Module 1: The science and management of air quality

Contents

1 Measuring air pollution

1.1 Measurement and management

To manage and monitor changes in air pollution it is necessary to measure the amounts of pollutants in the air. The two basic physical quantities used in measuring air pollution are mass and volume.

Mass, the amount of matter

The metric (SI) unit of mass is the kilogram with the symbol ‘kg’—about the mass of a one-litre carton of milk.

Other metric units of mass that are commonly used are the gram for household-sized amounts of material and the tonne for industrial-sized amounts:

- 1 kilogram (kg) = 1000 grams (g)
- 1 tonne = 1000 kg

For the very small amounts of air pollutants two smaller units are used:

- 1 milligram (mg) = 1/1000 g = 10^{-3} g = 10^{-6} kg
- 1 microgram (µg) = 1/1000,000 g = 10^{-6} g = 10^{-9} kg

It is common to use the term ‘weight’ interchangeably with ‘mass’ to indicate the amount of matter. Strictly, weight is the force of gravity on the mass.

For some toxic pollutants the much smaller unit of nanogram (ng) is used:
1 nanogram = 10^{-9} gram
= 10^{-12} kg

Volume, the space occupied by matter

The metric (SI) unit of volume is the cubic metre—about the volume of a home refrigerator.

Other metric units of volume that are commonly used are the cubic centimetre and the litre:

- 1 cubic metre (m^3) = 1000 litres (L)
- 1 L = 1000 cubic centimetres (cm^3), or
- 1 cm^3 = 1/1000 L = 10^{-3} L = 10^{-6} m^3

The cubic centimetre is the same size as one millilitre (mL).
It is standard to use the capital ‘L’ here to avoid confusion with the numeral ‘1’.

Relative amounts of air pollutants

Common ways of indicating the relative amounts of air pollutants are:

Concentration as ‘mass per volume’:

- milligrams per cubic metre
  mg/m^3 or $mg\ m^{-3}$
- micrograms per cubic metre
  $\mu g/m^3$ or $\mu g\ m^{-3}$

A ratio of 'volume of pollutant per total volume of air':

- parts per million ppm
- parts per billion ppb

The non-standard unit 'parts per hundred million' (pphm) may be encountered in some early data.

Conversion tables for common air pollutants

To convert from parts per million (ppm) to micrograms per cubic metre (µg/m^3) for	at **0°C** multiply by	at **25°C** multiply by
ozone	2141	1962
nitrogen dioxide	2053	1880
sulfur dioxide	2858	2619
carbon monoxide	1250	1145
methane	716	656
hydrogen fluoride	893	818

Only gaseous pollutants can be expressed as the volume per volume ratio (v/v)—never particulate pollutants. However, both forms can be expressed as mass per unit volume.

To convert from volume per volume to mass per volume the temperature, pressure and chemical properties of the gaseous pollutant must be used.

To convert from micrograms per cubic metre (µg/m^3) to parts per million (ppm) for	at **0°C** multiply by	at **25°C** multiply by
ozone	0.0004670	0.0005097
nitrogen dioxide	0.0004872	0.0005318
sulfur dioxide	0.0003499	0.0003819
carbon monoxide	0.0008002	0.0008734
methane	0.001397	0.001525
hydrogen fluoride	0.001120	0.001223

Changes in temperature or pressure cause the volumes of gases to change much more markedly than the volumes of solids or liquids. So, when dealing with air pollution, it is necessary to have agreed conditions of pressure and temperature when quoting data.

Two conditions commonly used are:

STP = 'Standard Pressure & Temperature': 0^0C and one atmosphere pressure.

NTP = 'Normal Pressure & Temperature': 25^0C and one atmosphere pressure.

1.2 Interpreting measurements

In addition to mass, volume and relative amount, two other parameters are important for the measurement and interpretation of the levels of emissions and of ambient air pollution:

- the **rate of emission** from an activity or premises
- the **time periods** over which amounts or concentrations of pollutants are measured.

The **technology of measurement** also needs to be taken into account in several other respects:

- the **collecting efficiency and representativeness of the sampling devices and instruments** being used to make the measurements
- the **sensitivity of the analytical methods** being used, either online within the measuring instrument itself or 'back in the laboratory'
- how **the uptake by humans** of the pollution is related to the instrument measurement and associated analysis.

Amounts and rates of emissions

For air quality management and regulatory purposes the plant conditions during emissions measurement need to be known, and for ambient air quality measurements the meteorological conditions need to be known.

The ideas associated with the dispersion of pollutants will be discussed in more detail in the next section on meteorology. This section deals with the basic ideas associated with the amounts, concentrations and rates of the discharges.

Pollutant emissions from activities and premises typically disperse to a greater or lesser extent depending on:

- where and how they are released
- their temperature
- the rate of discharge
- the topography of the surrounding land
- the prevailing meteorological conditions
- and, to a much lesser extent, the exit velocity of discharge.

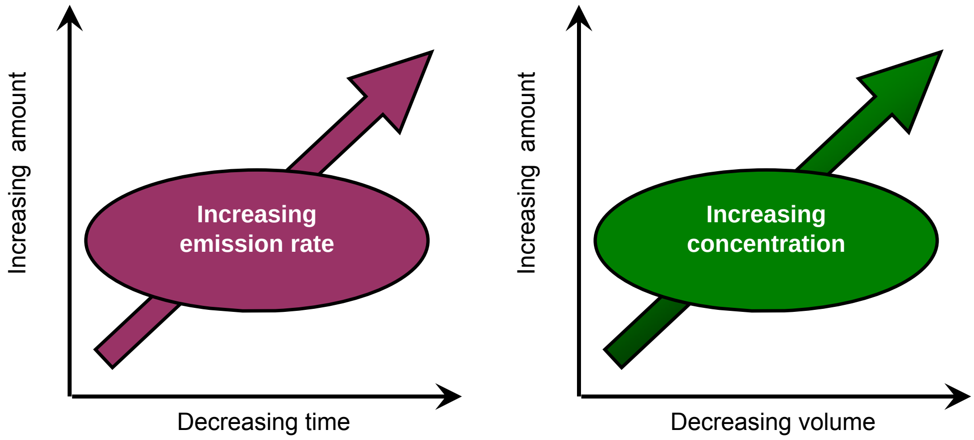
The potential impact of pollutant discharges from activities ranging from the smoke of stubble burning in a rural area, through dust on a construction site, to unpleasant odours from a fast food shop begins with **how much** is released, the **rate** at which it is released and the **type of pollutant**.

For example an **acute event** may occur in which an amount of a pollutant is discharged over a short period of time, maybe only a few minutes. This may result in a serious impact in the immediate vicinity—such as odours from a food shop giving rise to complaints, wind-blown dust emissions near sensitive land use on neighbouring properties or the discharge of a toxic chemical in an accident.

The discharge of the same amount of such pollutants over a long period of time—that is, at a much lower rate—may not have the same level of impact. However, if the pollutants have long-term health effects, such as exposure to fine particles or cumulative toxic materials, the reverse may be true: short-term higher-concentration exposures may have little effect while long-term lower-concentration exposures may have a damaging effect.

When assessing or regulating the discharges from any activities it is important to address management of both normal operations and the potential for acute events when the rate of emission may be high.

Amounts, volumes and concentrations



The discharge to the air of a given amount of pollutant may take place over a short or long period of time—at different rates. When dispersed this same quantity of pollutant will then be mixed into another larger volume of air.

The **concentration of a pollutant** and the **time over which this is averaged** are the significant parameters in terms of impact on the local environment or human health; and consequently on its measurement and the regulatory standards in the atmosphere that are set for its management.

For example 100 g of emitted CO when confined within a closed space like an unventilated basement car park of volume 10,000 m^3 has a concentration of 10 mg/m^3. When dispersed into the open air, say into a volume that is one hundred thousand (10^5) times greater, the same amount has a concentration of only 0.1 $\mu g/m^3$.

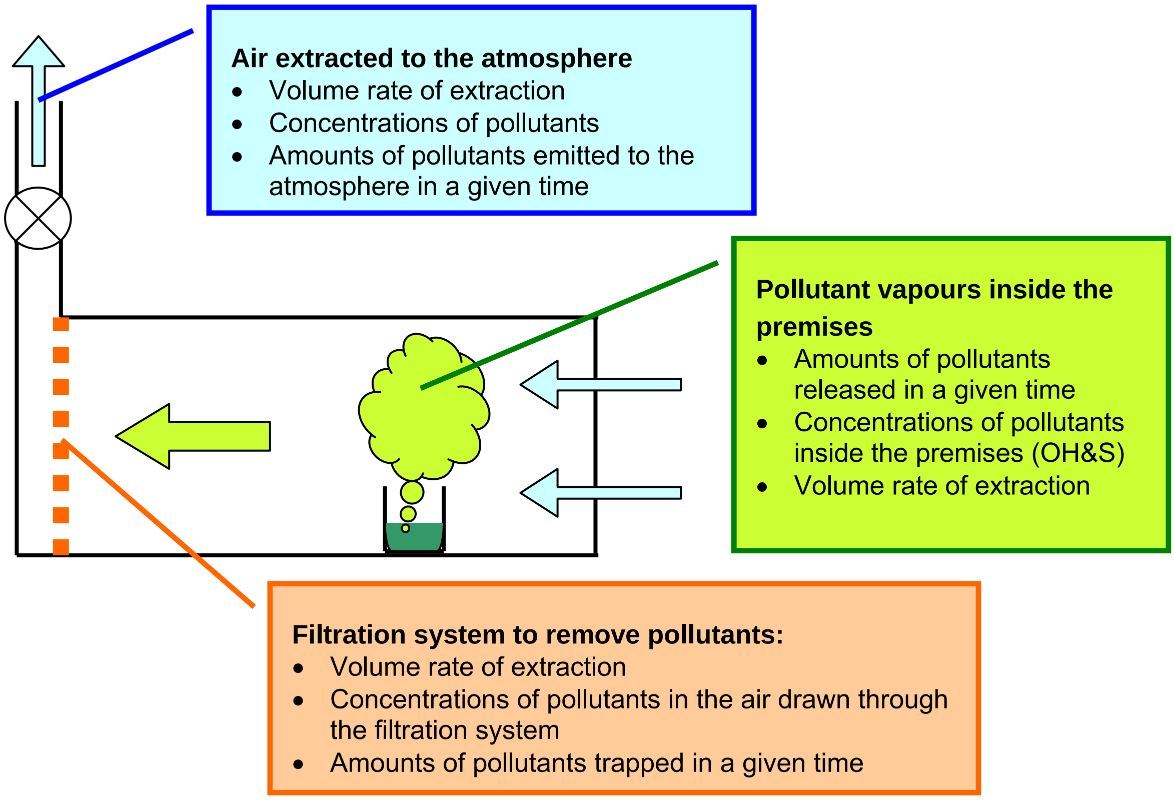
Rates and times

The rate at which pollutants are discharged from a premises is an important consideration for operators and regulators in their management of the surrounding air quality. This rate is related to:

- the **amount** of the pollutant released in the activity
- the **time** over which this occurs
- the **rate** at which inside air containing the pollutant is **extracted** to the outside atmosphere
- the **capacity** of the premises' filtration system **to remove** the pollutant from the air being extracted.

