Guidance

Monitoring ambient air: choosing a monitoring technique and method

How to approach sampling ambient air and the sampling and analytical techniques to use.

From: **Environment Agency (/government/organisations/environment-agency)**
Published 10 September 2024

Applies to England

Contents

1. Decide the sampling approach

1.1. Omnidirectional sampling or directional sampling

Often, ambient air quality surveys are designed to assess the impact of a particular regulated process, works or site. You can determine the source contribution by omnidirectional sampling or directional sampling.

You can carry out omnidirectional sampling from all directions or under all wind directions. When you assess the data, consider the frequency and occurrence of winds from the direction of the suspected source.

Directional sampling is when you link an active sampling system to a wind vane and anemometer. The system allows sampling to occur only when the wind is blowing from a specified direction and is above a minimum wind speed.

The most common approach is omnidirectional sampling.

Directional samplers are most useful when there is a clearly defined suspected source of the pollutant and the background air concentration is low in comparison. In this case you would locate a single directional sampler downwind of the source for an appropriate duration. This should give a good estimate of that source’ s contribution.

It can be an advantage to use a directional monitoring unit that has a two-component wind-vane-operated sampler. One component collects the sample when the wind arrives from the direction of the source. The other collects a sample arriving on winds from the remaining directions.

Most active directional apparatus collects the sample from a pre-selected wind direction arc of say 30 to 70 degrees that has the axis of interest as its centre line. You should choose the distance from the source to allows the use of an acceptance arc in this range. At the same time, you must take account of the type of source. For example, the plume from an elevated source, such as a chimney stack, will usually reach ground level after a downwind distance equivalent to between 10 and 20 times the stack height. But you could get a more accurate estimate from atmospheric dispersion modelling studies.

Emissions from other interfering pollution sources within the acceptance arc will lead to an overestimation of the contribution of the targeted source of interest. If there are other sources that lie outside the acceptance arc, then consider their contribution as part of the background concentration. You can minimise these situations by carefully choosing the most suitable sampling distance from the suspected source, in conjunction with an appropriate acceptance arc. If this is not sufficient, you can position several directional samplers in different directions around the works. This will obtain an integrated value of the contribution of the targeted source relative to that of other sources and the general background. Alternatively, you can set up directionally resolving equipment to sample from 3 or more wind sectors.

1.2. Fixed-point sampling

The most common sampling system is that of a network of monitoring points at fixed locations. Each point provides concentration measurements. They could be instantaneous spot-concentration values or time-averaged concentrations, from a fixed point in space. The success of a fixed network of on site samplers will be dependent on the care with which you choose the locations. Section 8 of monitoring ambient air: monitoring strategy (https://www.gov.uk/guidance/monitoring-ambient-air-monitoring-strategy) covers the principles applying to the location of fixed monitoring points in detail.

1.3. Open-path methods

An alternative, less-common approach is open-path measurement made directly in the atmosphere. No extraction or measurement of a sample of air takes place within the instrument at a localised point. Instead, you determine the average concentration of a specifically targeted pollutant over a long measurement path. Some methods allow the concentration to be spatially resolved. Most, however, give the average concentration over the whole path length. This is useful for assessing the transfer of pollutants across site boundaries and along roads and runways. But it may be difficult to interpret integrated-path data.

Another open-path technique, laser interferometry detection and ranging (LIDAR), can measure aerosol particles. Differential absorption LIDAR (DIAL) can carry out range-resolved measurements of specific pollutants over several kilometres by analysing backscattered laser radiation.

LIDAR and DIAL are particularly suitable for producing two-dimensional or three-dimensional maps of pollutant concentrations over large areas such as industrial complexes.

Measurement by open path techniques tends to be expensive because of the complexity of the equipment and data handling facilities.

You can use open path methods for mobile sampling. This may be vehicle-mounted instruments for carrying out measurements from many locations, or for measuring the pollution concentration profile along a given route. Systematic traversing of a plume emitted from an elevated point source is an application well suited to mobile monitoring systems. But because meandering of the plume can distort the pattern, each traverse gives only an approximation to the instantaneous cross wind spread of the plume. You need several hours of sampling to define the plume envelope in a way that could relate to patterns observed from fixed networks.

