Chapter 10

Conclusions and recommendations

1004. In summarising current understanding and answering the questions posed by Defra, it has become apparent that further work should be instigated to assist in any future policy analyses on suspended particulate matter. These activities are outlined in this chapter in the form of some concluding statements, followed by recommendations for further monitoring and research activities. Whilst there is no question that basic scientific research in this area would be helpful, this would not necessarily improve understanding of the underpinning processes on a timescale that would be useful to Defra's immediate policy requirements. The activities described below, therefore, largely focus on monitoring because in the short term this offers significant opportunities to improve understanding in national terms without unduly focusing on specific pollution episodes, field campaigns or localized issues. In formulating this chapter, AQEG has adopted a pollutant-by-pollutant or component-by-component approach rather than a process-based approach dealing with sources, emissions, dispersion, transformations and removal processes.

1005. The Air Quality Expert Group took the view that unless mass closure could be achieved between the particulate matter (PM) components and $PM_{2.5}$ and PM_{10} mass, it would be difficult to assess the causes of exceedence and the appropriate remedial measures. Hence, each of the main PM components is discussed in turn, before PM_{10} and $PM_{2.5}$, and before turning to research and monitoring requirements.

10.1 Particulate sulphate

1006. Particulate sulphate makes a substantial contribution to the regional background PM levels upon which urban, roadside and kerbside increments are built. There is no evidence for any urban or traffic enhancement of particulate sulphate levels. Rural particulate sulphate concentrations have declined steadily since measurements began in 1977, although between 2000 and 2003 levels have risen slightly. Particulate sulphate levels have not declined as rapidly as rural SO_2 levels or SO_2 emissions. There has, therefore, been a steady increase in the fraction of airborne sulphur species present as particulate, reflecting an increase in the oxidising capacity of the atmosphere with time.

1007. There is a need to understand the relationship between particulate sulphate trends and SO_2 emissions and to build confidence in the regional model assessments of future particulate sulphate concentrations under the influence of the UNECE Gothenburg Protocol and the EU National Emissions Ceilings Directive.

1008. **It is recommended that continuously recording instruments for particulate sulphate are deployed because we currently have no understanding of the behaviour of particulate sulphate concentrations in PM pollution episodes and their coupling with ammonia and particulate nitrate levels.** Without this understanding, it will be difficult to develop robust strategies for the reduction of the regional background PM levels upon which urban, roadside and kerbside levels are superimposed.

10.2 Particulate nitrate

1009. Particulate nitrate makes a substantial contribution to the regional background PM levels upon which urban, roadside and kerbside levels are superimposed. Because of the marked downwards trends in rural sulphate levels, particulate nitrate now makes up the largest component of regional background levels. There is some evidence for urban enhancement of particulate nitrate levels. Particulate nitrate has never been monitored satisfactorily in terms of spatial coverage, time resolution or by methods that are artefact-free. It is present in the atmosphere as fine mode ammonium nitrate and coarse mode sodium and calcium nitrates. There is inadequate information on the split between these forms on an hourly, daily and seasonal basis. Furthermore, we have no quantitative information on how the different forms of particulate nitrate are detected by the different PM_{10} and $PM_{2.5}$ monitors deployed in the UK. Currently, the monitoring base for particulate nitrate is so unsatisfactory that robust policy formulation for particulate nitrate is difficult.

1010. Continuous monitoring of particulate nitrate is currently carried out at two locations in the UK, but this is wholly unsatisfactory in terms of spatial coverage. In addition, continuous measurements of nitrate in the coarse particle fraction are not undertaken. **It is recommended that additional continuously recording nitrate monitors are deployed to understand the phenomenology of nitrate episodes, to understand their correlation with sulphate and PM episodes, to identify the extent of any urban enhancement in nitrate levels and to validate the models used to estimate future trends in regional particulate nitrate levels though to 2010 in response to the UNECE Gothenburg Protocol and the EU National Emissions Ceilings Directive. Measurements should be carried out in both the PM_{coarse} and $PM_{2.5}$ fractions.**

10.3 Elemental or black carbon

1011. Elemental or black carbon emissions arise mainly from diesel vehicles in urban areas and represent the component of primary PM emissions in which we have the greatest confidence. Elemental carbon is one of the few PM components for which there is a discernible urban increment. The indications are that urban elemental carbon levels have been declining steadily as coal burning has been phased out. Monitoring of elemental carbon on a continuous basis is currently carried out at four sites in the UK, but this is inadequate for policy assessment and development purposes. **It is recommended that the current monitoring regime be expanded and that additional continuous monitors are deployed at urban background, kerbside and roadside sites.**