Air pollutants like dust and solvent vapours are customarily taken out of work areas within premises by means of extractor fans and ducting through filters or absorbers to stacks. It is important that the **volume rate of flow** through these is large enough to remove enough air to keep the concentration of pollutants inside at an acceptably low level. Removing the pollutants from the workplace into the outside air may solve the occupational problem but leaves the pollution problem. The environmental impact of these discharges must be managed.

> Interior air quality is an issue of workplace health and safety rather than an environmental one.
>
> Some local council officers have found it helpful to work in collaboration with WorkCover officers when addressing the related air quality issues within and arising from premises and activities.



The **filtration system** being used must then be able to remove enough of the pollutants so their concentrations in the flow from the stack into the outside air are also acceptable—an environmental pollution issue. When any extracted air is discharged to the outside atmosphere from a stack, the location and height of the stack must allow acceptable **dispersion**.

1.3 DECC monitoring network

The NSW Government commenced air quality monitoring 50 years ago. During this period the monitoring network has been maintained, expanded and developed into a modern, reliable and accessible management tool.

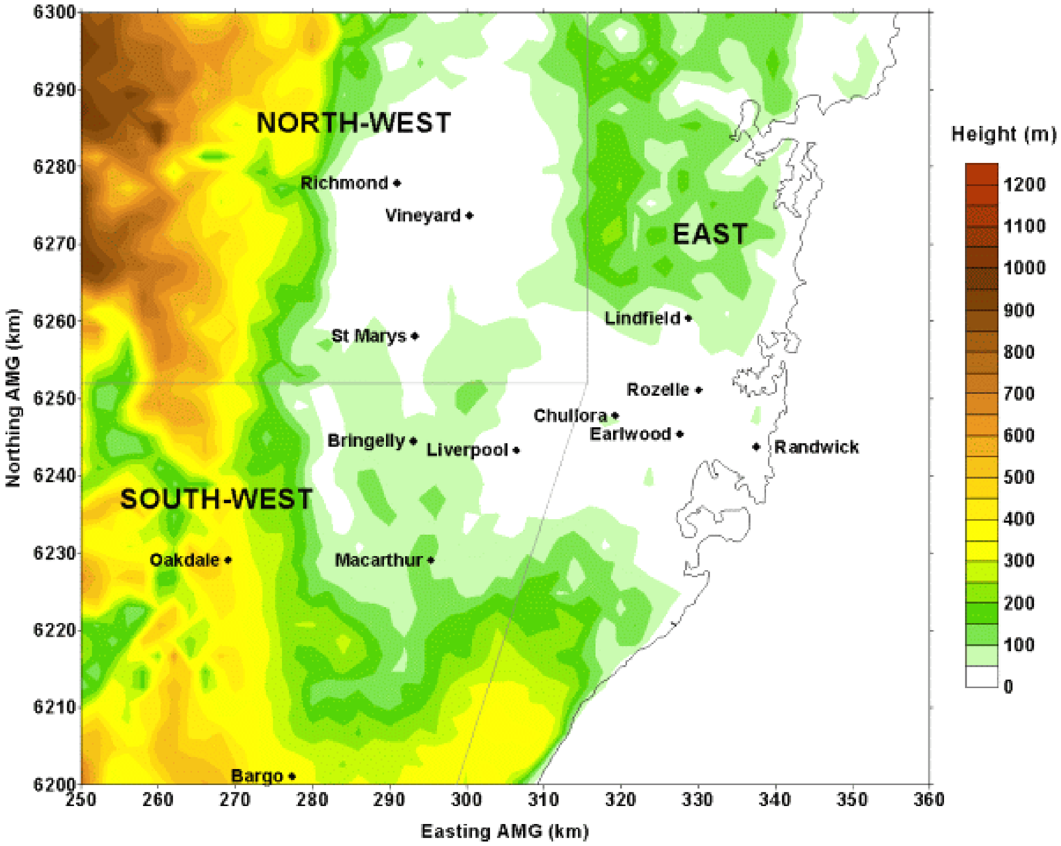
Extensive information on the DECC monitoring network is available from the DECC website at www.environment.nsw.gov.au/air/airqual.htm.

Rural monitoring sites are located in the following cities; most are operated by DECC in collaboration with the local council:

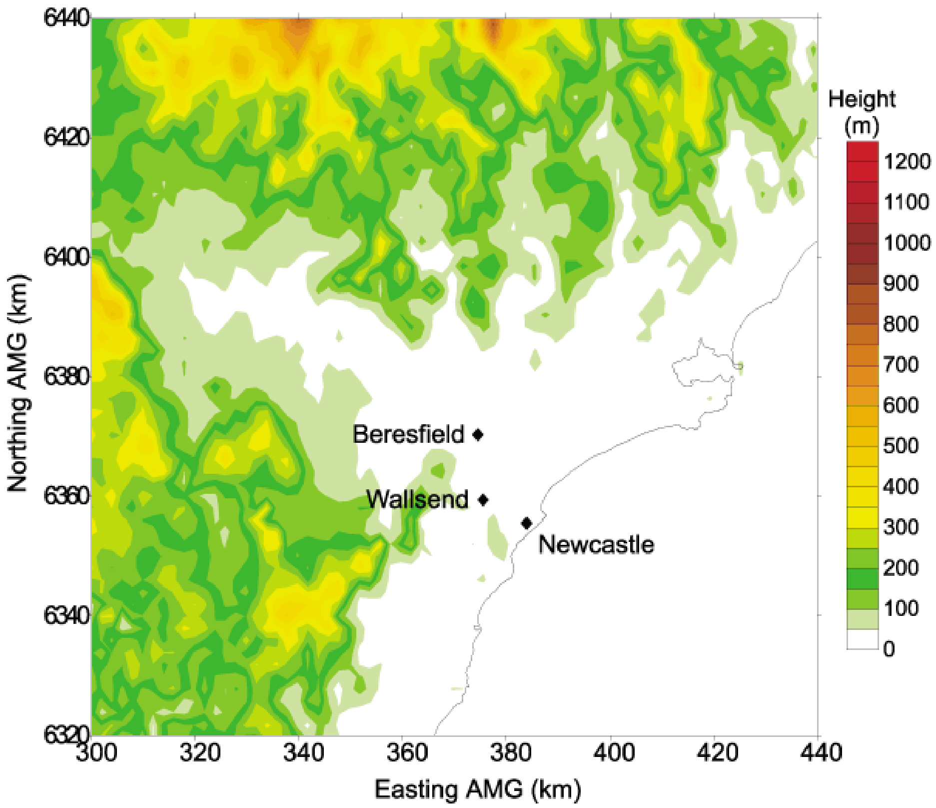
Albury	TEOM PM_{10}
Bathurst	TEOM PM_{10} and ozone
Tamworth	TEOM PM_{10}
Wagga Wagga	TEOM PM_{10}

The current monitoring network for Sydney, the Lower Hunter and the Illawarra regions are shown below. In each map the colours show the heights above sea level.

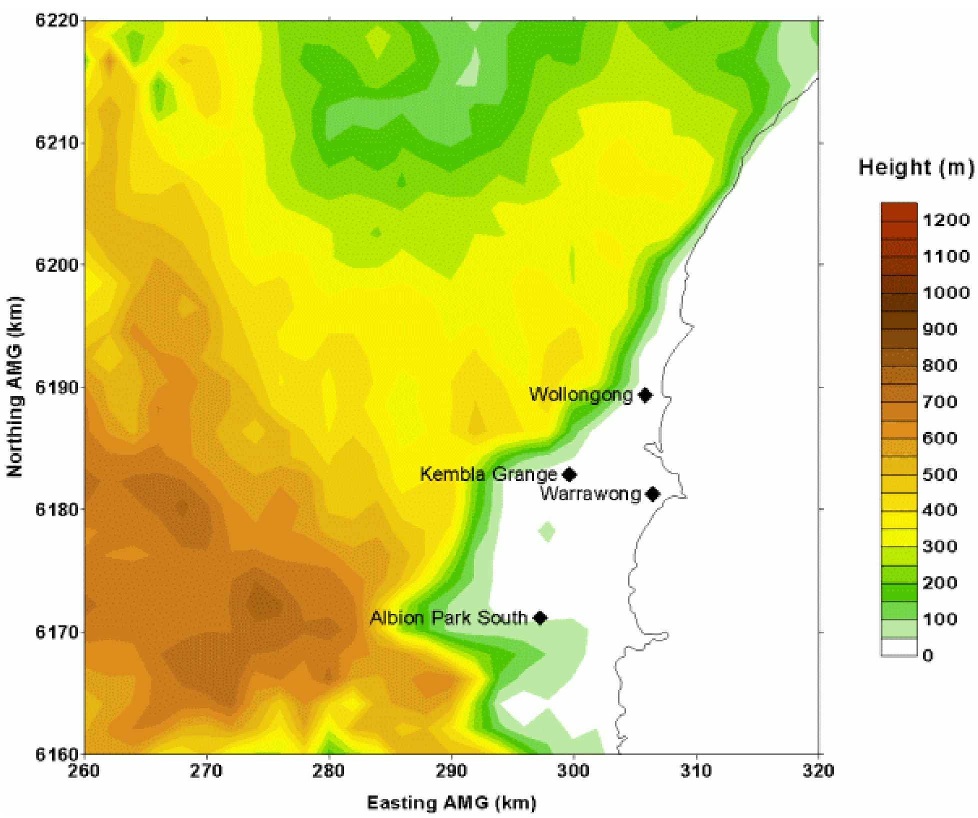
The current DECC monitoring network in the Sydney Metropolitan Region



The current DECC monitoring network in the Lower Hunter



The current DECC monitoring network in the Illawarra



Purposes of the DECC network

The current purposes of the DECC network are to:

- measure the quality of outdoor air to which the general community is exposed
- provide information needed for daily bulletins & forecasts (e.g. the Regional Pollution Index) and health warnings
- indicate progress in air quality management, and
- provide inputs to planning.

DECC monitoring locations

DECC monitoring locations (‘monitoring stations’) are carefully located according to accepted standards to allow consistency of measurement over time of the general atmosphere in an area. Each location takes account of regional meteorology and the proximity of sources. Some local councils provide support to DECC in the operation of monitoring stations.

The monitoring stations are not intended to measure the impact of specific sources, such as individual factories or transport corridors.

Monitored air pollutants and data

The air pollutants routinely measured in the network include:

- ozone (O_3)
- nitrogen oxides (NO_x)
- sulfur dioxide (SO_2)
- carbon monoxide (CO)
- particulate matter as:
  – total suspended particles (TSP)
  – particulate matter smaller than 10 µm (PM_{10})
  – particulate matter smaller than 2.5 µm ($PM_{2.5}$)
  – visibility effect measured by nephelometry
- lead (Pb).

