects of particles on mortality (Department of Health, 2001). This considered two reports (Health Effects Institute, 2000; Institute of Occupational Medicine, 2000) which provided further analysis of the earlier results of the US studies. COMEAP concluded that it was more likely than not that a causal association existed between long-term exposure to particles and mortality. This was considered transferable to the UK although it was noted that the quantitative impact might not be exactly the same. The Committee considered it was preferable to assess the size of the effect and comment on it rather than ignore it but emphasised that there were great uncertainties in the process which needed to be made clear. The key uncertainties were whether the results could be explained by undetected confounding, whether high exposures in the past lead to an overestimation of the effect, what lagtimes and what duration of exposure are required for the effect and a lack of understanding of the underlying mechanism.

2.3 CARDIOVASCULAR ADMISSIONS

At the time of the COMEAP report in 1998, it was not considered that the evidence for an effect of particles on cardiovascular admissions was sufficient for quantification. Since that time further studies have been published and air pollution and heart disease is now a very active research area. A COMEAP statement on Effect of Particles on Admissions to Hospital for Treatment of Cardiovascular Disorders has recently been published and recommends using a summary estimate of a 0.8% increase in cardiovascular admissions per 10 $\mu g/m^3$ increase in PM_{10}. This statement was not available at the time of the preparation of the PM_{10} consultation documents and the Committee therefore recommended using a summary estimate of a 0.6% increase in cardiovascular admissions per 10 $\mu g/m^3$ increase in PM_{10} for the purposes of sensitivity analysis. This estimate of 0.6% has been also been used for the revised benefits claculations presented here for consistency with the earlier work (Stedman et al, 2001c).

2.4 PM10, UV AND SKIN CANCER

Some exploratory work has been done looking at the predicted small increase in levels of uv if particle levels are reduced and the possible size of a resultant increase in skin cancer. This is not

sufficiently developed to use in this cost benefit analysis but is an illustration of the fact that the health effects of policies to reduce pollution may not always be beneficial for every outcome. Details of this analysis are presented in section 5.8.

2.5 TEOM AND GRAVIMETRIC MEASUREMENTS

The reference method for the Air Quality Daughter Directive limit values and AQS objectives for PM_{10} is the use of a gravimetric instrument. All the analyses presented in the Technical Annexe and supporting documents are based on TEOM (Tapered Element Oscillating Microbalance) or equivalent instruments, which are currently widely used within the UK national monitoring networks. A scaling factor of 1.3 has been applied 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 intercomparisons with the Directive Reference Method. Much of the PM_{10} concentration data reported within this study are given in units of μgm^{-3}, gravimetric, meaning that TEOM data has been scaled by the 1.3 factor to give a representation of concentrations as measured by a gravimentic, or equivalent instrument.

The American studies of the long term effects of particles were based on gravimetric data. Modelling results have therefore been multiplied by 1.3 to convert to the equivalent gravimetric concentration before calculation of the long term effects. For the short-term effects, the concentration-response functions are based on PM_{10} (measured by TEOM).

2.6 HEALTH EFFECTS OF PM_{10} AND $PM_{2.5}$

There is much current debate about whether the effects of PM_{10} are in fact due to fine particles, $PM_{2.5}$. The Expert Panel on Air Quality Standards (EPAQS, DETR, 2001) considered this issue in its report on the most appropriate metric on which to base a particle standard. The report concludes that PM_{10} continues to provide the most appropriate basis for a standard although it recommends that the issue should remain under active review.

The crucial point for cost-benefit analysis is to ensure that the benefits correctly match the type of particles being reduced by the proposed policies. The analysis of the long-term health benefits associated with the measures to reduce ambient PM_{10} concentrations illustrated here have been derived from associations between ambient concentrations of $PM_{2.5}$ and life expectancy (the American studies of the long term effects were based on gravimetric $PM_{2.5}$ data). The HEI reanalysis (HEI, 2000) of the studies of long term exposure to particles found that the effect was more strongly linked to gravimetric $PM_{2.5}$ than to PM_{10} or $PM_{10-2.5}$ (coarse particles). 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.

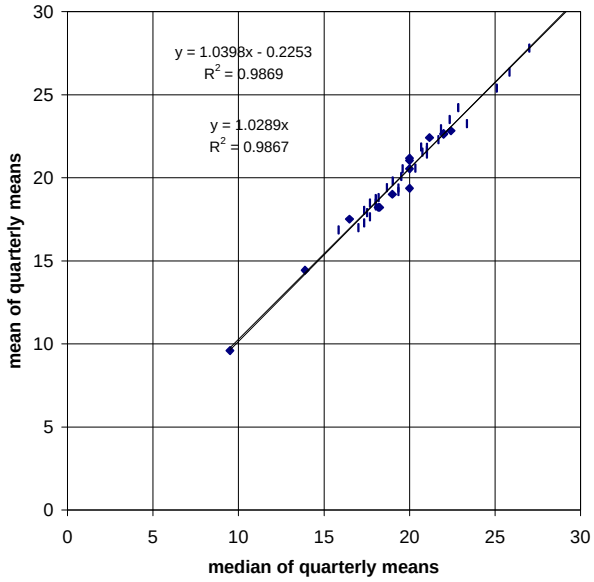
- The particle sources with the greatest impact on population weighted annual mean background concentrations are also those with the highest percentage of primary emissions in the fine fraction, such as emissions from road traffic combustion.
- The bulk of the reductions in ambient concentrations due to reductions in secondary particle concentrations (particles formed in the atmosphere by reactions between gaseous pollutants) will be in the fine fraction.
- The TEOM to gravimetric conversion factor of 1.3 (as recommended by APEG, 1999) 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 (See Stedman et al 2001a and Stedman et al 2001b). 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 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 here represents a reasonable approach.