1.4. Mobile point-concentration measurements

You can measure point-concentrations continuously from a mobile platform, usually a vehicle or a drone. You can deploy these systems to precisely quantify emissions of one or several pollutants.

Concentration measurements taken from a drone have the advantage of sampling plumes above the ground. When sources are elevated above ground it can be difficult to investigate or even detect pollution if you measure at ground level. Particularly if you have limited access downwind of sources.

In drone-based sampling, you may collect concentration measurements in a series of horizontal transects at various altitudes downwind of sources. Combined this data with meteorological (wind) data and measurements of background concentrations, to produce an estimate of pollutant emissions rates using the principle of mass-balancing. Take care to sample beyond the sides and the top of any expected plume and as close to the ground as is practicable. If obstructions or flight restrictions prevent this then other methods may produce better results. It may also be desirable to conduct measurements upwind of a source. This will characterise the local atmospheric background and account for potential contributions from sources upwind.

Each individual flux estimate is subject to high uncertainty because of the variability of plume morphology and advection. Averaging over multiple measurements may reduce and better quantify uncertainty. You should do a survey of gas concentration samples on a predefined flight path. You should do the survey as quickly as practicable to limit measurement uncertainty and bias. Also, you should characterise the relationship between wind speed and altitude in the planetary boundary layer. This will avoid overestimating emissions from measurements taken near to ground level. For more information, see Methods for quantifying methane emissions using unmanned aerial vehicles: a review. (https://research.manchester.ac.uk/en/publications/methods-for-quantifying-methane-emissions-using-unmanned-aerial-v)

Another mobile method of quantification – using instrumentation installed on ground-based vehicles – is to release a known rate of tracer gas such as acetylene. The tracer release should be co-located with the source of interest. You take continuous concentration measurements of the tracer and target gas (pollutant) in a series of transects downwind of the source. You can then use the ratio of these concentrations to derive an emission rate of the pollutant. It may be necessary to have several tracer release locations on large sites (such as a landfill). A limitation to this method is that it may not be possible to sample a plume because of a lack of access or the plume being high above ground level. For more information on this method, see Guidelines for landfill gas emission monitoring using the tracer gas dispersion method – ScienceDirect (https://www.sciencedirect.com/science/article/abs/pii/S0956053X18307876?via%3Dihub).

2. Choice of measuring method

For many pollutants, you must use a reference method to comply with standards. But, where no reference method is applicable, there are general principles to consider.

2.1. Method performance

The monitoring certification scheme (MCERTS) is the Environment Agency’s monitoring certification scheme for environmental permit holders. We use MCERTS to approve people, instruments, and laboratories. See Monitoring emissions to air land and water (MCERTS) (https://www.gov.uk/government/collections/monitoring-emissions-to-air-land-and-water-mcerts).

Wherever possible, you should choose MCERTS-certified instruments:

The MCERTS performance standard for continuous ambient air quality monitoring systems (CAMs). (https://www.gov.uk/government/publications/mcerts-performance-standard-for-continuous-ambient-air-quality-monitoring-systems)

This covers nitrogen monoxide (NO), nitrogen dioxide (NO2), sulfur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), particulate matter (PM_{10} and $PM_{2.5}$), benzene and benzene-like volatile organic compounds.

The MCERTS performance standard for open-path ambient air quality monitoring systems (OPAMS) (https://www.gov.uk/government/publications/mcerts-performance-standard-for-open-path-ambient-air-quality-monitoring-systems).

Using the differential optical absorption spectrometry (DOAS technique, this covers: NO, NO_2, SO_2, O_3, ammonia, formaldehyde, benzene, toluene, xylene, and methane.

Using the Fourier transform infrared (FTIR) technique this covers methane, ethene, propene, ethane, benzene, toluene, m-xylene, p-xylene, o-xylene, carbon monoxide, nitrous oxide, ammonia, formaldehyde, isobutene, and 1,3-butadiene.

You can also measure many other gases.

MCERTS certification of CAMS and OPAMS makes sure that instruments meet the requirements the Ambient Air Quality Directive (2008/50/EC) and the amending Directive (EU) 2015/1480.

