Knowledge Transfer Proposal from the Lancaster Environment Centre: The Case for Support

DEMONSTRATING TECHNIQUES FOR AIR-POLLUTION-SOURCE PERFORMANCE ASSESSMENT

1. Introduction

Measurements of ambient air-quality have been made routinely in the UK for many decades. The number of measurements has expanded substantially in the past decade following the implementation of the National Air Quality Strategy [1]. This has increased the number of pollutants and sites measured, and the number of local meteorological records taken to help interpret the air-quality data (mainly of wind speed and direction). It has also fostered a new community of air-quality practitioners with their own professional body, the Institute of Air Quality Management.

The collected air-quality data are generally used to check if the local pollution climate complies with air-quality standards. For this purpose they are summarised as annual statistics e.g. as annual-average concentrations, or as the total hours per year exceeding a designated concentration value. Although such summary statistics serve to check compliance, they only use part of the information available in air-quality and meteorological data for the purpose of assessing the performance of sources and policies. In particular, they do not readily or routinely show:

(A) Changes in the contributions of different sources, activities & background amounts to ambient levels.
(B) Changes in air quality associated with particular directions, times of day, or weather conditions.
(C) If policies to reduce the impacts of specific sources are progressing according to plan.
(D) Underlying trends in air quality & source performance, after normalising for variable meteorology.
(E) How well dispersion models predict component events in summary statistics, especially peak events.
(F) Which dispersion conditions deliver peak impacts, and how these conditions vary between periods.
(G) Which directions contribute most to overall high-percentiles at a site, and so are priorities for control.
(H) The emission rates of different sources (e.g. stacks, landfills) & how they vary with time and space.
(I) How monitoring networks can be optimised to maximise the information value in measurements.

There have been several attempts to make better use of routine air-quality monitoring data for purposes like A-I i.e. for tracking the performance of individual sources and for managing air-quality more effectively. For example as long ago as 1981, a study in East Strathclyde showed how polar plots of concentration and wind speed may be used to identify individual stack sources of sulphur dioxide [2]. More recently, similar plots have been produced for studies of NO_2 around Heathrow airport [3]. Although these attempts have shown the advantages of better methods for presenting and interpreting air-quality data, these advantages have not been generally recognised or the methods transferred into regular use by practitioners. This is despite the fact that information like A-I would make for more robust, rapid and cost-effective decisions in air quality management. Such information is not only useful for managing traditional community pollutants like SO_2, PM_{10} and NO_x, but it is also needed for managing new priority pollutants like anthropogenic greenhouse gases (e.g. methane from landfills) and biogenic emissions of photochemical precursors (e.g. isoprene from vegetation).

Better information from aerometric analysis would not only benefit air-quality, but also those economic and societal activities that emit air pollutants (e.g. energy use, transport, waste disposal) or are impacted by them (e.g. human and ecosystem health). Moreover, new air-quality legislation is being drafted that will need this kind of more detailed information on emitter performance e.g. in order to reduce population exposure to “no-threshold” air pollutants like particulates that do not have “no effects” levels. Methods that use aerometric data to give information like A-I routinely are therefore useful for future air-quality applications, as well as for promoting more sustainable economic, societal, and resource-use practices.

We are proposing a knowledge transfer project that will convince air-quality practitioners of the advantages of “smarter” aerometric analysis methods that give information like A-I. We will demonstrate and advocate these advantages in a range of practical air-quality situations, so the methods are established in regular use. We will show how existing and novel techniques can be used to exploit air-quality data more fully and rigorously, and crucially how the extra information can benefit operational and policy decisions e.g. by giving earlier and clearer advice on the performance of individual sources, or on the progress of specific policies. The methods will not only enable measured concentrations to be better exploited, but will also be applied to modelled concentrations - so helping to improve prediction and management of air quality in future.

We think the best way to show that the novel aerometric analysis methods are beneficial and practical, is to apply them to case-studies involving real-life air-pollutant sources, data and management decisions. Major industrial sources provide excellent cases for developing and demonstrating such methods, as they are relatively discrete sources and are well-documented, being regulated by the Environment Agency. The Agency's teams for Air Science and Ambient Air Quality Monitoring have collaborated for several years with Lancaster University on developing air-quality analysis methods, & we will build on this experience.