2.7 MEANS AND MEDIANS

The American studies of the long term effects used medians to represent particle concentrations. Figure 2.1 shows a comparison of the annual mean of quarterly means and the median of quarterly means for UK network PM_{10} monitoring data for the period from 1996 to 2000 inclusive. It is clear that the annual mean provides an excellent estimate of the median and COMEAP therefore considered that annual means could be used as a direct surrogate for medians (Department of Health, 2001).

Figure 2.1 comparison of quarterly mean PM10 data at national network sites 1996 - 2000 (ugm-3 TEOM)



2.8 HEALTH EFFECTS OF SULPHUR DIOXIDE

Although this report concentrates on policies to reduce particles, some of these policies also reduce sulphur dioxide. The overall reductions in UK total emissions of sulphur dioxide implied by the additional measures to reduce PM_{10} are about 12% of the baseline sulphur dioxide emissions in 2010 (from reductions in emission from the domestic and refineries sectors). Therefore, the health effects of sulphur dioxide are discussed here.

Sulphur dioxide is an irritant gas that, in high concentrations, provokes bronchoconstriction: i.e. narrowing of the airways. Epidemiological studies have shown, as in the case of particles, that day to day variations in concentrations of sulphur dioxide are associated with the number of deaths occurring each day and also with admissions to hospital for the treatment of respiratory diseases. There is also evidence linking concentrations of sulphur dioxide with chest symptoms and with the use of bronchodilator therapies. These findings have been supported by work in the UK. There is evidence from the United States that long term exposure to sulphate particles may increase the risk of death. Sulphates are produced by oxidation of sulphur dioxide. (The contribution of sulphur dioxide to secondary particle (sulphate) formation has been included in the modelling of PM_{10} concentrations.)

The 1998 COMEAP report presented the concentration-response coefficients listed in Table 2.2 linking concentrations of sulphur dioxide with effects on health.

Table 2.2: Dose Response Coefficients

Pollutant	Health Outcome	Dose-response coefficient
Sulphur dioxide	Deaths brought forward (all causes)	+ 0.6% per 10 $\mu g/m^3$ (24 hour mean)
	Respiratory hospital admissions	+ 0.5% per 10 $\mu g/m^3$ (24 hour mean)
Source: COMEAP (1998)		

The points made in section 2.1 concerning these being deaths brought forward not extra deaths also apply here.

2.9 HEALTH EFFECTS OF NITROGEN DIOXIDE

Although this report concentrates on policies to reduce particles, some of these policies also reduce nitrogen dioxide. Therefore, it is worth considering the health effects of nitrogen dioxide.

The COMEAP quantification report (Department of Health, 1998) recorded inconsistencies in the evidence relating to the effects of nitrogen dioxide on health. Increases in daily deaths were found to be associated with increases in daily average concentrations of nitrogen dioxide but this finding was not supported by evidence of effects on either respiratory or cardiovascular deaths. There is some evidence that hospital admissions for respiratory diseases are related to concentrations of nitrogen dioxide although COMEAP did not consider the evidence sufficiently robust for quantification because it was difficult to separate the effects from those of particles. UK work has shown that exposure to nitrogen dioxide enhances response to allergens and may increase the prevalence of respiratory infections in children. Volunteer studies have shown effects on lung function in asthmatics. There is some evidence for long term effects of nitrogen dioxide although the evidence is weak. It should also be noted that nitrogen dioxide can be converted to nitrate which is a component of the particle aerosol and can contribute to ozone formation.

COMEAP did suggest a concentration-response function of a 0.5% increase in respiratory hospital admissions per 10 $\mu g/m^3$ for nitrogen dioxide. This is used here for sensitivity analysis only.

The contribution of oxides of nitrogen to secondary particle (nitrate) formation has been included in the modelling of PM_{10} concentrations.

Emissions of oxides of nitrogen also contribute to ground level ozone via a complex series of photochemical reactions, which also involve volatile organic compounds. Small reductions in emissions of oxides of nitrogen can lead to either small increases or small decreases in peak ozone concentration, depending on the relative locations of sources and receptors. The overall reductions in UK total emissions of oxides of nitrogen in 2010 implied by the measures to reduce PM_{10} (from the road traffic and refineries sectors) are relatively small (about 3%) and the impact of this reduction on ozone concentrations has not been assessed.

3 Method Of Quantifying Health Benefits

3.1 SHORT TERM EFFECTS

Because both the concentration of air pollutants and the density of population vary across the UK, modelling of exposure to pollutants is needed in calculating their effects on health. As described in the previous IGCB report (DETR, 1999), the following sequence of steps is adopted in calculating the short term effects on health e.g. respiratory hospital admissions. These steps are described in more detail in the COMEAP and EAHEAP reports (Department of Health, 1998; Department of

Health, 1999) and the Quantification of Health Effects for the First review of the Air Quality Strategy (Stedman *et al*, 1999).

1. The country has been divided into 1 km grid squares and the annual average concentration of pollutants and resident population has been estimated for each. The former has been derived from the national mapping of the UK pollution climate and the latter from census data (from the 1991 census, updated to provide estimates for 1995).