Compliance with the Data Quality Objectives (DQO) for regulated pollutants is mandatory and recommended as targets for unregulated pollutants. The current versions of the Ambient Air Quality CEN standards (The European Committee for Standardization) that define the standard reference methods for monitoring of the pollutants covered by the Directive, are available in [standard methods for monitoring and UK approach (https://uk-air.defra.gov.uk/networks/monitoring-methods?view=eu-standards)](https://uk-air.defra.gov.uk/networks/monitoring-methods?view=eu-standards).

The standard methods are a template for instrument performance testing. They specify a series of tests and requirements for analysers to achieve and to demonstrate whether a particular analyser's uncertainty fulfils the DQO. You can then use this information as a stamp of approval for the use of specific analysers (in their tested configuration) in national monitoring networks.

There is also an MCERTS performance standard for indicative ambient particulate monitors. These instruments give a good indication of particulate concentrations. They do not achieve full compliance with the performance standards for particulates.

Also, there are low-cost, typically sensor-based, monitoring instruments available for a range of gases, as well as particulate matter. Their low price usually involves some compromise on measurement performance.

Where you use an automatic instrument, the preference is to use an MCERTS certified CAMS or OPAMS for the survey. There will be occasions this option is not available or suitable. In such cases you should consider the performance characteristics of the method when determining how well a monitoring technique suits a particular application. The same applies to manual techniques because they are not covered by MCERTS performance standards. You should consider the following performance characteristics.

Method sensitivity
This is the amount of indication (the response) produced per amount of air pollutant sampled. To measure small changes in air pollutant concentrations you need a highly sensitive method. Note that these small changes may be at low or at high concentration levels.

Limits of detection and measurement range
For a method of a given sensitivity, there will be a minimum air pollutant concentration that will produce a measurable response. This is the limit of detection. It is influenced by the level of background noise signal or the magnitude and variability of blank values. The method should also produce a linear or other known response to the air pollutant concentration over a particular range. For an instrumental method, there may be one measuring range or it may be possible to switch between different measuring ranges. For indirect methods, you must collect enough sample to enable the use of the analytical end method in its measurement range. You can alter the range by varying the amount of

air sampled and hence the amount of pollutant collected. Do this by altering the sampling flow rate or by altering the duration of sampling. However, you must also consider the measurement average time required.

Speed of response
This is most relevant for direct-reading instrumental methods, especially when you take measurements over short averaging periods. The instrument must be capable of responding to the pollutant with sufficient speed to enable resolution of the pollutant concentration peaks and troughs of interest.

Selectivity and specificity
The measurement method should be specific for the pollutant of interest or be selective enough to distinguish and quantify the pollutants of interest from unwanted species. At times it may be desirable to monitor with a non-specific method that measures a group of compounds that have similar chemical properties. An example is the acidimetric method of measuring net gaseous acidity in air samples, expressed as the equivalent concentration of sulfur dioxide.

Susceptibility to interferences
There are species other than those of interest that could potentially affect the measurement result, giving either a positive or a negative interference. Examples are:

- the presence of water vapour in many infrared analyses
- the presence of organic acids when analysing fluoride by ion chromatography

For samples collected for fluoride analysis, the stability of the sample is important.

Accuracy and precision
Method characteristics can have an influence on either the precision or the accuracy, or both. The overall combined uncertainty (U) of a result is the estimate of the range of values that you expect the 'true' value to fall within. It combines in a single value both the precision (the degree of agreement between the successive measurements) and accuracy (how close the measurement is to the 'true' value). The combined uncertainty is conventionally expressed at a confidence level of 95%.

For example: nitrogen oxides concentration = 500 $\pm$ 35 ppm.