The techniques we will develop around A-I for getting better information and decisions from air-quality data will apply not only to ambient measurements, but also to predictions by atmospheric dispersion models. Such models cover different distances, periods and processes - including the advection, dispersion, deposition and chemical reaction of pollutants. When comparing predictions and observations, it is important not only to check how well they agree but also that the processes underlying the predictions are correctly ascribed and reproduced i.e. to check a model "gives the right answer for the right reasons". Our techniques will allow more detailed dissection and diagnosis of model performance so that underlying processes are better audited, and so that parameterisations or data that need improving are more easily identified. Lancaster University & Agency Science have extensive experience of assessing air-quality with short-range dispersion models (e.g. ADMS) and our proposal will build on this. A recent trend is towards using larger "one-atmosphere" models to simulate multi-scaled air-pollution problems e.g. particulates that have both local primary components and regional secondary components. The Agency's Air Science team have been collaborating for several years with the University of Hertfordshire on the implementation and testing of such "one atmosphere" models in the UK e.g. USEPA's Community Multi-scale Air Quality modelling system (CMAQ). Our proposal will build on this experience of multi-scale models, as well as on our experience of local-scale models, so that better assessment methods will be available for both scales.

2. Previous and preparatory studies

The potential for exploiting air-quality data better to help with source surveillance and air-quality management is shown by recent examples of our work. These provide the foundation for our proposal to develop methods, to demonstrate them with case studies, and to disseminate them to the practitioner community. The following sections give relevant examples:

2.1 Confirmation of fuel sulphur management in power stations.

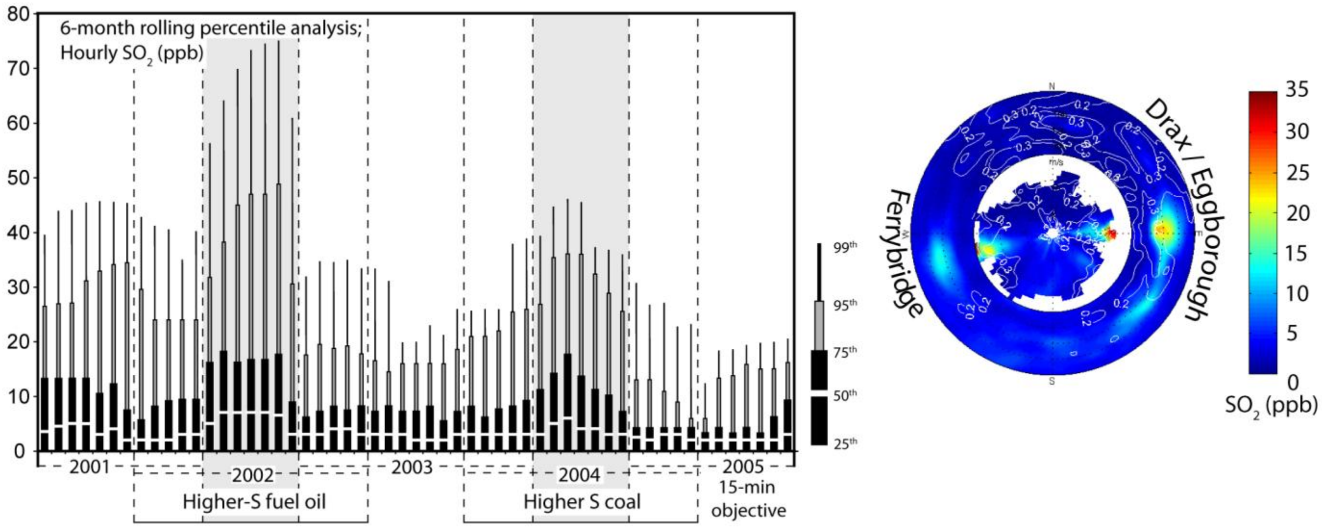


Figure 1 SO_2 normalised for dispersion and direction: Aire Valley 2001-05

Coal- and oil-fired power stations have had to progressively reduce their SO_2 emissions in recent years, ready to comply with a new ambient standard starting in 2005. Data from an SO_2 monitor lying downwind of Ferrybridge power station in North Yorkshire, have been analysed to identify dispersion conditions when the station's plume makes a readily distinguishable impact at the monitor. Concentric bi-polar plots (Figure 1) show how monitored SO_2 concentrations depended on wind speed and time-of-day, and were used to infer the particular dispersion conditions (i.e. wind speed/direction and time-of-day) during which the signal from the power station was strongest relative to other effects. The record of monitored concentrations during these conditions has been compiled, based on a 6-month rolling average (to reduce seasonal variations), as shown in Figure 1. This shows a general decline in SO_2 impacts towards 2005 ready for the new standard, although there are temporary excursions to higher SO_2 impacts that agree with separate data on the sulphur content of fuels being burnt. This shows that novel analysis of air-quality data can be used to verify the individual emissions performance of a major industrial source.