1012. Elemental carbon emissions are projected to decline further as diesel exhaust emission controls are introduced. **It is recommended that continuous monitoring of elemental carbon is carried out at urban, roadside and kerbside locations to check that the new diesel vehicle emission standards are having the desired effect in the UK. It is recommended that traffic increment studies are repeated with continuously recording elemental carbon monitors to enable a robust test of the emission inventories to be completed.**

10.4 Organic carbon

1013. Monitoring of organic carbon on a continuous basis is currently carried out at four UK sites, but this is inadequate for policy assessment and development purposes and scientific understanding of this important PM component is rudimentary. Particulate organic carbon is important for policy because it is one of the few PM components for which there is evidence of a demonstrable urban enhancement above regional background levels. Particulate organic carbon is present in the urban environment either as primary or secondary material. The main source of primary emitted particulate organic carbon in urban areas is diesel traffic and includes semi-volatile organic compounds derived from diesel fuels and lubricants that attach themselves to pre-existing particles. At rural locations, secondary particulate organic carbon dominates primary particulate organic carbon, particularly during summertime. Photochemical reactions oxidise natural biogenic and manmade organic compounds to low volatility species that can condense on pre-existing particles. Secondary particulate organic carbon makes a substantial contribution to regional PM levels during summertime.

1014. **It is recommended that continuously recording organic carbon monitors are deployed at urban background locations without delay.** Furthermore, these instruments should be employed in studies of urban, roadside and kerbside increments to validate emissions inventory estimates of the emissions of semi-volatile species from diesel fuels and lubricants.

1015. **It is recommended that the contribution from secondary organic carbon to regional PM background levels be determined.** It will be important to separate the contributions from the oxidation of terpenes of natural biogenic origins from that from the oxidation of aromatic compounds of man-made origins. Currently, there is no understanding of how concentrations of secondary organic carbon particulates vary across the UK and during summertime regional pollution episodes. Furthermore, there is no understanding of how these levels might change in the future and whether they will be influenced by the implementation of the UNECE Gothenburg Protocol and the EU National Emission Ceilings Directive.

10.5 PM_{10}

1016. Urban background PM_{10} concentrations have shown a steady decline during the 1990s, but during 2000 to 2003 these downwards trends have slowed up and some sites have shown an increase. The current PM_{10} monitoring network is an important European asset and should be maintained in its current state to follow trends through to 2010. **An increase in rural PM_{10} monitoring is recommended for determining urban increments, for the quantification of regional PM_{10} background levels and for the characterisation of PM_{10} episodes, when co-located with ozone monitors.** Further rural PM_{10} monitoring would also improve the performance of urban dispersion modelling and local authority air quality assessments.

1017. A detailed evaluation exercise to compare the performance of a variety of PM_{10} samplers and analysers commenced in 2004. **Upon completion of this exercise it is recommended that the current default USEPA adjustment factor applied to TEOM PM_{10} data be reviewed and, if appropriate, all data**

within the UK Air Quality Information Archive be rescaled. Of additional concern are the potential losses of semi-volatile nitrate and organic species from measurements in the existing UK network. **It is also recommended that either a continuous method of monitoring PM_{10} that is not subject to losses of semi-volatile species and positive artefacts be identified or that routine measurements be carried out for the 'core particulate' mass, with additional monitoring to quantify the semi-volatile components.**

10.6 $PM_{2.5}$

1018. There is currently an inadequate level of co-located $PM_{2.5}$ and PM_{10} monitoring in urban background and rural sites for policy assessment purposes. **Further rural $PM_{2.5}$ monitoring is recommended to assist in the characterisation of regional $PM_{2.5}$ background levels, the quantification of urban increments and the characterisation of $PM_{2.5}$ episodes.**

1019. A detailed evaluation exercise to compare the performance of a variety of $PM_{2.5}$ samplers and analysers commenced in 2004. **Upon completion of this exercise it is recommended that the current default USEPA adjustment factor applied to TEOM $PM_{2.5}$ data be reviewed and, if appropriate, all data within the UK Air Quality Information Archive be rescaled.**
Of additional concern, as with PM_{10}, are the potential losses of semi-volatile nitrate and organic species from measurements in the existing UK network.
It is also recommended that either a continuous method of monitoring $PM_{2.5}$ that is not subject to losses of semi-volatile species and positive artefacts be identified or that routine measurements be carried out for the 'core particulate' mass, with additional monitoring to quantify the semi-volatile components.