These pollutants are described in section 3 of this Module.

The measurements are generally continuous except for TSP and lead which are measured on a 6-day repeating cycle giving 61 samplings per year.

Meteorological conditions are also routinely measured in the network, including wind speed, direction and turbulence.

> The methods and instruments used to monitor these pollutants are scientifically complex and do not need to be understood in order to use the monitoring data. Further information is available on the DECC website: www.environment.nsw.gov.au/air/nepm/index.htm

1.4 Interpreting DECC monitoring data

DECC routinely reports monitoring data collected in the network. The data is available on the DECC website www.environment.nsw.gov.au/air/airdata.htm and is updated daily or quarterly, depending on the parameter.

The regional pollution index (RPI)

As a consequence of a major review of monitoring needs in 1993, a regional pollution index (RPI) is calculated and reported twice daily for three regions in Sydney (Eastern, North Western and South Western), three sites in the lower Hunter and four sites in the Illawarra.

The morning RPI covers the period from 3.00 pm the previous day to 6.00 am that day (15 hours) and the afternoon RPI covers the period 6.00 am to 3.00 pm that day (9 hours). The RPI reports are based on measured concentrations of ozone and nitrogen dioxide and a measure of visibility. A simple description of how the RPI is calculated can be found on the DECC website: www.environment.nsw.gov.au/air/rpi.htm.

Variability

The observed variability for different pollutants arises from many different factors:

- the physical and chemical behaviour of the pollutants in the different seasonal weather conditions
- changes in people's travel and energy use patterns at different times of the year
- seasonal patterns in the use of wood heaters
- seasonal cycles in farming practices
- hazard reduction burning in cooler months
- the occurrence of natural events like droughts, dust storms, rainfall and bushfires.

If the total amount of air pollution discharged by sources only changes slowly, as is the case for large urban or industrial areas, then the main variability in air quality will depend on daily and weekly patterns of discharge and daily and seasonal variations in meteorology and weather.

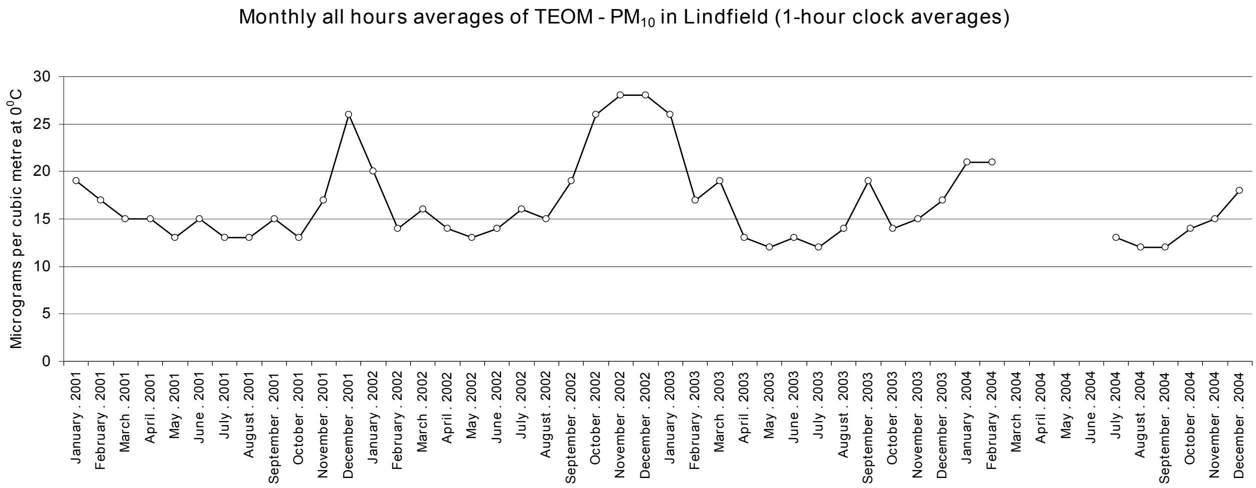
So the **changes in traffic flow throughout the day**, with morning and evening peak periods, will markedly change the rates of emissions of nitrogen oxides (NO_x) and volatile organic compounds (VOCs). Likewise activity patterns on weekdays will be significantly different from those on weekends.

Dispersion is affected by **variation in synoptic conditions.** During the day some synoptic patterns favour conditions where dispersion is governed by synoptic winds or regional sea breezes, while at night, dispersion can be influenced by regional topography and 'stable drainage' flows. More of these aspects are considered in the following section on meteorology.

Measured ambient pollutant concentrations depend on many factors and a general trend may be overlaid with the consequences of particular events.

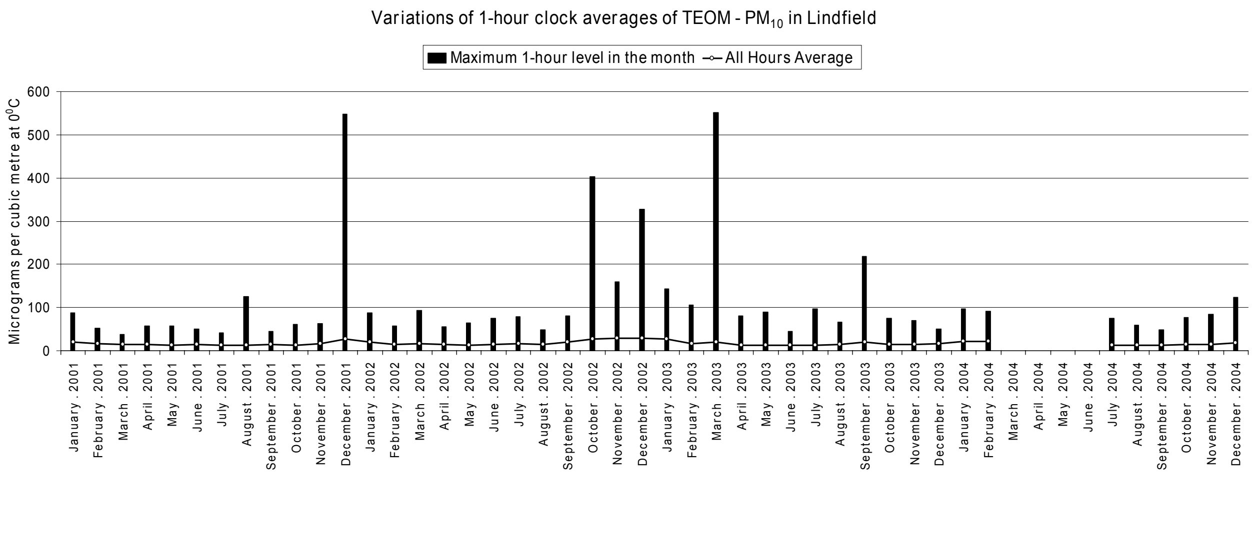
There will also be significant **seasonal influences due to weather.** Dispersion tends to be generally greater in summer than in winter. However, the higher temperatures and stronger radiation from the sun during summer makes this the principal season for photochemical smog and ozone formation. Bushfires of course occur principally in the hot summer months and contribute significantly to particulate pollution.

The graph below shows the variations in **monthly *all hours* averages** for concentrations of particulate matter at one Sydney metropolitan monitoring station, as reported in the DEC *Quarterly Air Quality Monitoring Reports*.



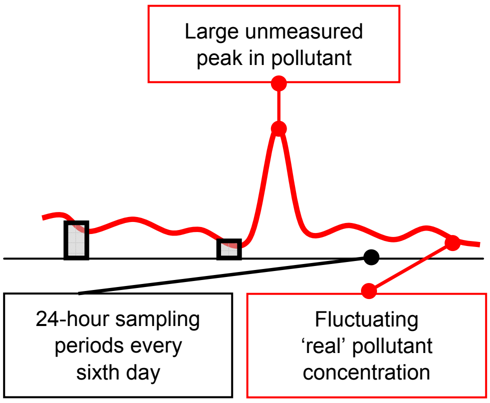
It is evident that the monthly averages smooth out large spikes in concentrations that occur over shorter periods of days or even hours. This can be seen in the next graph showing the **maximum 1-hour concentrations in each month** for the same monitoring station at Lindfield.

The two graphs here are not meant to be representative of regional or even local trends. They are intended only to illustrate variability and how different averaging methods give very different pictures.



The *Quarterly Air Quality Monitoring Reports* published by DECC contain monitoring data for the key pollutants and can be accessed at: www.environment.nsw.gov.au/air/datareports.htm

Intermittent sampling



In the case of some pollutants the sampling has been intermittent by choosing to take **24-hour samples every sixth day**. This protocol reveals trends in particulate pollution over longer periods of months, seasons and years but may miss acute events that occur on days when sampling is not done. In the diagram the sharp peak is not recorded simply because it did not occur on one of the sampling days.

Averaging periods

It is important to consider the averaging period for air pollution monitoring data. Ambient monitoring is usually carried out in accordance with NEPM monitoring protocols—that is, for the following different time periods for different pollutants:

- 1 hour (clock hour average)
- 4 hours (rolling 4-hour average of 1-hour averages)
- 8 hours (rolling 8-hour average of 1-hour averages)
- 1 day (calendar day)
- 1 year (calendar year).

In general, existing pollution and meteorological patterns result in the maximum measured concentrations becoming lower with longer averaging times; that is, a maximum daily average is typically much lower than a maximum 8-hour or maximum 1-hour average.

Air quality data for the same pollutant can only be compared for similar averaging periods.

Data for different averaging periods cannot be directly compared.

Different averaging periods are used in some aspects of air quality management such as impact assessment. These include for example:

- 10 minutes (sulfur dioxide)
- 15 minutes (carbon monoxide)
- 7, 30 and 90-day (rolling) averages (hydrogen fluoride).

Longer averaging times tend to relate to pollutants which can have longer term cumulative effects on health, vegetation or property—for example, the toxic metal lead which is described in more detail below.

Shorter sampling times tend to relate to acute, immediately detected pollutant impacts, such as those resulting from sulfur dioxide and ozone exposure.

Health and meteorological aspects of averaging

It is important to appreciate that there are two factors that are associated with the averaging times specified for air pollutants in standards:

- **health impacts**—pollutants having chronic impacts (e.g. heavy metal toxics) tend to be specified by longer averaging times, while those having acute effects tend to be specified by shorter averaging times, and
- **meteorological and climatic effects**—variability in air movements and air turbulence generally result in ambient concentrations being lower for longer averaging times for a constant rate of emission from a point source.

The relationships between averaging time and impact and between averaging time and meteorology tend to coincide, but are not necessarily identical. Hence care is needed in considering all aspects of exposure as illustrated below:

Health impacts, averaging times and exceedences

For some pollutants, clinical and epidemiological research indicates their health impact is essentially chronic and mainly due to prolonged exposure causing cumulative damage to some body organs or tissues. If this is the case, the NEPM may include a standard with a long averaging period of one year and an associated goal of zero exceedences of this. This is appropriate only on the assumption that the human body can effectively deal with somewhat higher maximum concentrations over shorter exposure times and without either irreversible damage or permanent accumulation of the pollutant within some part of the body.