2.2 Policy analysis for primary NO_2 near an urban motorway.

In recent years, some diesel-powered vehicles have been fitted with traps to reduce particulate emissions, although these have also inadvertently increased primary NO_2 emissions. Data from a monitor near the M4 at Hillingdon have been analysed directionally and by time-of-day in order to identify when/where the signal of raised primary NO_2 from road traffic is strongest, so it can be tracked for policy purposes. Low wind speed conditions and winds between c. S and c. SW direction during the morning rush-hour (before the onset of diurnal photochemical processes), provide the best account of 'tailpipe' emissions. This signal can be normalised to a defined range of wind speeds to show emission performance more consistently, without major variations due to meteorology. Monitored NO_2 concentrations are compiled as percentiles for rolling 13-month periods and are shown in Figure 2. There is a clear onset of raised NO_2 concentrations towards the end of 2002 that is consistent with the introduction of particulate traps and with the timing of 'change-points' in primary NO_2 identified in other studies. This kind of directed and normalised source surveillance is useful for checking on the performance of specific emitters and policies.

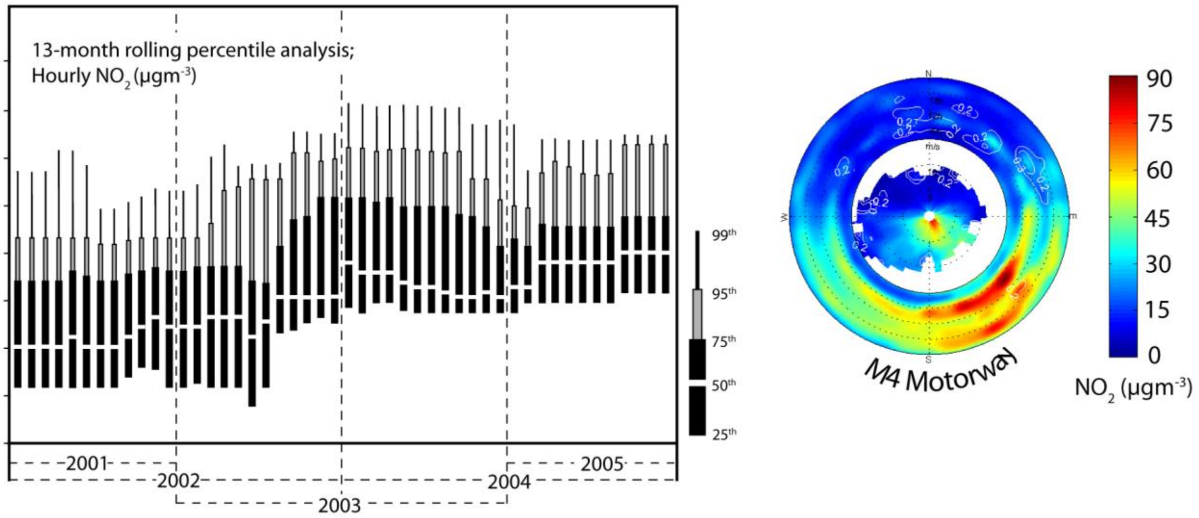
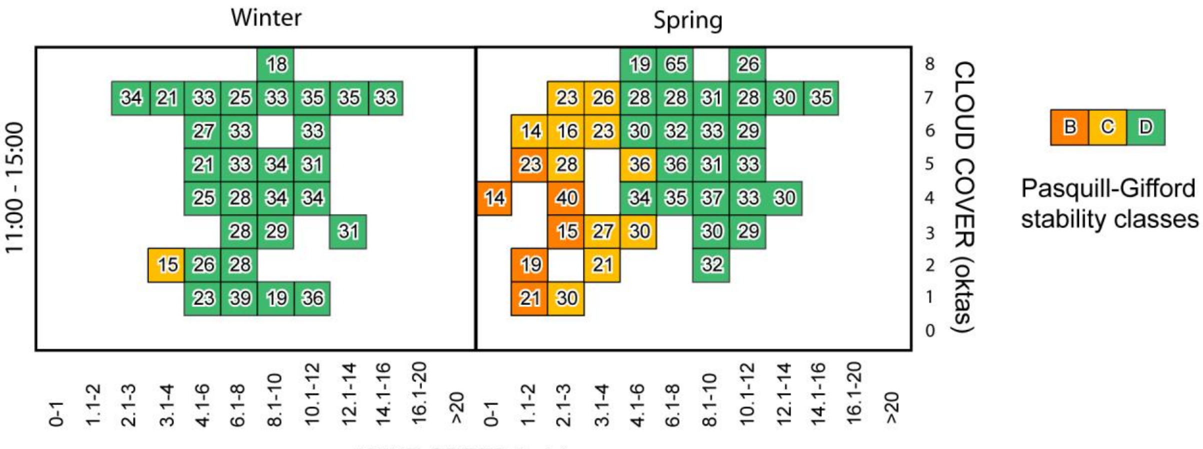


Figure 2 NO_2 morning rush-hour peak normalised for dispersion & direction: London Hillingdon 2001-5.