10.7 Ultrafine particles

1020. Although laboratory toxicological studies show ultrafine particles to be more toxic per unit of mass than coarser particles, the proportion of PM_{10} mass comprised by ultrafine particles is very small and the contribution of ultrafine particles to adverse health outcomes is currently not well quantified. Atmospheric measurements of ultrafine particles show clear evidence for two types of sources: formation from road traffic emissions and new particle formation in rural areas through homogeneous nucleation. The magnitude of both sources is critically dependent on pre-existing atmospheric particle loadings and upon meteorological factors. Given the highly variable nature of these formation processes and the uncertainties regarding both the contribution of ultrafine particles and the relative influences of particle size and composition in eliciting adverse health effects, it would not be appropriate at the current time to envisage formulating an air quality standard in relation to the mass or number concentration of ultrafine particles alone.

10.8 Particulate iron

1021. Particulate iron is a valuable tracer for non-exhaust particulate emissions. **It is recommended that daily monitoring of particulate iron is begun with a view to establishing whether the Site-specific Receptor and Forecast Model employed by Defra for its policy assessment could be extended to**

include a daily assessment of non-exhaust traffic emissions using particulate iron as a tracer. Furthermore, daily kerbside and roadside monitoring of particulate iron may dramatically improve our understanding of the impact of non-exhaust traffic emissions on air quality in the vicinity of roads and highways away from industrial sources.

10.9 Natural PM sources

1022. A number of natural PM sources have been identified in this report that make a substantial contribution to hourly and daily PM levels. These include sea salts, wind-driven resuspension of crustal material, Saharan dusts, forest fires and secondary particulate organic carbon from terpene-oxidation. These natural sources have produced elevations to both PM_{10} and $PM_{2.5}$ levels and their presence has been inferred by meteorological and air quality data analysis. No attempt has been made to assess their overall significance on a regional or national basis. Generally speaking, those episodes have been analysed that gave the highest concentrations and smaller episodes have been lost in the PM background.

1023. A more considered analysis of natural PM sources could be made by linking together the Defra PM Air Quality Forecast Model to the rural and suburban PM network observations. Natural PM episodes would appear as periods and regions of systematic model underestimation. Coupling together a forecast model with a real-time network with some form of data assimilation scheme would allow a rigorous determination to be made of the magnitudes of natural PM sources on a regional and national basis.

10.10 Other manmade sources

1024. A number of manmade sources of PM components have been identified in this report for which well-tried emission inventory approaches may not be appropriate because of the lack of statistical data. These include bonfire nights, construction and demolition, open burning of garden waste, agricultural waste burning, wood burning stoves and fires and fugitive emissions from industrial plant, refuse handling and quarrying, some of which are episodic.

1025. Again, a more considered analysis of these man-made sources could be made by linking together the Defra Urban PM Air Quality Forecast Model with urban PM monitoring data. The presence of these other manmade sources would be indicated by systematic model underestimation at particular times and locations. Coupling together a forecast model with a real-time network with some form of data assimilation scheme would allow a rigorous determination to be made of the magnitudes of these other manmade sources of urban PM.

10.11 Ozone and PM air quality

1026. Although it is generally understood that in the summertime there is a strong link between ozone and PM air quality, rural PM monitoring has been inadequate to quantify the link with any accuracy. Furthermore, it is not straightforward to quantify how summertime PM concentrations might respond in the future to the implementation of the UNECE Gothenburg Protocol and the EU National Emissions Ceilings Directive and whether they might decline in line with

summertime ozone levels. Although modelling tools are available to address these questions, the rural PM monitoring base has been insufficient to validate model performance for particulate sulphate and nitrate. **It is recommended that continuous monitoring of particulate sulphate is begun at a rural ozone monitoring site (alongside existing particulate nitrate, PM_{10} and $PM_{2.5}$ measurements) with a view to validating photochemical model performance during summertime PM and ozone episodes.**

1027. Measurements of continuous elemental/organic carbon at this rural site should be used to quantify the contribution from secondary organic aerosol to regional background PM levels. Currently, we have little understanding of whether there are episodes in particulate organic carbon and, if they do occur, whether these episodes correlate with ozone and PM episodes. Air mass attribution may help to determine whether the likely precursors to secondary organic aerosols are manmade or natural biogenic sources.