For some pollutants (including those with chronic impacts), the medical evidence indicates that short term exposures do in fact have acute detrimental effects on people’s health, particularly the vulnerable in the community such as children, the elderly and those with existing medical conditions. In these cases the NEPM standards are specified for much shorter averaging periods of one, four or eight hours.

As clinical and epidemiological research continues to identify the health impacts of both long-term and short-term exposures to different concentrations of different pollutants, the air quality standards and goals, and other regulations, may be adjusted to reflect this new knowledge.

1.5 Additional campaign monitoring

From time to time DECC carries out monitoring campaigns for specific pollutants such as volatile organic compounds (VOCs), as precursors to ozone formation, and toxic air pollutants. More information is available from the DECC website: www.environment.nsw.gov.au/air/toxics.htm

1.6 Site-specific monitoring

Some large industries are required to install ambient monitors in locations affected by their operations to measure the specific impact from their emissions, where these are significant. The results of this monitoring are reported to DECC or the Department of Planning, or both departments.

Usually there are requirements established through development consent conditions for these monitoring results to be made available to the public through local monitoring committees.

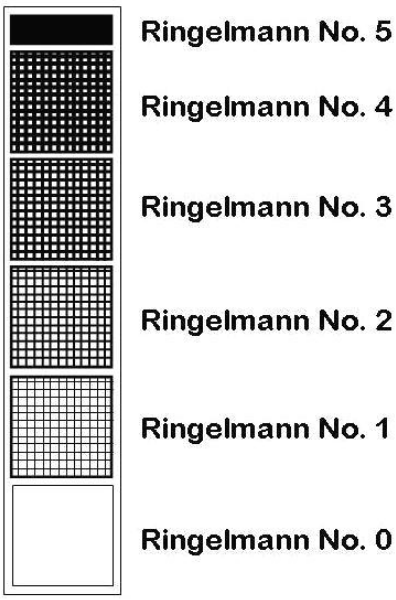
1.7 Emission monitoring and measurement

Emission concentration limits specified for non-scheduled premises are for:

- black smoke or opacity, and
- particulate matter.

Occasionally councils will wish to specify testing for toxic and odorous emissions, but most emission testing will be related to the above two forms of air pollution.

Ringelmann chart



This is a diagrammatic representation only. Always use the standard charts for readings!

Smoke and the Ringelmann chart

Incomplete combustion results in the formation of black-to-grey smoke because of the black carbon formed in the burning process. This has traditionally been measured using a Ringelmann chart under specified conditions.

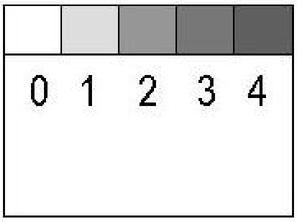
The method is described here in more detail than most emission tests since it is the one test in the Regulation which can be carried out by council officers unaided.

The Ringelmann chart

The Ringelmann chart in its original form is constructed by cross-hatching 10 cm white squares with black lines so that the squares are successively covered with black in gradations of 20% from white to completely black. The black coverage of the squares, which appear as shades of white → grey → black when viewed from the recommended distance, is then designated with a number as follows:

20% coverage	Ringelmann No 1
40% coverage	Ringelmann No 2
60% coverage	Ringelmann No 3
80% coverage	Ringelmann No 4
100% coverage	Ringelmann No 5

Miniature Ringelmann Chart



This is a diagrammatic representation only.

Always use the standard charts for readings!

Smaller, pocket-sized charts have been produced by the British Standards Association which have pigmented squares of equivalent 'greyness' to the standard chart.

Note that the North American standards for the Ringelmann method specify a different method of reading with respect to illumination. Be sure to use the Australian/British method.

The Ringelmann method

The method of using the Ringelmann chart specified in *Approved methods for sampling and analysis of air pollutants 2005* is the method specified in Australian Standard AS 3543–1989 (being equivalent to British Standard BS 2742:1969).

The principle of reading the Ringelmann chart

The principle of reading the Ringelmann chart requires comparing the shade of the smoke emitting from the top of the stack to the closest shade on the chart. It only applies to black smoke (not coloured smoke).

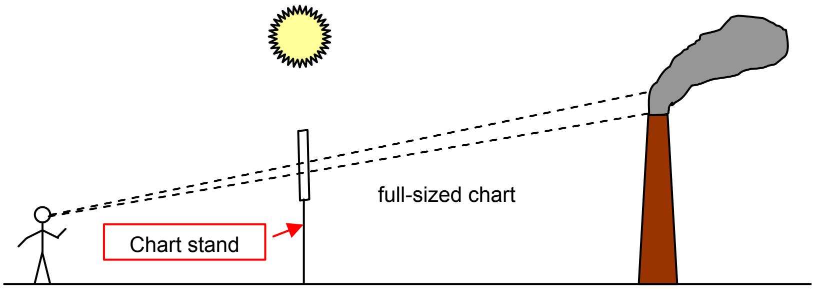
The proper location of the chart, the observer, the stack top and the sun (or sky illumination in overcast conditions) are precisely defined in the Standard and must be followed if the readings are to be accepted in any enforcement or legal action.

In practice, **reading the full size chart is difficult in most urban settings** and requires a holder which is able to be both independently secured and elevated about 4 m above the ground surface, usually at a distance of 10 to 15 m from the observer.

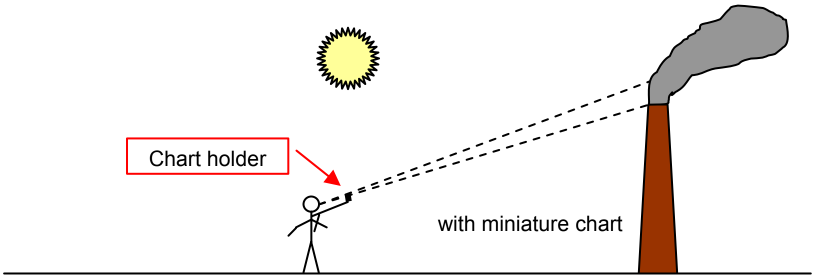
The **miniature chart**, if marginally more difficult to read consistently, **will be found easier to manipulate**. However, even this requires a small holder of about 1 m in length to read properly.

The diagrams below show configurations that could be used by local government officers.

Using the full-size Ringelmann chart



Using the miniature Ringelmann chart



> Any officer intending to use the Ringelmann chart should refer to the instructions and the Standard and follow them carefully in preparing for and making the observations.

Calibrated in-stack measurement

> The percentage 'opacity' of a gas stream is the percentage of incident light scattered and absorbed by the particles in the gas:
>
> % opacity =
> 100 – % transmittance

The POEO (Clean Air) Regulation also allows for **opacity** to be measured by a calibrated in-stack instrument. In-stack instruments operate on the principle of suspended particles scattering and absorbing a beam of light. The light transmitted through the gas carrying smoke or other particles is measured.

Approved Methods for Sampling and Analysis of Air Pollutants (AMSAAP) sets rigorous requirements for instruments measuring opacity for enforcement purposes. Note that these instruments, called 'transmissometers', are an order of magnitude more expensive than commonly installed 'smoke meters', although both types work on the same principle of measuring light transmission. With appropriate situation-specific calibration, transmissometers can be used to measure particulate emissions continuously. (See section 1.7 'Continuous particulate measurement'.)

Stack instruments can be required as conditions of consent or as part of a notice or direction in industries where maintaining clean combustion is a priority.

However, high-quality ‘transmissometer’ instruments are relatively expensive (typically $20,000 to $40,000 each) and should not be required for the majority of small-to-medium installations which are not likely to present combustion problems in operation, especially if gas fired. A simple ‘smoke meter’ usually gives adequate warning of a combustion problem to the operator.

The relation between opacity and Ringelmann limits

The opacity corresponding to the Ringelmann 1 limit in the Regulation is 20%.

However, opacity measured instrumentally can be applied to any colour ‘smoke’, unlike the Ringelmann method which can only be applied to black/grey smoke.

In-stack measurement of particles

Isokinetic testing requires that measurements of gas velocity at each testing point in the stack or duct be undertaken, and the suction into the sampling probe maintained at a rate to ensure the velocity of the gas entering the probe is the same as the velocity of the gas passing the probe—hence the term *iso* (= the same) + *kinetic* (= moving).

If the sample is not taken in this way, it will not be representative of the gas being sampled.

Particulate emissions must be measured using an **isokinetic technique** to obtain an accurate reading. This requires that a stack test be organised and set up with the necessary standard fittings in the flue or stack and with appropriate and safe access platforms for the testing team.

Isokinetic testing is important if an accurate and legally acceptable test is to be obtained for any gas stream containing particles or liquid droplets. Purely gaseous pollutants do not need to be sampled isokinetically. Isokinetic sampling can add substantially to the difficulty and cost of testing.

Many of the tests for toxic pollutants (e.g. metals, dioxins, polyaromatic hydrocarbons) may involve isokinetic testing since some of the pollutants will be present in particulate, aerosol or droplet form. Also, if the gases are very hot or contain much moisture, it may be necessary to use a heated probe for the testing (to avoid condensation on the probe).

Analysis of particulates extracted

The sample gases withdrawn from the stack are passed through an efficient filtration system and the particles collected weighed and analysed as required. The results are corrected to conditions corresponding to dry gas at 0 C and standard atmospheric pressure. If the test is made on a boiler or incinerator the result must also be corrected to 12% carbon dioxide, so a representative carbon dioxide test must also be carried out during the test.

Testing location

An important factor is to position the testing location in a section of the duct or stack which has relatively even flow distribution. Ideally this is 10 stack diameters downstream from a bend or fan outlet, but this ideal sometimes has to be compromised.

What to look out for

There are pointers for local government officers to look out for when tests are being conducted. If the testing contractor does not appear to be following sound procedure the testing and results can be questioned and a second opinion sought.

The methods are fully specified in AMSAAP and tests should only be carried out by accredited and experienced testers. The testing team should be fully familiar with the requirements of the Regulation and Standard and the situations in which the various techniques should be applied.

> The key factor to appreciate is that if local government officers specify particulate testing, the inherent methodology of in-stack measurement of particles is relatively difficult and requires considerable time and effort to organise and carry out.
>
> Thus stack tests for particulate emissions or requiring isokinetic sampling should only be specified when there is a clear justification.
>
> Typically a one-off test can cost from $5,000 to $30,000 depending on the set-up costs involved (e.g. stack openings, platforms, access ladders, etc.).

Continuous particulate measurement

The technique and instruments used for measuring opacity for compliance (the ‘transmissometers’ described in section 1.7 ‘Calibrated in-stack measurement’) can also be used for indirect continuous measurement of particulate concentrations.