2. A baseline level of the given health-related and pollution affected events e.g., daily deaths, hospital admissions for the treatment of respiratory diseases has been assigned to each grid square. These have been obtained from National Statistics. The 1998 COMEAP report used rates for all deaths and all respiratory admissions (except for ozone where emergency admission rates were used). Later calculations used rates for deaths excluding external causes and emergency respiratory hospital admissions. The baseline rates have been updated for this report and were as follows: deaths excluding external causes 1025.7 per 100,000 for 1998; emergency respiratory hospital admissions (ICD10 J00 to J99) 942 per 100,000 for 1999/2000; emergency cardiovascular admissions (ICD10 I20 to I52) 733.7 per 100,000 for 1999/2000. Rates for England and Wales (deaths) or England (hospital admissions) were assumed to apply to the whole of the UK.

3. By combining the data from (1) and (2) and applying a coefficient linking the pollutant concentration with the relevant effects, the expected health effects can be derived. For this report, the coefficient is applied to the expected fall in concentration from the additional policies being assessed. This will give the benefit to health per grid square produced by the fall in concentrations of air pollutants expected to occur under the additional policies;

4. Summing the results obtained in (3) gives the relevant totals for the regions or for the UK.

An equivalent result can be obtained as follows.

1. Multiply the population and concentration in each grid square, sum the results across the grid squares and divide by the total population to give a population weighted mean.

2. Multiply the baseline rate for the health effect (usually expressed per 100,000 population per year) and the total population to give the total expected baseline health effects for that year.

3. Multiply the total baseline health effect by the change in this health effect (from the concentration-response function and the calculated change in population weighted mean pollutant concentration.)

Acute effects calculations are carried out using raw TEOM data for the change in PM_{10} concentration as recommended by COMEAP (1998).

The COMEAP report in 1998 was based on urban areas only (most studies of health effects were done in cities). The calculations are based on all areas here but urban areas do in fact dominate the population weighted mean as both population and pollution are higher in urban areas.

Details of the air quality modelling methods used to calculate the maps of annual mean background PM_{10} and NO_2 concentration in each grid square in 2010 for the baseline and illustrative additional measures scenario are provided in the AQS consultation document (DEFRA et al 2001) and supporting documents (Stedman et al, 2001a and Stedman et al, 2001b). Maps of annual mean background SO_2 concentration in 2010 for the baseline and illustrative additional measures scenario were calculated using the dispersion modelling approach adopted for the first review of the AQS and described by Abbot and Vincent (1999).

3.2 LONG TERM EFFECTS

The methodology is based on that in the IOM report (Institute of Occupational Medicine, 2000) although slightly different assumptions have been used (Department of Health, 2001). The basic strategy is, for a given population,

- obtain information on current mortality rates

- predict future mortality using current rates and lifetables and some assumptions about future demography, in the absence of changes in air pollution (the baseline scenario)

- create an alternative scenario by adjusting mortality rates according to evidence regarding the effect of pollution on mortality, but leaving other baseline assumptions unchanged

- compare predicted life expectancy (or some other appropriate summary measure) between the baseline and alternative scenario, to give estimates of the effect of the pollution change,

- examine how sensitive these estimates are to changes in the underlying assumptions.

The calculations are for changes in all-cause mortality in those over 30 (as in the cohort studies).

The baseline scenario is based on the numbers of deaths in each sex and age group found in England and Wales in 1995. This is used to predict future mortality. It is assumed that the mortality rates identified in 1995 will not change over time, that birth rates will remain constant and that the net effect of migration does not alter population sizes or mortality rates. (The IOM report found that changing these assumptions had only a small effect on the results.) The lifetable calculations were applied to give the total life years lived for the following populations:

1. The (predicted) population of England and Wales in 2000, plus all new cohorts born up to 2010, followed up to 2110;
2. The (predicted) population of England and Wales in 2000, plus all cohorts born right up to 2110, followed up to 2110;
3. The (predicted) population of England and Wales in 2000, followed for only 20 years, to 2020.

(New cohorts are all those born in a particular year).

Population 1 represents the population alive in 2010 followed up for their lifetime (up to 101 years) to 2110. However, this option omits the benefits to those born after 2010. These are included in Population 2 although the cut off was still at 2110 to allow easy comparison with

Population 1. Population 3 is equivalent to population 1 or 2 but cut short at 2020 (new cohorts between 2000 and 2020 are not added because the results are only applied to those over 30 and the new cohorts do not reach this age by 2020). This population is included because the costs and benefits become increasingly uncertain as time goes on.

The calculation of the long term effects was done in two stages. Firstly, the Institute of Occupational Medicine (IOM) was commissioned to produce the gain in life years for an illustrative 1% drop in mortality rate by running lifetables. This was chosen for arithmetic convenience to provide a 'standard factor'. Secondly, this was scaled to the drop in mortality rate per $\mu g/m^3$ $PM_{2.5}$ recommended by COMEAP (0.1%) and the drop in pollutant concentration being examined. Previous work by IOM had shown that the results scale approximately linearly according to the change in mortality rate. This section describes the first stage.

The reduction in mortality rate was applied in one step in 2010 (the likely target date for an objective) and then maintained thereafter.

Lagtimes of 0, 20 and 40 years were assumed. The cohort studies give no direct information on lagtimes but the relative risk is similar in those under and over 50. COMEAP therefore considered that a lagtime of more than about 40 years was unlikely (Department of Health, 2001). The lagtimes were represented by the reduction in mortality rate being applied immediately in 2010 or in 2030 or 2050. It was assumed that the reduction in mortality rate was the same at all ages over 30.