2.3 Auditing of dispersion conditions causing peak plume impacts.

We have developed a new scheme, the 'Dispersion Calendar', to identify & analyse individual dispersion conditions that cause peak plume impacts from a particular source at given monitoring site [4]. The detailed auditing of raised concentrations is achieved by categorising meteorology into seasonal, time-of-day, cloud cover and wind speed 'bins', and can be used to identify the dispersion 'signature' of individual sources. Observed concentrations in the Calendar can also be compared with those predicted by models, so a model's performance can be checked and improved. If a model correctly predicts concentration values, the Calendar can be used to check if the model is predicting 'the right value for the right reasons'. It can also be used to assess if the specific dispersion conditions that deliver peak plume impacts may happen more often under climate change. A detailed audit of how modelled changes in climate will affect peak plume impacts at sensitive receptors, will enable plume emission permits to be ‘climate-proofed’. Figure 3 shows a Calendar example section for 1100-1500 in winter and spring. The numerals denote the average top-decile SO_2 concentrations (μgm^{-3}) modelled at a receptor 10 km downwind of a ‘typical’ large power station. Such auditing of impacts v. dispersion is useful for planning cost-effective improvements in air quality.



	Winter												Spring											
CLOUD COVER (oktas) \ WIND SPEED (m/s)	0-1	1.1-2	2.1-3	3.1-4	4.1-6	6.1-8	8.1-10	10.1-12	12.1-14	14.1-16	16.1-20	>20	0-1	1.1-2	2.1-3	3.1-4	4.1-6	6.1-8	8.1-10	10.1-12	12.1-14	14.1-16	16.1-20	>20
8							18										19	65		26				
7			34	21	33	25	33	35	35	33					23	26	28	28	31	28	30	35		
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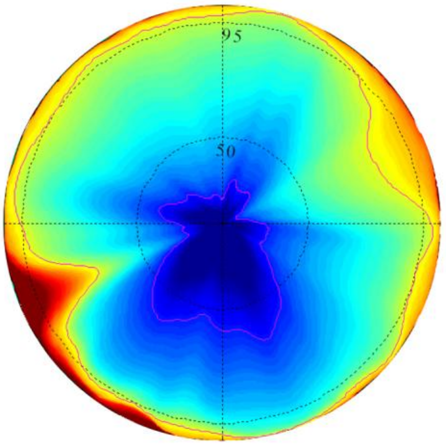
Figure 3 Top-decile concentrations of SO2 (μgm^{-3}) for individual dispersion conditions

2.4 Directional attribution of high-percentile statistics

Air quality standards to protect human health from short-term impacts of community air pollutants are commonly based on high-percentile statistics. It is therefore useful to audit high-percentile events at a monitoring site in order to identify which directions contribute more to the overall high-percentile statistic; controls can be targeted more effectively on sources in these directions. We have developed a novel “percentile-percentile” plot for presenting this information (Fig 4). The plot compares axial percentiles evaluated for each direction with azimuthally-integrated percentiles evaluated over all directions. An example is given using monitored 15-min SO_2 concentrations near Aberthaw power station S Wales. This shows that WSW winds from the station contributed most to overall high percentile statistics, although there were also high-percentile contributions from the opposite direction of Cardiff. Such information is useful for reducing individual source impacts to meet percentile air-quality standards.



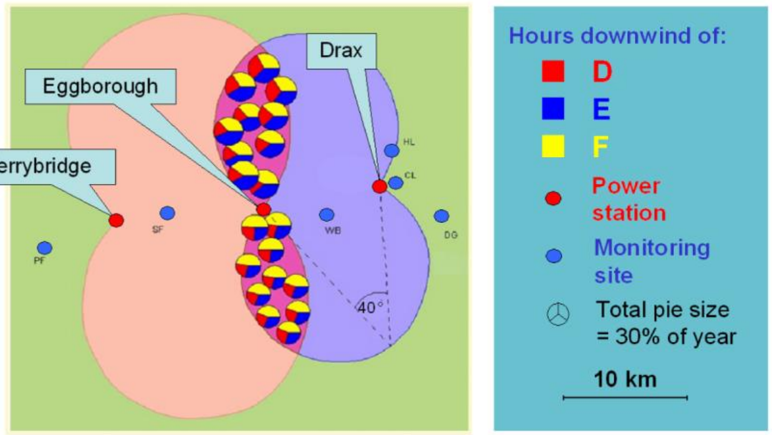


Figure 4 Percentile-percentile plot (Section 2.4). Figure 5 Monitor optimisation analysis (Section 2.5).