There is not a simple relationship between the mass of particulate matter present in a gas being discharged and the light interference properties of the particles, thus a correlation has to be made for each situation before mass emissions of particulates can be reliably monitored. However, once such site-specific relationships are established—that is, the instruments are calibrated to the situation—continuous monitoring can be a valuable adjunct to managing environmental performance, especially for a process which is inherently variable.

Continuous gaseous measurement

Local government will only rarely have to consider gaseous monitoring of pollutant emissions, but should be aware that there are many well-developed techniques for monitoring gaseous pollutants both on a specific-testing basis and continuously.

Typical gases which can be monitored continuously include:

- nitrogen oxides
- sulfur dioxide
- volatile organic compounds (as hydrocarbons)
- acid gases
- hydrogen fluoride
- carbon monoxide
- carbon dioxide
- oxygen.

Further discussion about the nature, trends and impacts of gaseous pollutants is contained in Module 1 section 3.

More detailed technical information about the principles and operations of the instruments now available for these measurements is easily found using an internet search engine.

Odour testing is discussed further in section 3 of this Module.

The guidelines in Module 3 address particular premises or activities where odour problems typically arise.

Odour emission testing

There is no reliable method of directly measuring odour by scientific instruments. **The best odour detecting instrument remains the human nose**. Odour tests involve taking samples of air at the point of emission and quickly transferring the samples to a panel of carefully selected odour observers. The panel determines essentially the degree of dilution of the odour required to reach the point of non-detection.

There are several methods for this type of testing and it is highly specialised, and therefore also relatively expensive. Even then significant differences persist between the various methods used to measure odours.

For relatively minor problems careful field assessment of the odours might be more practical and effective than calling for expensive odour testing.

Local government officers should be aware of the uncertainties and expense involved in odour testing which usually needs to be interpreted in terms of atmospheric dispersion modelling—another expensive component of the assessment.

2 Meteorology and air quality

2.1 Atmospheric stability

For managing air quality it is helpful to have some qualitative understanding of how atmospheric conditions change with time of day or night and with wider weather conditions—in other words how the atmosphere ‘works’ at the local and regional scale[1].

> The main causes of changes in atmospheric stability are heating of land surfaces by the sun during the day and cooling of the surfaces by the radiation of heat at night.

Neutral stability

With a moderate to strong wind in moderate sunshine or an overcast sky the atmosphere will be in a state of ‘**neutral stability’**. This condition depends on the physical properties of the air and water in the atmosphere. In neutral stability the temperature of the air decreases uniformly as we go upwards, at about 1^0C per 100 m. This uniform temperature gradient continues up to about 10 km above the earth’s surface. However, the region of most interest for pollution is the lowest two kilometres.

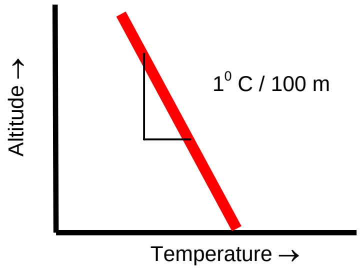
During conditions of neutral stability a parcel of air moved to a different height will have the same density after moving as the surrounding air at that height. So there is no density difference, or buoyancy, tending to move it back again.

This explains the term ‘neutral’. Also pollutants are mixed readily and predictably in the wind in neutral conditions. So they disperse and dilute as they are blown downwind from the release point.

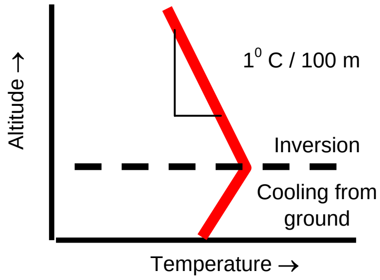
By applying meteorological science to the conditions we can predict fairly accurately what the concentration of pollutants will be at different locations away from the source.

> **Atmospheric stability**
>
> The idea of atmospheric stability is complex and can sometimes be confusing.
>
> The atmosphere is said to be **‘stable’** when conditions inhibit the *vertical motion* of air and the resulting turbulence that causes mixing and dilution of pollutants.
>
> In an **‘unstable’** atmosphere turbulence is enhanced by the conditions and so there is an increase in mixing and dilution.
>
> A **‘neutral’** atmosphere neither inhibits nor enhances air turbulence.
>
> It is an interesting fact that the atmosphere can be very unstable under some low wind conditions but at other times neutral, even with high wind speeds.

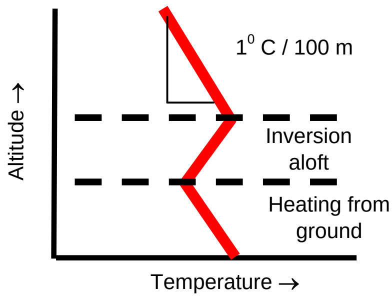
[1] This discussion of meteorology is not intended to provide a general introduction to meteorological science, but rather to introduce in practical terms those aspects of the atmosphere which are likely to be of immediate interest to local government officers.



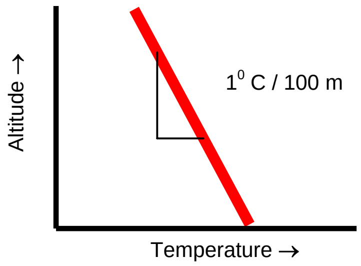
Neutral stability – mild day



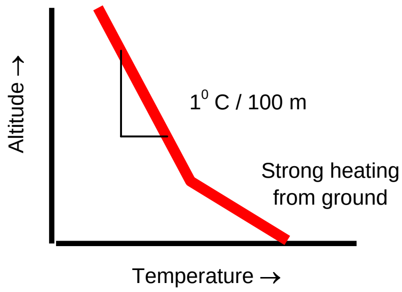
Stable, inversion – night



Breaking inversion – morning



Neutral stability restored – day



Unstable – still, hot, sunny day

Inversions

When the air temperature **increases** (rather than decreases) with height this is called a temperature inversion.

During the day the ground is heated by incoming solar radiation. After sunset, when there is no incoming solar radiation, the ground loses energy and cools. The air immediately above the ground is also cooled and becomes denser. The thickness of the cold layer of air extends upwards as the night draws on. The air below is now cooler than the air above.

So, somewhere above the ground there is now warmer air than at the ground. This is called a '**radiation** or **nocturnal inversion**'. If the term '**temperature inversion**' is used without any qualification it usually refers to this type of inversion. The lower atmosphere is now said to be '**stable**' because the higher warm layer restricts vertical mixing of air and any pollutants in it.

There are other types of inversion but the radiation inversion is the most important when considering dispersion of pollutants emitted near to the surface.

A **stable atmosphere** and a **temperature inversion** have some important effects on pollution released:

- The stable atmosphere is less turbulent and the pollution is less mixed. Both horizontal and vertical mixing are restricted. That is, the concentrations downwind are less diluted.
- The temperature inversion can trap warm pollution closer to the ground than during the day when its heat would carry it higher into the air, so with reduced height the downwind concentration is again less diluted.
- In some circumstances a temperature inversion can stop elevated pollution from reaching the ground.

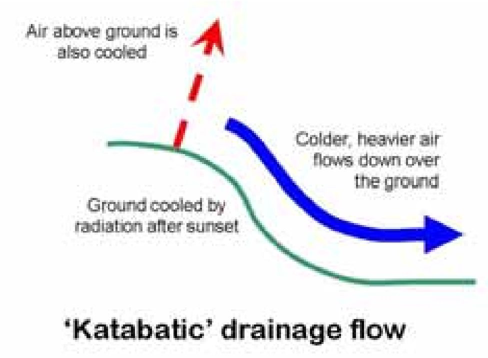
Instability

During a hot, still day, when the sun beats down strongly, the ground can become very hot and heats the air at the surface. The hot less dense air rises rapidly and results in large eddies (convection) causing an **unstable atmosphere.** The turbulence created generally results in better mixing of pollutants in the air but can also bring pollutants discharged at height to the ground.

Contrary to popular belief, very windy weather—the sort that blows our umbrellas inside out—is not meteorologically unstable. It is entirely 'neutral', just very turbulent.

Katabatic or 'down-slope' air movements

Stable cool air, formed near the ground at night, has important consequences for pollutant dilution and dispersion in valleys or land depressions. When it forms on high land such as hills or mountains, this cool air becomes denser and flows down over the sloping land surfaces into the valleys where it can accumulate in low-lying depressions. The technical term is a **'katabatic' flow** (from the Greek words *kata* = down and *batikos* = able to go).

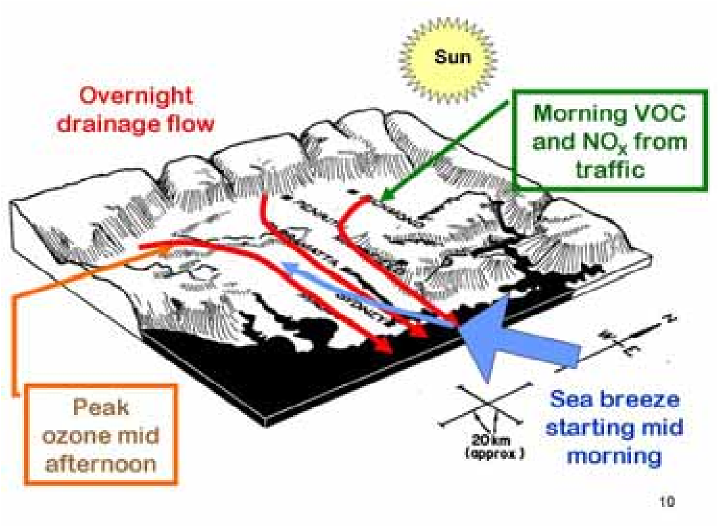


Because these drainage flows depend on the cooling and heating of the land they are not usually important when it is heavily overcast or rainy.

Under such overcast or rainy conditions the atmosphere stays 'neutral' day and night, the temperature varies less from day to night and pollution disperses in the wind in the normal way.

Nocturnal 'drainage' flow

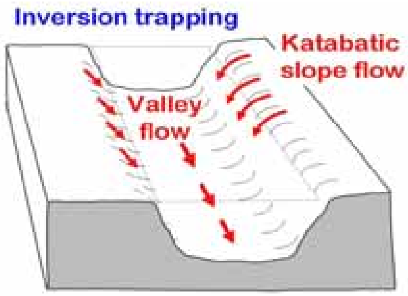
Katabatic flow coupled with inversions can play a significant role in pollutant dynamics over regions such as the Sydney Basin. The Sydney Metropolitan Area is like a huge basin with mountains to the west and hills to the north and south, but with the east side open to the ocean. Cold, stable air formed at night over the Blue Mountains and the Hornsby and Sutherland plateaus flows down into the basin and makes its way steadily eastward towards the ocean. This is sometimes referred to as the nocturnal 'drainage' flow.