The life years gained are shown with and without discounting at 1.5%. Discounting takes account of the view that people tend to prefer to receive a benefit sooner rather than later. A discussion of the choice of 1.5% is in the IGCB report (DEFRA, 2001).

Table 3.1 shows the difference in total life years lived between the baseline scenario with no reduction in mortality rate and the total life years lived with an illustrative 1% drop in mortality rate.

Table 3.1: Results of simulations quantifying (in millions of life years) the effects of introducing an illustrative 1% reduction in all-cause mortality hazard rate. Results are given raw and discounted for 2000 into the future at 1.5% per annum.

Population (England and Wales)		Followed up to year	Population (m)	Discounted?	Effect begins in year		
					2010	2030	2050
1	Alive in 2000 plus cohorts born up to 2010 inclusive	2110	58.96		4.61	3.29	1.91
				Discounted	2.16	1.31	0.63
2	Alive in 2000 plus cohorts born up to 2110 inclusive	2110	124.10		5.98	4.67	3.27
				Discounted	2.49	1.63	0.95
3	Alive in 2000	2020	52.45		0.27	0	0
				Discounted	0.21	0	0

Source: IOM

Cohorts refer to those born in a particular year. Figures in the population column relate to the numbers of people in England and Wales who contribute to the lifetable at some stage including those under 30 in 2110. It does not imply that they are all alive concurrently nor that they all experience a reduction in mortality rate for a whole lifetime (some are already old when the reduction occurs and, for population 2, others are still young when follow up stops in 2110).

The table shows clearly the effects of delaying the impact, which are almost exactly linear in the length of delay; and the effects of discounting at 1.5%, which are greater for longer delayed impacts.

The table also shows the increased benefits gained if people born after 2010 are included (population 2) and the underestimate of the benefits if only a short timescale is used.

The standard 'long term effect factor(s)' derived above can then be scaled to the particular scenarios under examination. Scaling can be applied to size of population, reduction in mortality rate per unit concentration and actual reduction in particle concentration.

The standard factor applies to the population of England and Wales whereas the particle concentration reductions discussed here apply to the UK as a whole or the sub-regions described in Table 4.1. If it is assumed that age distribution and background mortality rates are similar across regions, the standard factor can be adjusted by multiplying by the ratio between the relevant national or regional population and the population of England and Wales. (The IOM report has examined the sensitivity of results to changes in baseline rates and found that this did not have much impact. Thus, small differences between regions can be ignored.) For example, the population of England and Wales in 1995 is given as 50,704,778 within our GIS system and that of the UK in 1995 as 57,386,758. Therefore the number of life years gained for the UK population from 2010 to 2110 followed for their lifetime (population 2) can be calculated as 6.77 million (5.98 * 57,386,758 / 50,704,778).

There are a variety of options for reductions in mortality rate per per 1 $\mu g/m^3$ reduction in annual mean $PM_{2.5}$. COMEAP (Department of Health, 2001) recommended a 0.1% reduction in hazard rates for a 1 $\mu g/m^3$ reduction in annual mean $PM_{2.5}$ as a best estimate. This gives a gain in life years of 0.677 million per 1 $\mu g/m^3$ reduction in annual mean $PM_{2.5}$. Other reductions in mortality rate will be examined in sensitivity analysis and are listed in Table 3.2.

Table 3.2: Different reductions in hazard rate

Reduction in hazard rate % per $\mu g/m^3$ $PM_{2.5}$ + COMEAP comment
0.1 'most likely'
0.3 'reasonably likely'
0.6 'less likely'
0.9 'implausibly large'

The scaling for the actual reduction in particle concentration is analagous to the calculation of short-term effects using the population weighted mean concentrations multiplied by the adjusted standard factor (0.677 million life years per 1 $\mu g/m^3$ reduction in annual mean $PM_{2.5}$) in place of the concentration-response function. The population weighted mean is calculated using the current population whereas the standard factor is based on future populations. Care needs to be taken to ensure that these match up. However, if it is assumed that new birth

cohorts are added in the same way across the country, then the population weighted mean would not in fact change (both the numerator and denominator would be increased by a constant factor). The key determinant of the population weighted mean is the distribution of population relative to the distribution of particle concentrations rather than the absolute size of the population.

3.3 ROUGH ESTIMATE OF LIFE YEARS GAINED FROM REDUCTION IN ACUTE EFFECTS

The preferred method of estimating the size of the effects of short term exposure on mortality has already been described in section 3.1. However, for comparison with the long term effects, a rough estimate of the life years gained from a reduction in the acute effects can be made with some assumptions about the likely loss in life expectancy from a death brought forward. The loss of life expectancy involved in a death brought forward is actually unknown although some evidence suggests it is likely to be up to at least a month or two. COMEAP chose to use a range of 2 to 6 months (Department of Health, 2001). Once this assumption is made, it is simply a case of multiplying the calculated reductions in deaths brought forward by 2 to 6 months. (Note that different methods of calculating reductions in deaths brought forward are required according to whether estimating the effects of the population in a particular year followed up for their lifetimes or the total population in each year including new birth cohorts).

4 Results For Central Scenario

4.1 INTRODUCTION

The results for the central population scenario are discussed in this section. Sensitivity analyses are discussed in section 5. The central population scenario is described in Box 4.1.