2.5 Optimising monitoring networks to distinguish and track point-source impacts

Major industrial complexes contain multiple point sources whose ambient impacts need to be monitored efficiently using well-placed networks. Monitoring sites should be optimised so individual plumes can be clearly distinguished and regularly assessed (based on wind direction frequency) using as few monitors as possible. We have undertaken such an optimisation analysis for monitoring sites around power stations in the Aire Valley of Yorkshire, where there are 6 sites over a 30 x 10km area (Fig 5). Our analysis has identified 2 zones where monitors can distinguish between the performances of different stations and where their plumes are advected relatively frequently (c. 30% of year). Potentially, 2 monitors in these zones could give comparable assessment performance to the existing 6 monitors. Such analyses can therefore enable savings in monitoring costs for the same, or better, surveillance of individual sources.

2.6 Using data assimilation methods to infer landfill emissions from fenceline monitoring

Landfill emissions of methane contribute importantly to anthropogenic emissions of greenhouse gases, but are difficult to estimate because of their spatial and temporal variability. We have undertaken a model-based pilot study to try and infer emissions from multiple fenceline monitors using an iterative data assimilation procedure (Figure 6). We propose to develop this technique further and, if successful, to disseminate to the practitioner community. This kind of assimilation scheme is potentially applicable to other area-source situations e.g. intensive agriculture sites, biogenic emissions, construction sites. Moreover, this technique shows how monitoring and modelling data can be integrated in order to generate new information, on emission patterns and rates, that is not available from either type of data individually.

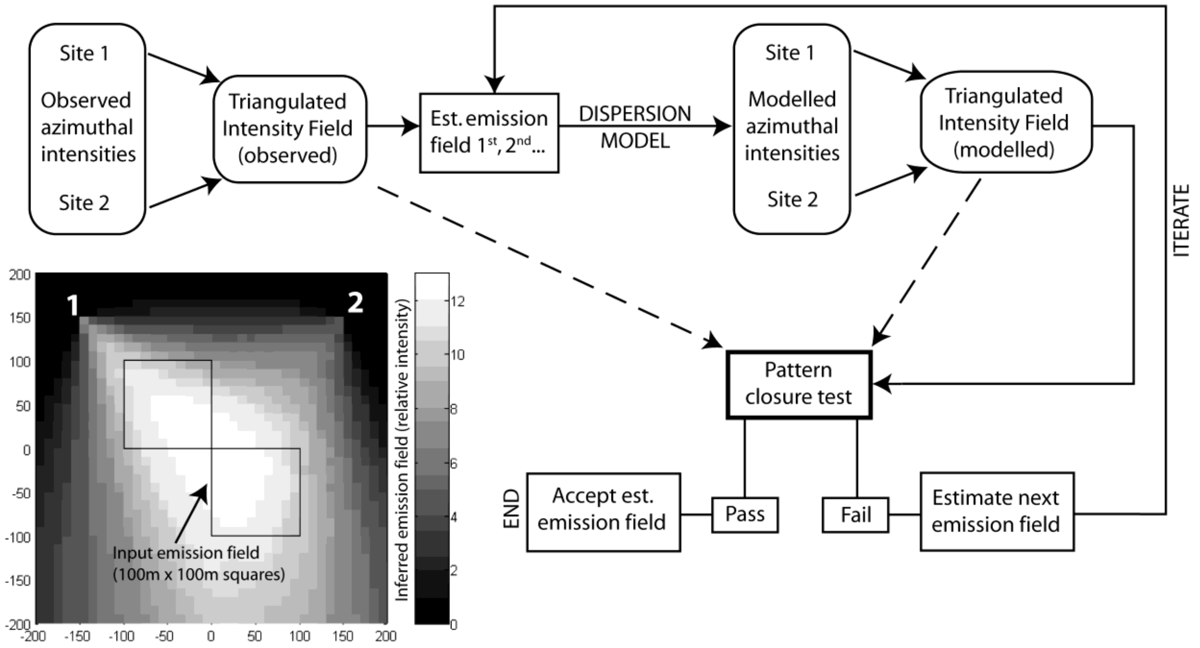


Figure 6 Schematic of a Data Assimilation Method to Estimate Landfill Emissions

3. Workplan

3.1 Progressive approach

We will undertake and disseminate a series of case studies that will progress in complexity from:

- Traditional community pollutants (e.g. SO_2 from combustion), to emerging priority pollutants (e.g. NH_3 from agriculture, CH_4 from landfills).
- Well-defined individual sources (e.g. isolated tall stacks), to more complex and proximate multiple sources (e.g. refineries, urban areas).
- Cases where background sources contribute little to ambient concentrations so that local sources are distinct to cases where background contributes substantially so local sources are harder to distinguish.