You can estimate the repeatability (r) for any single result by multiplying the standard deviation (s) by the value of the mathematical function known as Student's t (obtained from t-tables) appropriate for that (large) number (n) of repeats at 95% confidence limits:

r = t.s

The bias (d) is the difference between the mean (x) of the results and the accepted 'true' value (m) of the reference gas:

d = x − m

The uncertainty (U) is the combination of the random and systematic errors:

U = d + r

The International Standards Organisation (ISO) (https://www.bipm.org/documents/20126/2071204/JCGM_100_2008_E.pdf/cb0ef43f-baa5-11cf-3f85-4dcd86f77bd6) publishes general guidance about uncertainty. Guidance on estimation of uncertainty for analytical measurements is available from Eurachem (https://www.eurachem.org/images/stories/Guides/pdf/QUAM2012_P1.pdf) and the Royal Society of Chemistry (https://pubs.rsc.org/en/content/articlelanding/1995/an/an9952002303).

2.2 Other monitoring method considerations

Other factors which may influence the choice of monitoring method are:

Method cost
One factor in the choice of measurement method is the resources available, both financial and human. There are wide variations in the capital costs and running costs of different measurement methods. Some simple, inexpensive apparatus can be labour-intensive when used for extended durations and may incur additional analysis costs. Automated monitoring equipment is available for unattended operation, but the capital costs are higher, and you must meet ongoing running and maintenance costs.

New low-cost, sensor-type monitoring instruments are now able to reach down to the low concentrations typically found in ambient air. But their low price usually involves some compromise on accuracy, precision, and specificity.

Reliability and unattended operation
Methods vary in the degree of manual operation and continuing attention they need. For example, direct-reading continuous analysers can need frequent calibration. Indirect methods may require renewal of reagents. Long-term reliability and unattended operation would be of crucial importance in a network of monitoring sites at remote locations. This may be less important for a short-term survey close to the laboratory.

Method complexity
When selecting a method, you should consider the availability of technical staff who have the necessary experience, or who you can train. Manual methods are less complex than direct reading continuous analysers, which can require a higher degree of ability in the event of operational failure. Even with simpler methods it is important that you arrange adequate training and instruction.

Manufacturer support
This is especially relevant for instrumental techniques. Important considerations are:

- the extent of back-up available from manufacturers in the event of equipment malfunction
- the availability and delivery of consumable items and spares
- the turn-around time for servicing and repairs
- the provision of replacement instruments if you must take some out of service

Portability and size
Generally, simpler, cheaper methods tend to be more portable than the more expensive, complex methods and can be particularly useful for obtaining many samples in a short time. Continuous analysers can be quite heavy and bulky and may need a warm-up time of several hours before monitoring can start. The exceptions are some remote methods. These tend to be expensive but are mobile by design and more capable of accurately characterising emissions fluxes at a moment in time.

Practical requirements
Some monitoring equipment operates in the open air. Some need very few facilities, if any at all (for example, deposit gauges, dust slides and diffusion tubes). Other instruments must have some housing to provide shelter, weatherproofing, and security. For example, a site containing several direct-reading continuous analysers will need a secure housing, air conditioning, and an electricity supply.

2.3 Low-cost air quality sensor systems

Low-cost, sensor-type monitoring systems can reach down to the concentrations typically found in ambient air. But their low price usually involves some compromise on accuracy, precision, and specificity.

The Air Quality Expert Group (AQEG) refer to low-cost sensors as devices designed to measure regulated pollutants in ambient air, for which equivalence with European or US reference methods has not been demonstrated and are often available at lower cost than reference-equivalent instruments. Low-cost in this context can mean many things, ranging from simple single pollutant sensor devices sold for less than £100 to relatively sophisticated multi-pollutant units that include communications and meteorological capabilities, costing several thousand pounds. The AQEG advice, [AQEG advice on the use of 'low-cost' pollution sensors – Defra, UK (https://uk-air.defra.gov.uk/research/aqeg/pollution-sensors.php)](https://uk-air.defra.gov.uk/research/aqeg/pollution-sensors.php), explains the typical trade-off between the price, compactness, mobility and lower power consumption of low-cost sensor devices and the accuracy and precision of the measurements. The trade-off can be because of low-cost manufacturing, or because the underlying measurement technique itself is more uncertain than reference methods.