Box 4.1: Central Scenario

Particle reduction scenario. A reduction of 0.897 $\mu g/m^3$ population weighted annual mean PM_{10} (or $PM_{2.5}$) gravimetric concentration, relative to the baseline (changes averaged over the base years 1996 to 1999), occurring in 2010 and maintained thereafter. This represents the impact of the illustrative package of possible additional measures to reduce PM_{10} concentrations.

Population 2 (Population of UK alive in 2010, plus all new cohorts born up to 2110, followed up to 2110)

Long term effects – 0.1% reduction in mortality rate per $\mu g/m^3$ $PM_{2.5}$ with discounting at 1.5%. Lagtimes of between 0 and 40 years were assumed.

Acute effects on mortality – none for particles, assumed to be included in long term effects above. Effect of changes in sulphur dioxide included.

Acute effects on respiratory hospital admissions – included for both particles and sulphur dioxide.

4.2 THE IMPACT OF AN ILLUSTRATIVE PACKAGE OF MEASURES ON AMBIENT PARTICLE CONCENTRATIONS

The impact of an illustrative package of possible additional road transport and stationary source measures on PM_{10} emissions has been modelled. 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 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. The effectiveness of the road traffic measures is greater for the revised emission factors used in this current study.

Full details of the illustrative package of measures and the impact on modelled PM_{10} concentrations can be found in the AQS consultation document (DEFRA et al, 2001), the IGCB report (DEFRA, 2001) and supporting technical documents (Stedman et al 2001a, 2001b, Stedman et al, 2001c and AEA Technology, 2001).

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.

Since the effects are being calculated on the basis of a reduction in 2010 which is then maintained, the predictions based on the different metereological conditions in the base years 1996 to 1999 have been averaged. It was considered that this range of metereological conditions is likely to be experienced over the years after 2010. Maps of SO_2 concentrations have, however, only been calculated for 2010 for the single 1998 base year meteorology. The

estimates of health benefits resulting from changes in SO_2 concentrations are relatively modest in comparison to the estimates for the long term effect of particles and we therefore considered that the additional computational demands of calculating SO_2 maps for other base years was not justified.

The changes in population weighted annual mean PM_{10} (assumed to be the same as the changes for $PM_{2.5}$) concentrations ($\mu g/m^3$, TEOM or gravimetric (TEOM x 1.3)) for the illustrative package of additional measures scenario in 2010, relative to the baseline are listed in Table 4.1.

Table 4.1: Changes in population weighted annual mean PM_{10} (or $PM_{2.5}$) concentrations ($\mu g/m^3$, TEOM or gravimetric (TEOM x 1.3)) for illustrative package of measures in 2010, relative to the baseline (changes averaged over the base years 1996 to 1999).

	Population, 1995	Illustrative package TEOM (for calculation of short term effects)	Illustrative package gravimetric (for calculation of long term effects)
Scotland	4,999,349	-0.404	-0.526
Wales	2,842,204	-0.636	-0.827
Northern Ireland	1,682,631	-0.479	-0.622
Inner London	2,284,191	-0.950	-1.235
Outer London	4,528,848	-0.841	-1.093
Rest of England	41,049,536	-0.706	-0.918
UK	57,386,758	-0.690	-0.897

4.3 LONG TERM EFFECTS OF PARTICLES, POPULATION ALIVE IN 2010 AND NEW COHORTS TO 2110

Table 4.2 shows that a 0.897 $\mu g/m^3$ reduction in particles is predicted to lead to a gain of 332,000 to 607,000 life years for the UK population over the years from 2010 to 2110. After discounting, this is equivalent to 96,000 to 253,000 life years gained. The range is due to the different assumptions about the lagtime between exposure and effect (assumed to be somewhere between 0 and 40 years). It should be noted that discounting has a greater effect for the longer lagtimes.

Table 4.2: Implied change in life years gained (millions) for the UK population 2010 to 2110, illustrative package of measures scenario (0.1% reduction in hazard rate per $\mu g/m^3$ $PM_{2.5}$)

Population	discounted ?	Followed until	Effect starts 2010	Effect starts 2030	Effect starts 2050
Population 2		2110	-0.607	-0.474	-0.332
	discounted*	2110	-0.253	-0.165	-0.096

* Central population scenario range

Table 4.3 gives the discounted results divided across the regions. The population of the respective regions is the dominant determinant of the result with the rest of England (without inner and outer London) giving the largest result and Northern Ireland the smallest. However,

the gains in inner and outer London are slighter greater than would be expected from the size of their populations. This is because there is more opportunity for pollutant reduction measures in urban areas than in more rural regions such as Scotland and Wales where there are fewer pollutant sources.

Table 4.3 Implied change in life years (millions) for the UK and regional populations, illustrative package of measures scenario (0.1% reduction in hazard rate per µg/m^3 $PM_{2.5}$, population 2, discounted)

	Effect starts 2010	Effect starts 2030	Effect starts 2050
Scotland	-0.013	-0.008	-0.005
Wales	-0.012	-0.008	-0.004
Northern Ireland	-0.005	-0.003	-0.002
Inner London	-0.014	-0.009	-0.005
Outer London	-0.024	-0.016	-0.009
Rest of England	-0.185	-0.121	-0.071
UK	-0.253	-0.165	-0.096

* Central population scenario range

4.4 EFFECTS OF SHORT TERM EXPOSURE TO PARTICLES ON RESPIRATORY HOSPITAL ADMISSIONS

The effects of short-term exposure are calculated on the basis of change in population weighted mean TEOM concentrations shown in Table 4.1. Table 4.4 shows that a 0.690 µg/m^3 reduction in particles in the UK is predicted to lead to 298 fewer respiratory hospital admissions in 2010 and 30100 fewer respiratory hospital admissions over the 101 years from 2010 to 2110. It is unclear whether the respiratory hospital admissions represent additional admissions or hospital admissions occurring at a different time. It should be noted that the studies on which these calculations are based do not distinguish one person being admitted to hospital several times from several different people being admitted to hospital. As with the long-term effects, the results in inner and outer London are greater than expected purely on the basis of the size of their populations.