This progression is shown schematically in Figure 7. It will ensure that methods of inferring source performance will be established first in simple situations, before being applied to more complex cases. It will also help to identify uncertainties & limitations at every stage, and how they may be reduced.

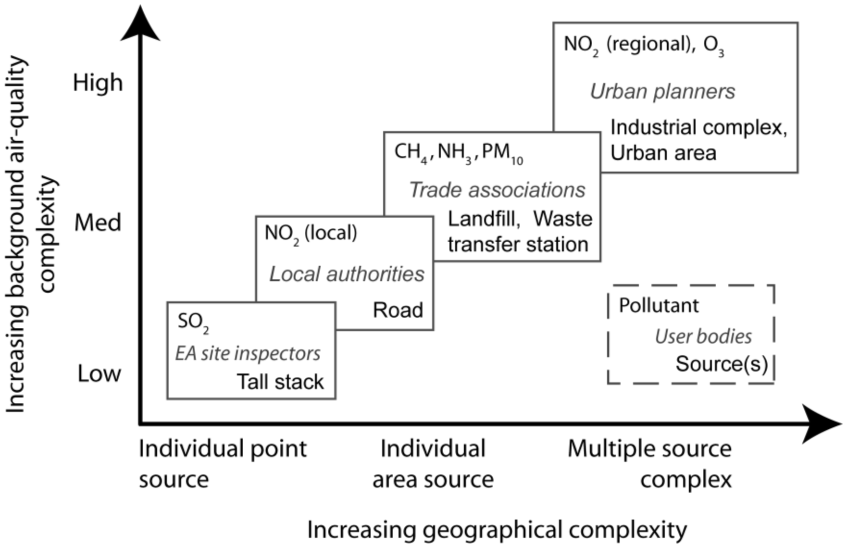


Figure 7 Improved aerometric analysis for air quality management/planning: Progression of studies from simple to complex cases.

3.2 Consultative approach

We aim to convince practitioners that information from additional air-quality analyses will deliver practical environmental and socio-economic benefits, so they use the methods and get the benefits routinely. For this we need case studies that are timely and topical in terms of new legislation, proposals for industrial or infrastructure developments, and emerging concerns re. emissions or impacts. Our previous and preparatory work gives us several options for case studies using earlier monitoring and modelling data; we also have options to obtain new data via Agency's monitoring team or via University modellers. Since we have several options, we can consult practitioners in order to identify those case studies which will be particularly effective at promoting uptake of our methods. We therefore propose to announce the case study programme to practitioner groups at an early stage (see Section 4) and to invite feedback on different case study options. This consultation will prepare the ground for more rapid adoption of our methods by practitioners when we report our results.

3.3 Case-Study Options

Our case studies will use previous and new measurements to inform practical decisions on air-quality management covering a range of pollutants, source types and receptors. In particular, our studies will show how techniques like those in 2.1-6 can give better information to resolve air quality questions like A-I. We are proposing 6 case studies and have already identified collaborating organisations for 4 of them: Halton BC, Lancaster CC, Environment Agency mobile monitoring team, Hertfordshire mesoscale modelling team. The other 2 case studies will be selected from a range of pre-scoped options after consulting the practitioner community; also within the other 4 studies there is further scope to modify the work in line with practitioner feedback. We believe that this flexible and responsive plan for case studies will maximise the effective transfer of knowledge to practitioners. The full list of studies available is:

- NO_x & PM_{10} impacts from road traffic in motorway & urban situations (Widnes, Lancaster).
- SO_2 , NO_x & PM_{10} impacts from major industrial complexes (Runcorn, Teesside, Scunthorpe).
- Detailed validation of modelling v. monitoring for local & multi-scale models (ADMS, CMAQ).
- Particulate impacts from waste transfer stations (e.g. Neasden) or steelworks (e.g. Port Talbot).
- Multiple pollutant impacts near motorways with other sources (M4/Heathrow; M1/Luton Airport)
- Ammonia impacts from intensive agriculture sites (e.g. Pen-Lon poultry farm, Wales).
- Methane impacts from landfills (e.g. Llandullas, Wales).
- SO_2 & NO_x impacts of long-range industrial plumes above the urban canopy at London BT Tower.
- Multiple pollutant impacts in sea port and adjacent urban environments (e.g. Dover)
- SO_2 & NO_x measurements at ground level near major power stations (as per Aire Valley).
- Use of data assimilation to infer rates and patterns of area-source emissions e.g. CH_4 from landfills.