10.12 Projected exceedences of future air quality targets based on the Site-specific Receptor and Projections Model

1028. The Site-specific Receptor and Projections Model has been able to account for the observed trends in PM_{10} levels at 16 urban background and kerbside sites during the period up to 2002 and has been used to assist Defra in the formulation of its strategy on future urban air quality. Its projections to 2010 point to the conclusion that it is unlikely that target air quality in terms of annual mean PM_{10} levels will be achieved on current policies at the selected urban background and kerbside locations. These projections take into account proposed controls to diesel exhaust emissions for cars and heavy goods vehicles and agreed reductions in secondary inorganic particulates through the implementation of the UNECE Gothenburg Protocol and the EU National Emissions Ceilings Directive. For air quality objectives and indicative limit values to be reached in 2010, then PM_{10} levels would need to decline at rates significantly higher than their historic rates at urban background sites and this does not appear plausible.

1029. **In view of the importance of this conclusion concerning the future exceedence of air quality objectives and indicative limit values, it is recommended that the Site-specific Receptor and Projections Model be extended and improved and these conclusions revisited.** Improvements should be made to the treatment of coarse particles and an approach adopted to the inclusion of a manmade coarse particles due to non-exhaust traffic emissions using daily measurements of particulate iron. Specific terms in the model should be included based on continuous measurements of particulate sulphate and particulate nitrate, elemental carbon and organic carbon.

10.13 Projected exceedences of future air quality targets based on dispersion modelling

1030. Dispersion models have been utilised to describe the fine scale distribution of PM concentrations across major conurbations and the increment in PM due to traffic. These models show that PM air quality on a large number of major road links will continue to exceed objectives and indicative limit values beyond 2010 on current policies.

1031. In view of the importance of these conclusions for policy, a number of improvements in these models are appropriate so that their robustness can be checked. Urban background monitoring of elemental and organic carbon would provide a more convincing test of model performance. Furthermore, urban monitoring of indicator species for coarse particulates could also provide a further test of model performance.

10.14 Local air quality management

1032. The UK has developed a sophisticated system of local air quality management. This is well suited to identifying local hotspots that are not necessarily identified through national studies. Air quality management areas have been established by 59 local authorities. These are areas where exceedences of the 2004 objectives for PM_{10} are likely. The majority of these are for traffic sources, but there are also air quality management areas for industrial, commercial and domestic sources of PM_{10}. The action plans being developed by the local authorities will help ensure that concentrations are driven down in these areas, but it is difficult to predict by how much conditions will be improved. As these measures will be focussed on local hotspots they will probably only make a marginal contribution to the wider reduction in PM emissions. The exception to this might be in London and other major conurbations, where many local authorities are working together to develop wider scale plans, for example, the low emission zone initiative being developed in London.

10.15 Future PM policy development

1033. In principle, future PM policy development can involve either/both the management of peak urban PM concentrations at hotspots or management of the regional PM background levels upon which urban, roadside and kerbside increments are built. Both policies have major uncertainties.

1034. Road traffic, especially heavy duty diesel traffic, produces three particular forms of PM pollution: elemental carbon from exhaust emissions, semi-volatile organic carbon from diesel fuels and lubricants and non-exhaust material. **Current emission inventories do not characterise the emissions of these three PM components with sufficient accuracy for urban PM policy development purposes and validation studies are recommended at roadside and kerbside sites.** Without these important inventory validation studies, it will be difficult to say with any certainty what the appropriate balance should be between controls to diesel exhaust emissions, fuels and lubricants and traffic management to meet future target air quality in any given situation.

1035. Management of future regional PM background levels appears to be an attractive policy option for the control of future exceedences of target PM air quality because it operates city-wide and does not require detailed understanding of the spatial distribution of PM exceedences. SO_2 emissions have been falling, both in the UK and in the rest of Europe, significantly faster than ammonia emissions. This has had the result that, with the increased availability of ammonia, there has been possibly an increasing formation of ammonium nitrate during the wintertime. This may be the explanation of why particulate nitrate has taken over from particulate sulphate as the most important PM component in the regional PM background. With the UNECE Gothenburg Protocol and the EU National Emissions Ceilings

Directive, the trend of SO_2 emissions reducing faster than NH_3 emissions will continue. This makes the assessment of future particulate nitrate concentrations and regional PM background levels difficult. Without studies of regional PM pollution episodes with continuous monitors for particulate sulphate, particulate nitrate, PM_{10} and $PM_{2.5}$ at rural sites, it will be difficult to assess future regional PM background levels with any certainty. Further attention should be given to the cost and feasibility of reductions in NH^3 emissions from agriculture in the renegotiation of the UNECE Gothenburg Protocol and the EU National Emissions Ceilings Directive.