Table 4.4: Changes in respiratory hospital admissions (additional or brought forward) in 2010 and from 2010 to 2110. Based on the changes in TEOM particle concentrations from Table 4.5 (illustrative package of measures scenario).

	2010	from 2010 to 2110
Scotland	-15	-1540
Wales	-14	-1380
Northern Ireland	-6	-613
Inner London	-16	-1650
Outer London	-29	-2900
Rest of England	-218	-22100
UK	-298	-30100

The figures in the report have been presented to 3 significant figures but the calculations retained all significant figures in the intermediate stages and only rounded at the end. This is why the figures in the right hand column of this Table are not exactly 101 times the figures in the left hand column.

4.5 EFFECTS OF SHORT TERM EXPOSURE TO SULPHUR DIOXIDE ON MORTALITY AND RESPIRATORY HOSPITAL ADMISSIONS

Several of the measures to reduce particles also reduce other pollutants. The reductions in sulphur dioxide are predicted to have the following benefits listed in Table 4.5. (Nitrogen dioxide is considered later with the sensitivity analysis).

Table 4.5: Changes in numbers of deaths brought forward and respiratory hospital admissions in 2010 for the illustrative package of measures scenario for SO_2.

	Deaths brought forward: SO_2	**Respiratory Hospital admissions: SO_2**
Scotland	-2	-2
Wales	-1	-1
Northern Ireland	-6	-5
Inner London	-1	-1
Outer London	-2	-1
Rest of England	-35	-27
UK	-48	-36

Not surprisingly, as the measures are designed to reduce particles, the reductions are not as great as for particles (see table 4.4). Over 101 years, in the UK, these reductions would be 4820 deaths brought forward and 3690 respiratory hospital admissions.

4.6 LONG TERM EFFECTS FOR TRANSPORT AND STATIONARYSOURCE MEASURES CONSIDERED SEPARATELY

Table 4.6 shows the reduction in population-weighted mean PM_{10} concentration, relative to the baseline in 2010, for the transport and stationary measures separately (see section 4.2 and the AQS consultation document (DEFRA et al, 2001) and the IGCB report (DEFRA, 2001).

Table 4.6 The changes in UK population-weighted mean background PM_{10} concentrations in 2010 for the components of the illustrative package of measures scenario, relative to the baseline (mgm^{-3}, gravimetric) 1996 to 1999 base years and implied change in millions of life years gained (population 2, discounted, hazard rate reduction 0.1% per µg/m^3 $PM_{2.5}$)

Sector	Change in PM_{10} (µg/m^3 population weighted mean)	Effect starts 2010	Effect starts 2030	Effect starts 2050
Stationary source measures	-0.620	-0.175	-0.114	-0.067
Road transport measures	-0.277	-0.078	-0.051	-0.030
Total	-0.897	-0.253	-0.165	-0.096

These calculations illustrate that the stationary source measures contribute more to the population weighted annual mean than the road transport measures. The benefits scale according to the differences in population weighted mean change in concentration i.e. omitting the road transport measures would reduce the benefits as well as the population weighted mean reduction in concentration by 25%. Ambient concentrations are, however, greater at the roadside than at background locations and measures to reduce emissions from road traffic are clearly more directly targeted at reducing these. The traffic measures would therefore be more effective at reducing roadside concentrations in London than the stationary source measures (see DEFRA et al 2001, Stedman et al 2001b, Stedman et al, 2001c). While the change in population-weighted mean background concentrations is directly linked to the quantifiable health benefits, it will not encompass all possible benefits of measures to reduce particle concentrations.

5 Results From Sensitivity Analyses

5.1 INTRODUCTION

The sensitivity analyses discussed below include some different populations and lengths of follow up, different reductions in mortality rate for the long term effects and some different health effects.

5.2 EFFECT OF USING DIFFERENT POPULATION SCENARIOS

As discussed in section 3.1, calculations have also been done for the population alive in 2010 followed up to 2110 without including people born after 2010 (population 1) and for the population alive in 2010 followed up to only 2020 (population 3). The results are listed in Table 5.1.

Table 5.1: Implied change in life years (millions) for the UK population, Illustrative package of measures scenario (0.1% reduction in hazard rate per µg/m^3 $PM_{2.5}$)

Population	discounted ?	followed until	Effect starts 2010	Effect starts 2030	Effect starts 2050
Population 1		2110	-0.468	-0.334	-0.194
	discounted	2110	-0.219	-0.133	-0.064
Population 2		2110	-0.607	-0.474	-0.332
	discounted	2110	-0.253	-0.165	-0.096
Population 3		2020	-0.027	0	0
	discounted	2020	-0.021	0	0

* Central population scenario range
Population 1 is population alive in 2000 plus cohorts born up to 2010 inclusive
Population 2 is population alive in 2000 plus cohorts born up to 2110 inclusive
Population 3 is population alive in 2000

As expected this shows that there are fewer life years gained for population 1 than population 2 as it omits the new cohorts. The decrease is of about 32,000 to 34,000 life years (13 to 33%) depending on lagtime. (For the longer lagtime, the omission of new cohorts is more important because the population who were alive in 2010 form a lower proportion of the total population in later years). The results for population 3 are even smaller (by 92 to 100%) due to the short length of follow up.