Large scale air flows and pollutants in the Sydney Basin
(Based on an original drawing done by Rod Bashford of Macquarie University for a paper by E. Linacre and C. Edgar presented at a Clean Air Conference.)

The mass of cold, stable air is also under a temperature inversion and traps and suppresses the dispersion of the pollutants emitted by the city—the origin of the characteristic brown haze over Sydney on winter mornings and the white haze on summer mornings.

As the sun heats the ground it warms the air above it and begins to break down the temperature inversion and restore the air to a neutral stability. Mixing improves and the pollution disperses until it is usually no longer visible by late morning.



Slope flow and valley flow—this sort of effect is evident along the Dumaresq River in Armidale

It is the temperature inversion that traps the emissions, the drainage flow then transports the pollution—often quite effectively across a large region.

The same sort of effect is also evident in the Hunter Valley and on a smaller scale in Armidale.

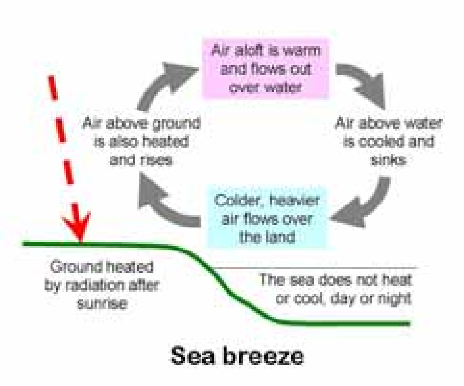
Inversions coupled with katabatic or 'down-slope' drainage flows of cold air at night trap and exacerbate pollution in regions such as Sydney, the Hunter Valley and in localities like Armidale.

When sea and land meet

There is another important effect whenever land and water meet. The temperature of a large body of water changes very little over the diurnal cycle of night-to-day and day-to-night. By contrast the land experiences much larger diurnal changes in temperature. Thus **the air over the water** tends to stay at a reasonably constant temperature day and night. But as we have seen above, the temperature of **the air over the land** does change quite markedly between day and night. This difference significantly impacts on the atmospheric movements where bodies of water like the ocean or large lakes adjoin land masses.

Sea breezes

The dynamics of air movement are such that this difference results in a sea breeze in the mid morning as the air over the land heats up, rises and is displaced by cooler air from the ocean. If it is not removed by more widespread 'synoptic flows' associated with high or low pressure regions, the hot air goes out to sea aloft, is cooled above the water, then settles and flows back over the land again. That is, a circulating cell may be set up and a sea breeze is created from the ocean to the land.



There are two effects on pollution in places like Sydney. The first is beneficial in that the sea breeze can bring in clean air from out to sea. The second is a detrimental effect, the accumulated pollution of overnight and early morning emissions caught in the drainage flow is blown back over the land by the sea breeze from mid morning to mid afternoon—Sydney then gets a double dose of its own pollution!

Smog in Sydney

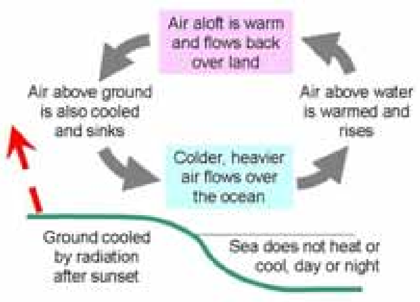
As we will see in section 3 of this Module, the sea breeze plays an important role in the formation of photochemical pollution in the Sydney Basin, which usually needs about three to four hours for the ingredient pollutants to 'cook' and form photochemical 'smog'. By the time they reach south-western parts of the basin in mid to late afternoon, emissions from the whole city, including from the western and north-western suburbs in the morning, are well cooked and can deliver a peak dose of 'smog'.

Of course there are also emissions from the Sydney CBD that contribute to the mixture. Sometimes the emissions from the previous day are also re-circulated by the combination of the sea breeze and drainage flows.

The overnight drainage flow and the sea breeze interact to influence pollution in Sydney, especially during summer when photochemical smog forms.

Land breezes and anabatic flows

The reverse of a sea breeze is a land breeze at night. At night the air over the ocean remains warmer than the air over the land due to the faster cooling of the land compared to water. The colder heavier air over the land then flows offshore to replace the warmer air above the water. A circulating cell that is the reverse of the daytime one may be set up, although the offshore land breezes are typically much weaker than the onshore sea breezes.



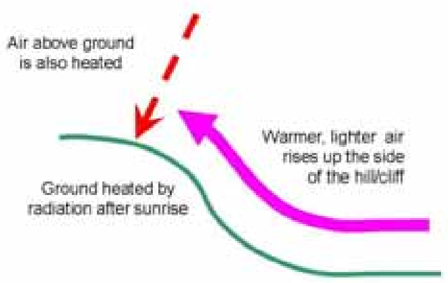
Land breeze

If the offshore flow is supported by a katabatic drainage flow, as it is in Sydney, then this tends to strengthen the flow of air from the land to the ocean at the shore. Similar effects can occur over other water bodies, notably lakes and dams, depending on their depth and capacity to hold heat.

Up-slope flow near steeply rising land

As there is a reverse of the sea breeze so there is a reverse of the katabatic flow, namely an **anabatic flow** (from Greek *ana* = up). This is usually only experienced in the vicinity of steeply rising land, such as the cliffs and mountains adjacent to the Illawarra coast.

The morning sun heats the cliff faces or mountain sides and this in turn heats the air next to it which rises rapidly. This is less important for air quality than the katabatic flow.



'Anabatic' up-slope flow

2.2 Pollution discharge and dilution

Pollution is moved as a plume by wind from a chimney or stack into the environment where it changes the quality of the air. The change in air quality depends essentially on two factors:

- the amount of pollution discharged, and
- the way in which the air moves in the atmosphere.

There is a simple relationship between **the amount of pollution** released from a source and air quality. Double the pollution discharge and the concentration of pollutant on the ground downwind also doubles, all other things staying the same.

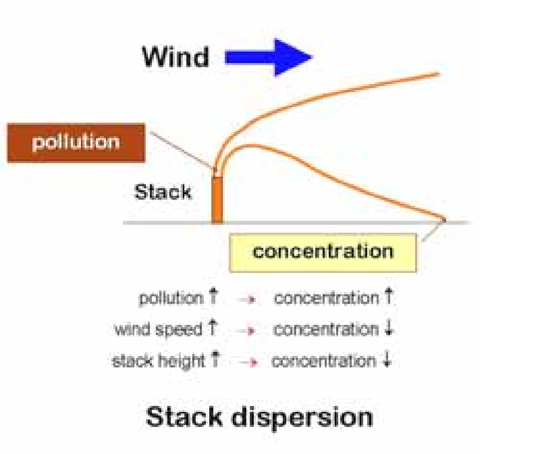
In general the **faster the wind speed** the more the dilution of the pollution from a stack and the lower the concentration. This is also a simple relationship—double the wind speed and halve the concentration, all other things staying the same.

The **further from the source** the greater the dilution of the pollution, with a few important exceptions explained below. But this is not a simple relationship—doubling the distance generally more than halves the concentration.

The **effective height of discharge** also influences the concentration of pollution at ground level. Generally the higher the effective height of discharge the less the maximum concentration of pollutant at ground level. But again this is not a simple relationship.

Dilution of pollution in the air, or 'dispersion' is quite complex and is understood through the science of meteorology. The capacity of the atmosphere to dilute pollution is also dependent on the mixing properties of the air blowing over the surface of the ground or water. This is the already described 'stability' of the atmosphere.

A 'plume' is a trail of pollution issuing from a localised source that spreads out as the trail travels downwind.



The **effective height of discharge** is composed of the physical stack height plus the plume rise due to its buoyancy and exit velocity.

Thus the temperature, the volume and the velocity of the gas being discharged are important factors determining ground level pollutant concentration.

However, the most significant factor for most premises that are regulated by local government will be **the height of the stack in relation to its surroundings**.

The concentration of pollution in the atmosphere downwind from a source depends on:

- rate of pollutant discharge
- wind speed
- distance downwind from the source
- effective height of the discharge
- stability of the atmosphere, and
- ground surface features (e.g. vegetation, trees and hills).

Of course all of the above relationships only apply to the dilution process alone. If pollutants are reacting in the atmosphere, such as in the case of photochemical pollution, then the concentration of an undesirable pollutant such as ozone may increase with distance from the source.

2.3 Behaviour of pollution plumes

Pollution released from a source, typically a stack from an industry or business, moves in a **plume**. In days gone by visible pollutants could be observed moving in a plume. Because of more effective removal of particles from industrial and vehicular emissions, much pollution is now invisible but is still very real.

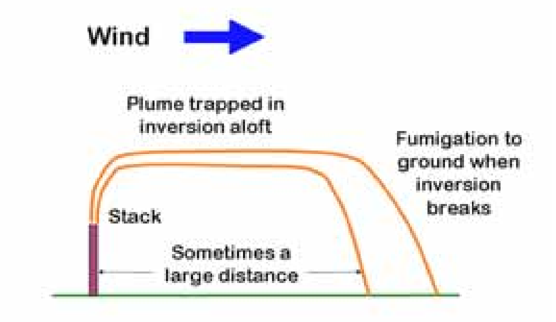
As described above, the wind, the atmospheric stability and the **effective** height of release (that is, the stack or chimney height plus plume rise) essentially govern the way the plume disperses in ideal circumstances. However, circumstances are rarely ideal and some examples will show how the first three factors can interfere with 'ideal' dispersion.

The way the plumes disperse depends on:

– the meteorology
– the topography
– the surrounding buildings, and
– the emission characteristics.

Trapping by or above an inversion layer

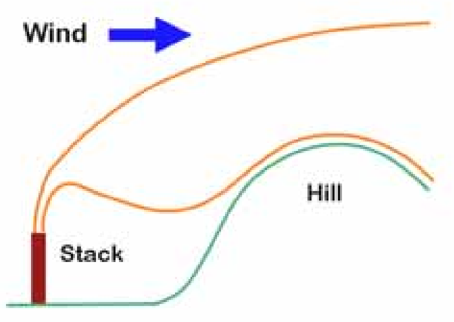
If the plume becomes trapped in an **inversion layer aloft**, the pollution can be transported, sometimes a large distance from its source and then **fumigate** to ground level. If the emissions are above the stable inversion layer the phenomenon called 'lofting' occurs. In either case, when the pollution moves to ground level, it can be difficult to trace its source.



Fumigation

Nearby hills

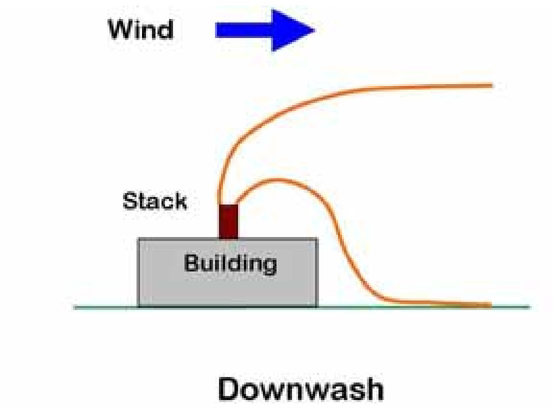
If there are medium to large hills or mountains near sources the plumes can impinge on this higher ground causing higher levels of pollution than would be the case in the 'ideal' situation. This effect is likely to be more important under stable atmospheric conditions.