The following public available specification (PAS) was sponsored by Department for Environment, Food and Rural Affairs (Defra) and developed by the British Standards Institution:

[PAS 4023:2023 Selection, deployment, and quality control of low-cost air quality sensor systems in outdoor ambient air – Code of practice (https://knowledge.bsigroup.com/products/selection-deployment-and-quality-control-of-low-cost-air-quality-sensor-systems-in-outdoor-ambient-air-code-of-practice?version=standard)](https://knowledge.bsigroup.com/products/selection-deployment-and-quality-control-of-low-cost-air-quality-sensor-systems-in-outdoor-ambient-air-code-of-practice?version=standard)

This PAS provides recommendations for the selection, deployment, maintenance, and quality assurance of low-cost air quality sensor systems as standalone units or as part of a network.

Typically, these sensors measure particulate matter by counting particles using a laser light scattering technique. For gases, they use electrochemical cells, metal-oxide semiconductor sensors or light absorption.

Many sensors are sensitive to changes in atmospheric humidity and temperature or can suffer interference from other air pollutants present at high concentrations. Additionally, most low-cost sensors have no facility for on-going calibration or quality control checks once in the field, unlike reference measurements. This means you cannot use low-cost sensors:

- as direct replacements for the reference monitors used by Defra in the Automatic Urban and Rural Network (AURN)
- for most ambient monitoring stipulated in permit conditions at sites regulated by the Environment Agency

There are some applications where low-cost sensors do have a role (examples below) and further applications may arise as the technology evolves.

Many different low-cost sensors are being commercialised and the technology and marketplace is evolving rapidly. For this reason Defra and AQEG have dedicated part of the UK Air website (https://uk-air.defra.gov.uk/research/aqeg/pollution-sensors.php) to providing regular updates on the science and application of low-cost sensors. The website gives information on sensor measurement uncertainties, together with recommendations and advice on where they may, or may not, be appropriate to use. It also has Links to the latest review articles on this subject.

It is essential that before you decide to apply low-cost sensors to study air pollution that you:

- consider in detail how accurate and stable those sensors are likely to be
- check whether this will be sufficient for the measurement objective

The AQEG advice on 'How do sensors perform compared to reference instruments?' (https://uk-air.defra.gov.uk/research/aqeg/pollution-sensors/how-do-sensors-perform.php) and 'When could I use a low-cost sensor?' (https://uk-air.defra.gov.uk/research/aqeg/pollution-sensors/how-could-I-use.php) provide useful information to help in this decision making.

The Mayor of London's 2018 'Guide for Monitoring Air Quality in London' (https://www.london.gov.uk/sites/default/files/air_quality_monitoring_guidance_january_2018.pdf) refers you to the findings on measurement reliability carried out independently in the United States by the Air Quality Sensor Performance Evaluation Center (AQ-SPEC) (http://www.aqmd.gov/aq-spec) program.

CEN has published CEN/TS 17660-1:2021 Air quality – Performance evaluation of air quality sensor systems. Part 1: Gaseous pollutants in ambient air (https://standards.iteh.ai/catalog/standards/cen/5bdb236e-95a3-4b5b-ba7f-62ab08cd21f8/cen-ts-17660-1-2021). It specifies performance requirements and test procedures. It groups sensors as follows:

- Category 1 – sensors in this highest category will meet all the requirements for semi-quantitative monitoring specified in the Air Quality Directive
- Category 2 – the intermediate category is for sensors meeting the requirements for some types of semi-quantitative monitoring permitted by the Air Quality Directive
- Category 3 – will be for sensors that do not meet the requirements of the Air Quality Directive, but would have value for other purposes, (for

example, portable sensors for indicative monitoring, citizen science, education, and screening work)

Category 3 is to make sure of a minimum quality of data, and to prevent the inappropriate use of any highly inaccurate and imprecise sensors.

There is an MCERTS certification scheme for indicative ambient particulate monitors (https://www.gov.uk/government/publications/mcerts-performance-standard-for-indicative-ambient-particulate-monitors).

CEN is in the process of developing a technical specification for particulate matter.

Contact us

General enquiries

National Customer Contact Centre
PO Box 544
Rotherham
S60 1BY

Email enquiries@environment-agency.gov.uk

Telephone 03708 506 506

Telephone from outside the UK (Monday to Friday, 8am to 6pm GMT)
+44 (0) 114 282 5312

Monday to Friday, 8am to 6pm.

Published 10 September 2024