As well as undertaking specific case studies, we will investigate alternative sources of meteorological data that practitioners can use to analyse their air-quality records, e.g. Numerical Weather Prediction (NWP) data, and will compare how such data perform against conventional local observations.

3.4 Programme of work

We propose a 3-year programme based around a PDRA fellowship at Lancaster Environment Centre under Dr Whyatt, where the Environment Agency project partner (Prof. Timmis) is also based. The fellow will visit Hertfordshire University to collaborate with Prof. Sokhi on applying source performance analysis methods to meso-scale model outputs. They will also make field visits with the Agency's ambient air quality monitoring, and attend user body meetings, conferences and workshops to disseminate the methods. The work has 3 overlapping strands. Firstly, a "*Consultation, Preparation & Tracking*" strand that will focus on consulting users, planning case studies, and monitoring/managing progress; this will be mainly in Year 1. Secondly, a "*Casework*" strand that will focus on executing 6 case studies, each of which will be done in 3 stages: *Scoping*, *Implementation*, and *Interpretation*; this will be mainly in Year 2. Thirdly, a "*Deliverables and Dissemination*" strand that will focus on communicating the results of case studies to practitioners by means of case study reports, presentations, a website archive, and a final report and workshop; this will be mainly in Year 3. The strands of work and their component activities are summarised in Figure 8, which shows how dependent activities will be sequenced e.g. how user consultations will precede planning of case studies.