10.16 Summary of research recommendations

1036. Research requirements have been identified in the following areas.

1037. Development of a better understanding of non-exhaust traffic emissions , including:

a. measurement of the particle size distributions of brake wear, tyre wear and road dust resuspension;

b. investigation into the distinct chemical signatures of particles from brake wear, tyre wear and road dust resuspension, which may allow them to be identified and quantified; and

c. assessment of factors such as driving mode, vehicle weight and speed and heavy acceleration and braking, which are likely to influence emissions of non-exhaust particles from vehicles.

1038. The provision of robust PM emissions factors, using UK sources, suitable for use in inventories and dispersion models. Specific emissions categories identified as of high priority include the following:

a. emissions of particulate matter from construction, mining and quarrying;

b. primary PM emissions from natural gas combustion;

c. primary PM from coal combustion;

d. PM emissions and abatement from industry;

e. effect of fuel quality on PM emissions from combustion of liquid fuels; and

f. non-road mechanical machinery.

1039. Improvements to and refinement of the current model for source apportionment of PM in the UK including work on:

a. multivariate receptor modelling statistical methods applied to multi-element datasets;

b. the use of molecular source tracers;

c. single particle techniques such as aerosol mass spectrometry; and

d. isotope ratio techniques.

1040. The provision of particulate matter monitoring and characterisation data to support epidemiological studies.

1041. Development of state-of-the art comprehensive aerosol models capable of handling particle size distributions and detailed chemistry for the UK.

1042. Development of models for the coarse component both from the urban background, for example from construction sites and from traffic, both direct and non-exhaust emissions.

1043. Improved modelling and understanding of the impacts of road characteristics, including traffic induced turbulence, vehicle exhaust height and urban topography. These will both increase confidence of the road type adjustment factors and improve the reliability of dispersion models adjacent to roads.

1044. Further modelling of $PM_{2.5}$ should also be conducted in anticipation of new air quality standards. However, reliable model validation will require appropriate resolution of the difference between the different measurement techniques (for example, stipulation of appropriate conversion factors) .

10.17 Summary

1045. The Air Quality Expert Group appreciates the efforts made by Defra in establishing a comprehensive network of continuous PM monitoring. This network has shown that despite a decade of decreasing PM levels during the 1990s, problems still remain and future air quality targets for PM will not be met on current policies. It recognises that it will be difficult to build a robust strategy of future PM based on $PM_{2.5}$ and PM_{10} monitoring alone. **It recommends that in the next phase of PM monitoring, Defra establishes a comprehensive network for individual PM components based as far as possible on continuously recording monitors and co-located with existing monitoring activities.**

1046. Recommendations for how the existing monitoring network should be expanded are set out above and are summarised in Table 10.1.

1047. The Air Quality Expert Group is strongly of the view that unless and until mass closure can be achieved between PM components and PM_{10} and $PM_{2.5}$ mass, quantitative policy assessment will be compromised by uncertainty in basic understanding.

1048. The Air Quality Expert Group requests the opportunity to revisit the question of future PM policy when the continuous monitoring of PM components is in place. **It recommends that consideration is given to a more flexible and holistic approach to urban air quality management and to the control of acid rain, eutrophication and ground-level ozone.** Such approaches might deliver a more cost-effective solution to future PM air quality than that based on PM alone.

Table 10.1 Summary of monitoring recommendations.

Measurement	Recommendation
Continuous $PM_{2.5}$ nitrate	Expand existing network to provide paired urban background/rural data at four locations throughout the UK including London.
Continuous PM_{coarse} nitrate	Expand existing network to include measurements at the four urban background/rural locations identified above.
Continuous elemental and organic carbon	Expand existing network to provide paired roadside/urban background data at four locations throughout the UK including London.
Continuous $PM_{2.5}$ sulphate	Expand existing network to provide paired urban background/rural data at four locations throughout the UK including London.
Daily iron concentrations (PM_{10})	Expand existing network to include all Defra Site-Specific Receptor Model sites.