The population scenarios chosen assumed the pollutant reduction occurred in one step in 2010 for simplicity. However, it is likely that the pollutant reduction will in fact come on gradually between 2000 and 2010. The results for population 3 (full pollutant reduction for 11 years from 2010 to 2020) can be used to give an upper bound for the effect omitted by ignoring a gradual reduction from 2000 to 2010. If the full reduction had occurred in 2000 (an extra 10 years), the undiscounted additional gain in life years would have been similar to that for population 3. This is 0 – 4.5% of the total answer for population 2. In fact, a linear reduction from 2000 to 2010 would probably give an answer of less than half of this (results are not linear with length of time at a particular pollutant level). In other words, ignoring the gradual reduction from 2000 to 2010, results in an underestimate of around 2% or less.

5.3 EFFECT OF DIFFERENT REDUCTIONS IN MORTALITY RATES

Table 5.2 shows the effect of the different reductions in mortality rate discussed by COMEAP. The reduction in mortality rate due to the reduction in short term effects alone is not included in the table but is discussed below.

Table 5.2: Implied change in life years (millions) for the UK population for different reductions in hazard rate (population 2, discounted, illustrative package of measures scenario)			
Reduction in hazard rate % per $\mu g/m^3$ $PM_{2.5}$ + COMEAP comment	**Effect starts in 2010**	**Effect starts in 2030**	**Effect starts in 2050**
0.1 'most likely'	-0.253	-0.165	-0.096
0.3 'reasonably likely'	-0.758	-0.496	-0.289
0.6 'less likely'	-1.520	-0.993	-0.579
0.9 'implausibly large'	-2.280	-1.490	-0.868

* Central population scenario range

These results scale in proportion to the change in hazard rate. Expressed as a percentage increase, the results are increased by 200%, 500% and 800% depending on the chosen reduction in mortality rate.

COMEAP considered it was possible, although unlikely, that there were no long term effects and that this possibility should be included in sensitivity analysis. The COMEAP comment on an estimate based on the short term effects alone was that the estimate was 'highly likely to be at least this large'. An estimate of gain in life expectancy based on the short term effects alone is discussed below starting with an estimate of the reduced numbers of deaths brought forward (Table 5.3).

Table 5.3 Changes in numbers of deaths brought forward in 2010 and from 2010 to 2110 for the illustrative package of measures scenario (population 2) Based on changes in TEOM concentrations from Table 4.2		
	Deaths brought forward in 2010	**Deaths brought forward 2010 to 2110**
Scotland	-16	-1570
Wales	-14	-141
Northern Ireland	-6	-626
Inner London	-17	-1690
Outer London	-29	-2960
Rest of England	-223	-22500
UK	-305	-30800

These results are then multiplied by an assumed loss of life expectancy per death brought forward of 2 to 6 months to give the results listed in Table 5.4.

Table 5.4 Implied change in millions of life years for the UK and regional population for acute effects only over the 101 years from 2010 to 2110, illustrative package of measures scenario (assuming loss of life expectancy between 2 months and 6 months per death brought forward) (population 2).

	2 months	6 months
Scotland	-0.00026	-0.00079
Wales	-0.00023	-0.00070
Northern Ireland	-0.00010	-0.00031
Inner London	-0.00028	-0.00084
Outer London	-0.00049	-0.00148
Rest of England	-0.00375	-0.01126
UK	-0.00513	-0.01538

So if there were no long term effects, there would be an estimated reduction of 30,800 deaths brought forward over 101 years in the UK with a gain of approximately 5,100 to 15,400 life years for the population. This compares with 332,000 to 607,000 life years gained if there are long term effects (using a 0.1% reduction in mortality rate per $\mu g/m^3$ $PM_{2.5}$), an increase of between 22 and 120 fold. This can also be expressed as a decrease of 95 to 99% as a result of omitting the long term effects.

For population 3 (follow up from 2010 to 2020), the estimated reduction in deaths brought forward from the short term effects for the UK would be 305 x 11 = 3350. For a loss of life expectancy of 2 to 6 months, this would be a gain in life years of 560 to 1680. This compares with an estimate of 0 to 2400 life years for the long term effects. So the figure for the long term effects could actually be lower. This is because the long term effects take time to build up. The reduction in mortality rate is only applied to those over 30 (the original studies did not examine the effect in those under 30) and it is possible that there is a lagtime of more than 11 years before the effect occurs. Therefore, the whole population is not experiencing the benefit in the first 11 years.

5.4 EFFECT OF ADDING OTHER HEALTH EFFECTS – CARDIOVASCULAR HOSPITAL ADMISSIONS

As discussed earlier, particles are also thought to have an effect on cardiovascular admissions. The influence of adding this effect is shown in Table 5.5 below. The estimates for deaths brought forward and respiratory hospital admissions are repeated for the sake of comparison.