Impingement

Nearby buildings

Most stacks that release pollutants are near or on buildings. These buildings affect the normal air flow around them. We become aware of this in windy weather when we can be hit by a blast of air on coming around the corner of a building. The effect on pollutant plumes in all wind conditions is to cause some 'downwash' of the plume and higher concentrations closer to the source than would occur for 'ideal' dispersion.



2.4 Predicting pollution effects

Several well proven air dispersion models that take account of all these factors are described in section 2.6 of this module. They require specialist expertise in air sciences and computing. Such services are best contracted as required for accurate predictions.

> Air pollution concentrations can be predicted by accurate modelling by dispersion experts. However, a practical knowledge of the factors affecting plume dispersion can address simple small-scale problems without the need to resort to expensive modelling.

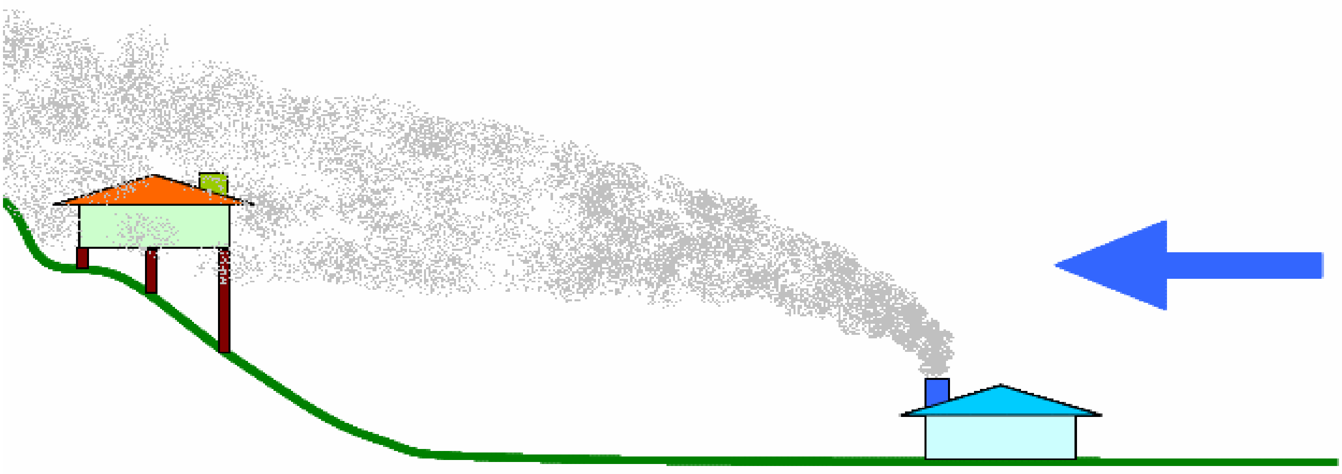
2.5 Two practical examples

Two examples of relevance to local government air quality management are described below. They illustrate how a **practical, qualitative understanding** can be a useful guide when assessing premises or activities.

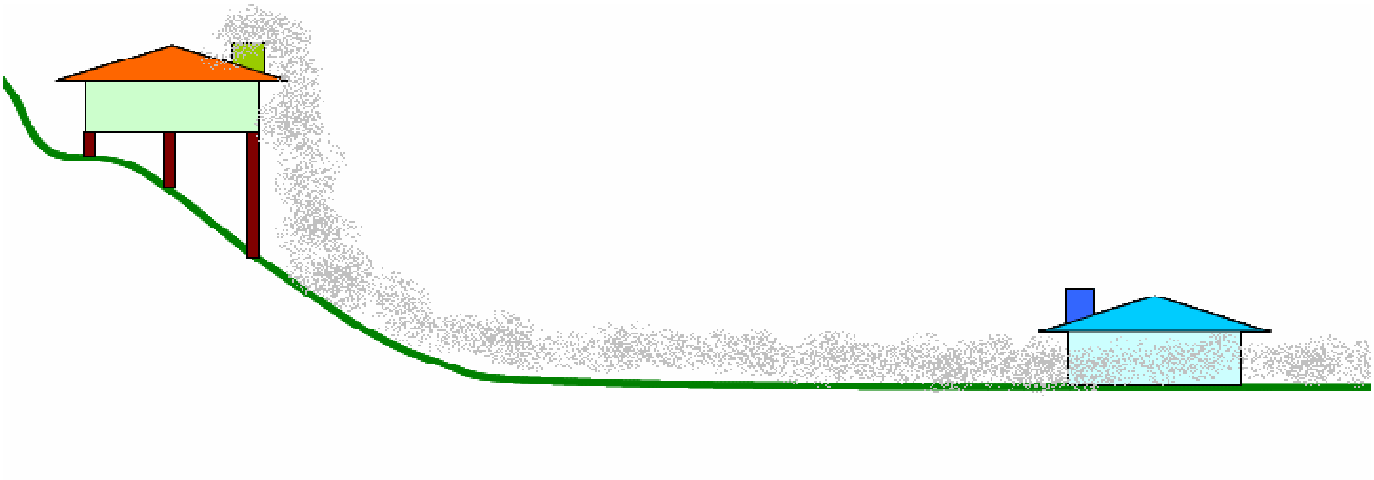
Domestic wood smoke in a valley

Near steeply rising ground, simply raising the height of the chimney on domestic wood heaters to the 'regulation height' above the roof line is not likely to be entirely effective.

In windy weather the plumes from lower houses will impinge on houses at higher levels.



On still nights the emissions from higher houses will be caught in the katabatic flow and tend to accumulate in the gullies below.



Understanding these sorts of situations and achieving satisfactory solutions can be achieved by applying the qualitative meteorological principles described above, without the need for expensive quantitative modelling.

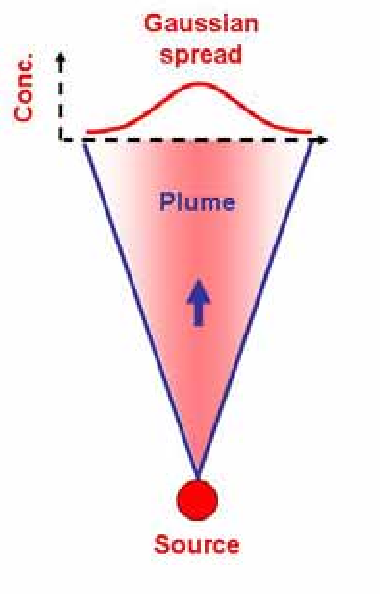
Stacks on seafront food shops

Fast-food shops are often located on the sea front in many coastal towns and suburbs. If the stacks were to be positioned on a low roof on the ocean side of a block of flats, food odours are likely in the flats whenever the sea breeze blows in mid-morning to early afternoon—that is, during lunch time.

The left hand photograph shows three fast-food shops in front of a multi-storey block of flats and over the road from the seafront at Bondi Beach.

Rather than three small stacks, each the ‘regulation height’ above the shops’ roofline, the local council has required all three to be serviced by a single large stack that is behind the flats and ‘the regulation height’ above the roof line of the block, as shown in the photograph on the right.

2.6 Air quality modelling



Air quality modelling is the prediction of pollutant concentrations in the area affected by a source or sources of air pollution. It takes account of meteorology, topography and the built environment or the area. It relies on:

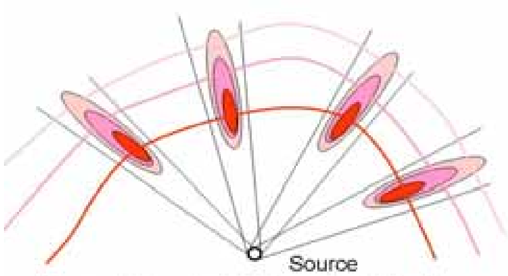
- the **physics and chemistry** of dispersion and reaction of pollutants in the atmosphere, and
- **mathematical formulations** of the physics and chemistry being translated into computer programs for ease of carrying out the multiple calculations required.

Pollutants have traditionally been assumed to disperse in a **Gaussian fashion** in the atmosphere. This means that if a set of concentration samples were taken simultaneously across the direction of movement of a pollutant plume, then a plot of concentration against cross-wind distance would look like the characteristic 'bell-shaped' curve of a normal statistical distribution, the Gaussian curve. The peak concentration would be at the centre of the plume.

Gaussian mathematics is used to predict the concentration of a pollutant at any point in space downwind of the pollution source. A computer can then calculate the downwind pollutant concentrations for a source across the full range of situations corresponding to the weather variations at the location—that is, wind speeds, wind directions and atmospheric stability. It is usual to apply hourly data for a year—that is 8,760 meteorological variations. When there is no local meteorological data, files of data typical for the region are used.

The computer can also calculate concentrations for multiple sources of pollution or area sources.

Isopleths



Concentration calculated for each wind direction and stability condition for each hour of the year. The concentrations are then summed by the program and isopleths drawn.

The resultant predicted concentrations are then added together by the computer and analysed as frequencies of concentrations experienced at various locations. The results are usually plotted as **concentration isopleths** on a map around the source. An isopleth is a line joining points of equal predicted concentration.

It is possible to produce concentration isopleths for time periods corresponding to the averaging periods in different air quality goals. For example, for sulfur dioxide, figures could be drawn separately to show isopleths for any or all of the predicted 10-minute, 1-hour and annual average concentrations.

Background air quality

In undertaking an assessment, consideration must also be given to the existing air quality of the region, the so-called **background concentrations** due to the diverse range of activities operating, most of which will not be included in the dispersion modelling. Often information on existing air quality will not be available and it must be estimated from nearby, or similar, areas. In areas with high background concentrations the addition of a new emission source may result in unacceptable predicted air quality impacts, requiring the consideration of mitigating measures.

AusPlume

The Australian version of the Gaussian model is the **AusPlume model.** It has been developed and maintained by the Victorian Environment Protection Authority over a period of more than three decades. (See www.epa.vic.gov.au/Air/EPA/pub391.asp)

It is generally adopted in most Australian jurisdictions and has a good record of reliable prediction, if applied with sound judgment and experience. However, there are many models derived from this basic Gaussian dispersion assumption. The US EPA's ISC model, also a Gaussian model, is widely used, giving similar results to AusPlume.

Puff models

In some situations, due to complex terrain or the need to accurately predict short-term concentrations, a more complicated type of model can be used. This assumes the dispersing pollutant behaves like a set of discrete 'puffs' or expanding clouds of pollutant in the atmosphere, rather than a continuous plume as in the Gaussian model.