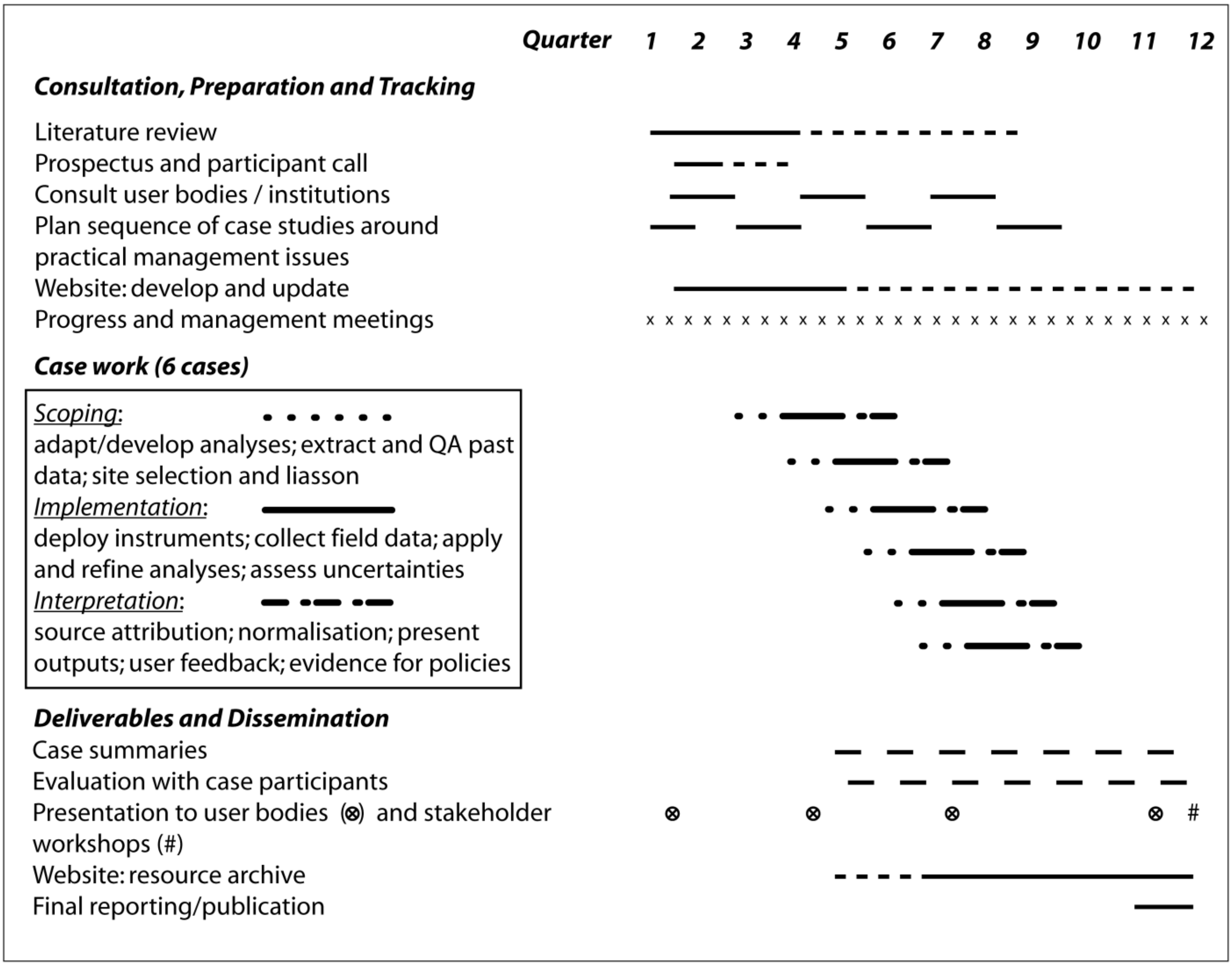


Figure 8 Project Management and Timescale

4. Dissemination

We will disseminate our methods to practitioners via (i) a website for announcements, progress reports & archived resources, (ii) case summaries & evaluation meetings, (iii) handouts & presentations to user bodies, (iv) conference posters/papers, (v) peer-reviewed publications, (vi) a final report and (vi) a closing workshop. In order to transfer the methods into regular use, we will show users that they can inform practical decisions on air quality (e.g. in management areas), resource use (e.g. fuels, abatement costs), societal behaviours (e.g. on transport, waste), health, (e.g. particulates) and quality of life. The project team have long-standing links to major air-quality bodies where we variously participate as committee members and regularly present technical papers e.g. Prof Sokhi chairs the MESONET NERC KT network. These links are confirmed by letters of support from Environmental Protection UK, Institute of Air Quality Management, Atmospheric Dispersion Modelling Liaison Committee, and we will use them to share outputs and take feedback. In the later stages of the work we will consider how users can receive more continuing information and advice e.g. through a KT Network or via an existing professional body.

5. Contributions from Project Partner

The Environment Agency project partner will contribute:

- Co-supervision (0.2 FTE) at the host site from Agency's Air Science Manager, Prof. Timmis.
- Additional advice from Air Science team members based at Lancaster, Solihull and Bath.
- Links to existing Agency air-quality students/fellows at Lancaster, Hertfordshire & Imperial College.
- Access to Agency monitoring data and summary reports, collected over c. 6-month campaigns at industrial sites as recorded by 2-5 mobile stations over the past 10 years.
- Advice & field visits from the ambient monitoring team manager, Dr Allott & team leader Mr Shutt.
- Links to Agency site inspectors & policy staff for translating technical outputs into operational practice and regulatory decisions; includes attendance at Agency air-quality conferences.
- Collection with ambient monitoring team of new/ongoing field data for industrial/urban case studies, subject to Agency operational priorities e.g. ongoing data above urban canopy on London BT tower.

6. Benefits

Air pollution is often an indication that resources are being used inefficiently, unsustainably or in a way that harms people and/or their quality of life. Techniques that give practitioners a clearer understanding of where air pollutants have come from, which activities have caused them, and whether or not control policies are working as planned, are therefore to be welcomed. Such techniques are particularly welcome when they enable more/better use to be made of measurements that have been collected at some cost, but whose information value is under-exploited. Moreover, having good information about pollution source performance, makes it easier to communicate and enforce policies to promote: cleaner technologies, pollution-charging, more sustainable behaviours, healthier environments, and a more resource-efficient economy. The techniques that we will develop and transfer are portable between different pollutants and specialisms (e.g. between monitoring & modelling), and will contribute to all these "strategic" benefits. They will also benefit the effectiveness of air-quality practitioners at a local level e.g. in individual industries, planning authorities, environmental health departments, and professional bodies. They are relevant to upcoming legislation (e.g. on exposure reduction approaches to air quality management), and they can be shared with other countries (e.g. in EU, developing economies) who would benefit similarly.

7. References

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[2] Williams M.L., Bower J.S., Maughan R.A., Roberts G.H. (1981) The measurement and prediction of smoke and sulphur dioxide in the East Strathclyde region: Final Report. Warren Spring Laboratory Report LR412(AP).

[3] McHugh, C., Williams, M., Price, C. and Lad, C. (2007) Air Quality Studies for Heathrow: Base Case, Segregated Mode, Mixed Mode and Third Runway Scenarios modelled using ADMS-Airport. CERC Report to Department for Transport, FM699/R23_final/07

[4] Malby, A., Timmis, R. and Whyatt, J.D. A framework for assessing the effect of climate change on the local dispersion of air pollutants, Submitted to Atmospheric Environment.