Table 5.5 Changes in numbers of cardiovascular hospital admissions and other outcomes in 2010 for the illustrative package of measures scenario for PM_{10}. Based on changes in TEOM concentrations from Table 4.2

	Deaths brought forward	Respiratory Hospital admissions	Cardiovascular Hospital admissions*
Scotland	-16	-15	-9
Wales	-14	-14	-8
Northern Ireland	-6	-6	-4
Inner London	-17	-16	-10
Outer London	-29	-29	-17
Rest of England	-223	-218	-128
UK	-305	-298	-174

* sensitivity analysis

The reduction in cardiovascular admissions is of a similar order to the effect on respiratory hospital admissions but a little smaller. Over the period 2010 to 2110, a reduction of 17,600 cardiovascular admissions can be estimated.

5.5 EFFECT OF ADDING REDUCTIONS IN OTHER POLLUTANTS (NITROGEN DIOXIDE)

Several of the measures to reduce particles also reduce other pollutants. The reductions in nitrogen dioxide are predicted to have the benefits listed in Table 5.6. Note that only the traffic measures have been included in this analysis. The reductions in UK NOx emissions implied by the illustrative package of measures to reduce particle concentrations in 2010 are approximately 23 ktonnes from road traffic and approximately 16 ktonnes from the refineries sector (out of a UK total for NOx emissions in 2010 of more than 1000 ktonnes). The impact of the reduction in road traffic emissions has been modelled since a significant proportion these emission reductions will take place in population centres and therefore strongly influence population weighted mean concentrations. Reductions in NOx emissions from the refinery sector are, however expected to have a relatively minor impact on the population weighted mean of background NO_2 concentrations and this impact has therefore not been modelled.

Table 5.6: Changes in numbers of respiratory hospital admissions in 2010 for the traffic measures component of the illustrative package of measures scenario for NO_2.	
	Respiratory Hospital admissions: NO_2*
Scotland	-11
Wales	-5
Northern Ireland	-3
Inner London	-17
Outer London	-27
Rest of England	-109
UK	-171

* sensitivity analysis

Over 101 years, in the UK, the reduction would be 17,300. Not surprisingly, as the measures are designed to reduce particles, the reductions are not as great as for particles (see Table 4.4).

5.6 EFFECT OF OTHER FACTORS INFLUENCING THE ESTIMATE OF REDUCTION IN PARTICLE CONCENTRATIONS

We have undertaken sensitivity analyses to investigate the likely upper bound of uncertainty in the more important input parameters in the air quality prediction models and the impact of these input parameters on the predicted baseline concentration in 2010 or the effectiveness of measures to reduce it. It is the latter that is important for the assessment of the health benefits of the additional measures.

Table 5.7 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 (Stedman, et al 2001c). This analysis was carried out using the site-specific projection models, rather than the mapping models used to estimate the changes in population weighted mean concentrations used to estimate the health benefits. Full details of the site-specific models and sensitivity analyses results are provided in the baseline report (Stedman et al, 2001c). The site-specific analysis is primarily based on city centre locations. Mean concentration in 2010 (averaged over the 4 base years) are about 20 μgm^{-3}, gravimetric at background sites and 22 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 5.7 Various sensitivity analyses for the predicted reduction in PM_{10} concentration (based on site specific analysis)		
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

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.

The changes in the table above probably overestimate the changes in population weighted mean. Although the changes cannot be compared directly with the population weighted mean, the changes are probably in the region of 10 or 20%.

5.7 EFFECT OF FURTHER DECLINES IN PM_{10} BEYOND 2010

PM_{10} concentrations have been assumed to drop in 2010 and then stay the same until 2110. PM_{10} concentrations will, however, continue to decline beyond 2010 due to the additional measures within the illustrative scenario, especially the particulate traps measure, which is predicted to reduce traffic emissions by 22% in 2010, 45% in 2015 and 56% in 2020, relative to the baseline. A sensitivity analysis on the long term health benefits of the package of measures, in which concentrations were assumed to reduce to the 2015 levels for the illustrative package of measures in 2010 and remain until 2110, was therefore performed. (Strictly, a lifetable should be run with a step reduction in 2010 and a further step reduction in 2015 but a combined reduction in 2010 is not expected to differ much compared with the overall time period of 100 years). This leads to an estimate of chronic health benefits approximately 4% higher than for the calculations based on the expected reduction of 0.897 $\mu g/m^3$ in 2010.

5.8 PM10, UV AND SKIN CANCER

Some exploratory work has been done looking at the predicted small increase in levels of UV (Ultra Violet radiation) if particle levels are reduced and the possible size of a resultant increase in skin cancer. This is not sufficiently developed to use in this cost benefit analysis, even as a sensitivity analysis but is an illustration of the fact that the health effects of policies to reduce pollution may not always be beneficial for every outcome.

The United Kingdom UVB Measurements and Impact Review Group report 'The potential effects of ozone depletion in the UK' (DoE,1996) gives an estimate of 12,000 per year extra cases of basal cell carcinoma in the UK for a 14 % increase in UVB exposure. This can be compared with an estimated range of possible increases in UK UVB exposure for a 10 μgm^{-3} decrease in PM_{10} of approximately 2.5 to 5 % derived from numerical modelling of the impact of boundary layer particles on UV exposure (Hayman, 1998 and Hayman et al, 1998). A decrease in population-weighted mean PM_{10} concentration of 0.897 μgm^{-3} can therefore be estimated to lead to a possible increase in cases of basal cell carcinoma in the UK of between 190 and 380 per year. It is important to note, however, that population exposure to UV is much more strongly influenced by behaviour patterns and clothing habits than small changes in UV radiation.

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