These so-called 'puff models' require more complex meteorological inputs and are more difficult and expensive to run. One commonly used in Australia is CALPUFF, a model approved by the US EPA for assessments involving complex meteorological situations.

TAPM

CSIRO's Air Pollution Model (TAPM) eliminates the need to have site-specific meteorological observations. Instead, the model predicts the three dimensional flows important to local-scale air pollution, such as sea breezes and terrain induced flows, against a background of synoptic-scale meteorological analyses.

The model is also able to account for differences in vegetation and soil properties across the region.

The **air pollution component of TAPM** uses the predicted meteorology and turbulence from the meteorological component, while the **Plume Rise Module** is used to account for plume momentum and buoyancy effects for point sources.

TAPM is also able to model chemical processes, such as the formation of photochemical smog.

More information can be found at www.dar.csiro.au/tapm/.

TAPM modelling uses a significantly different approach from the Gaussian plume models.

In Gaussian modelling the rate of dispersion of the plume is expressed as a mathematical function of atmospheric stability and distance from the source. Thus it requires site-specific wind data as well as a methodology for determining atmospheric stability.

TAPM on the other hand solves the fundamental equations of atmospheric motion and plume dispersion. It calculates the wind-fields and the motion and dispersion of plumes directly.

Features such as sea breezes and thermal internal boundary layers, which require specific methods for Gaussian models, are calculated naturally as part of TAPM.

Using modelling in the local government context

The experience and background of the modeller are critically important to achieving useful results. Predictions made by even the most experienced modellers should be treated as broadly indicative of the likely outcome.

The reliability of modelling results should not normally be pressed beyond about ± 20% for typical applications likely to be encountered in local government situations. **Computer models are only as good as the information put into them and the soundness of the assumptions made when using them.**

Local government officers need to be able to make sensible judgements as to when modelling is called for in the context of air quality issue and the comparative cost of mitigation measures.

Guidelines for both specifying and interpreting the reports from this type of specialist consulting service are set out in the introduction to Module 3 of the Toolkit.

3 Air pollutants

‘Air pollution’ can be said to be occurring when substances that have a detrimental effect on the environment are present in the air in greater than natural amounts.

In 1998 Commonwealth, State and Territory governments established national standards for **six key air pollutants**. This section deals with these and other pollutants commonly encountered in urban and rural areas, including their chemical and physical properties and recent trends in their occurrence in NSW. Particular emphasis is given to the pollutants which are most commonly managed and regulated by local government

For the purposes of management air pollutants can be conveniently grouped into four broad categories:

- gases
- particles
- odours
- toxics.

These four categories are neither strictly ‘scientific’ nor are they based on the key air pollutants, but they help to explain the occurrence and impacts of air impurities.

The six ‘**key air pollutants’** are also called ‘**criteria air pollutants’**. They are:

sulfur dioxide (SO_2)

carbon monoxide (CO)

nitrogen dioxide (NO_2)

ozone (O_3)

lead (Pb)

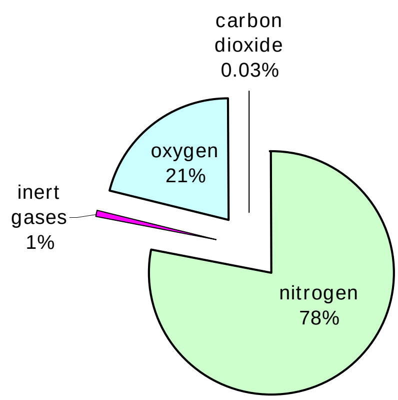
particles less than 10 μm.

Ozone is one of several ‘photochemical oxidants’ that are formed when a mixture of other pollutants in the air are exposed to sunlight to form the smog that is familiar in urban areas like Sydney.

3.1 The normal atmosphere

The atmosphere is made up mostly of gases with other microscopic liquid and solid particles (aerosols) dispersed in them. In ‘normal’ air the most abundant of the gases is nitrogen (N_2) making up about 78% of the volume. It is chemically unreactive at normal temperatures. The next most abundant gas is oxygen (O_2) at about 21%. Oxygen is a basic necessity for most living organisms and is the gas that supports combustion. Water vapour makes up a small, variable fraction of air (from 1%–3%). Evaporation and condensation of water play a significant role in atmospheric dynamics. Carbon dioxide (CO_2), a contributor to the greenhouse effect, makes up only 0.03% of the volume. This is less than the inert gas argon, which with other inert gases makes up nearly 1%. Water vapour also plays a significant ‘greenhouse’ role in the normal regulation of the earth’s temperature.

In addition, ‘normal’ air contains trace levels (that is, less than 0.002%) of gases that when present in larger concentrations are regarded as impurities or pollutants. Examples are sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen oxides (NO_x), ozone (O_3), ammonia (NH_3) and methane (CH_4).



Volumes of gases that make up ‘normal’ air

Water vapour is the gaseous phase of water. It should not be confused with mist or clouds which are made up of small droplets of condensed liquid water.

3.2 Gaseous impurities

Sulfur dioxide (SO_2)

Carbon monoxide (CO)

Nitrogen oxides (NO_X)

Volatile organic compounds (VOCs)

Ozone (O_3)

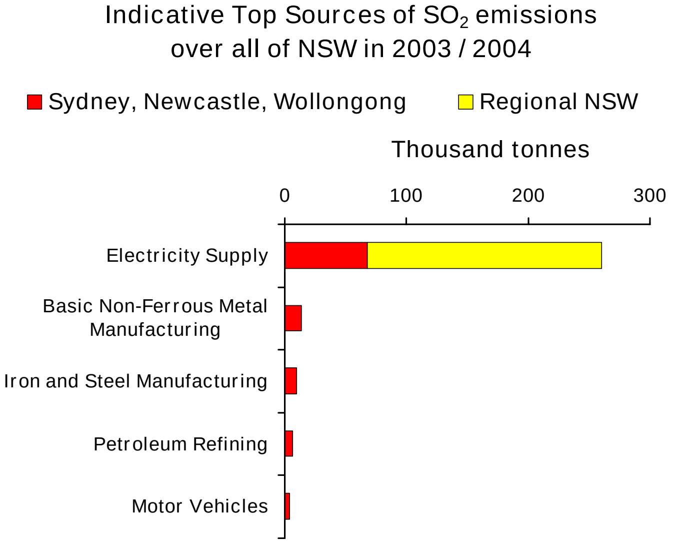
Sulfur dioxide

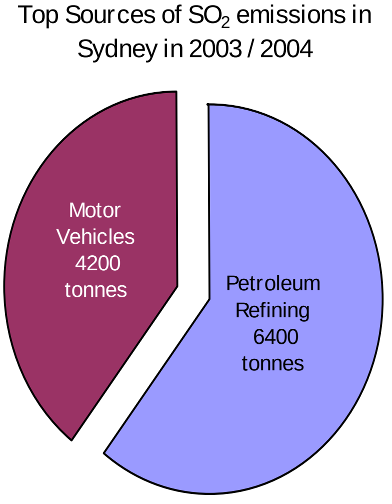
Sulfur dioxide (SO_2) is a colourless gas with a sharp, nasty smell, but it is usually noticed as a salty chemical taste in the mouth before being smelled. It is one of the six key air pollutants for which national goals have been set.

Sources of SO_2

Globally, human activities contribute over 100 million tonnes of SO_2 each year, mainly from the combustion of coal and fuel oil, with some contribution from the processing of mineral ores.

Significant amounts of SO_2 are also emitted in volcanic eruptions. For example, it is estimated that the 1991 explosion of Mt Pinatubo in the Philippines blasted from 15 to 30 million tonnes of sulfur dioxide into the air, as well as huge quantities of particulate matter.





Sulfur dioxide data from the National Pollutant Inventory

In NSW by far the largest contribution is from coal-fired power stations located outside of Sydney. In Sydney itself SO_2 is also present in motor vehicle emissions but this is now a less important source because national standards have already significantly reduced sulfur levels in fuels and will do so more in the future.

Impacts of SO_2 on human health

The effect of SO_2 on human health is to irritate the nose, throat and airways so as to cause coughing and shortness of breath. It aggravates asthma and chronic bronchitis and increases susceptibility to respiratory tract infections. The molecules can attach themselves to particles and if these are then inhaled they can cause more serious effects such as emphysema from long-term exposure.

A concern with SO_2 is people's short-term exposures to high concentrations in the near vicinity of activities that emit significant amounts of the gas, which under some meteorological conditions may be brought to ground level in high concentrations. Infrequently, high concentrations may also occur due to abnormal conditions within a facility—through industrial accidents or breakdown of poorly maintained equipment.

While SO_2 is the principal sulfur compound that is introduced into the atmosphere through human activities, it is only one of several sulfur compounds that participate in a global sulfur cycle. Others are hydrogen sulfide (H_2S, 'rotten egg' gas), dimethyl sulfide $(CH_3)_2S$ and sulfur trioxide (SO_3). These all participate in complex chemical reactions in the atmosphere.

These reactions can result in the oxidation of sulfur dioxide to sulfate ions in rainfall, a component of **acid deposition**. Another chain of reactions results in the formation of sulfate salts as fine particles that contribute to haze and may play a role in climate change.

Acid deposition

This refers to the deposition of aqueous acids, acid gases and acid salts from the atmosphere.

It has two components:

'**wet deposition**' (or 'acid precipitation' or 'acid rain'—although all rainfall is slightly acidic due to dissolved CO_2)

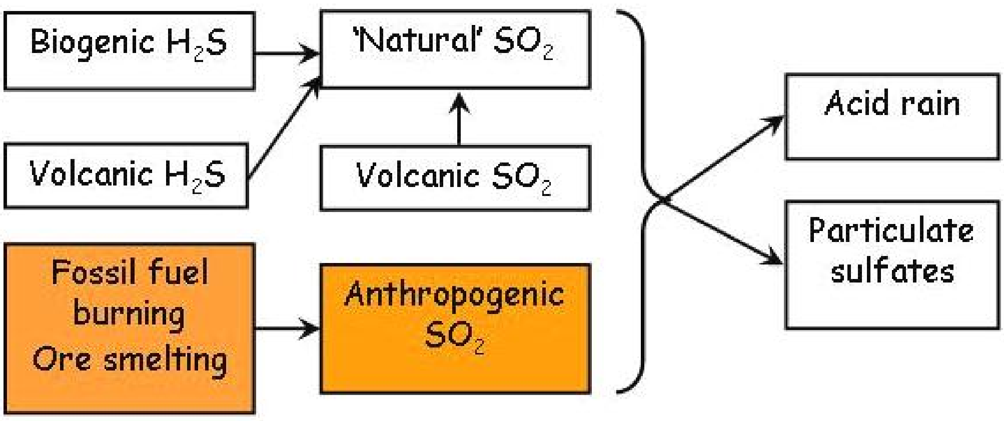
'**dry deposition**' of gases and particles.

In parts of the world where ecosystems are sensitive and acid deposition is high, the problems include:

– the death of fish and other aquatic fauna
– a reduction in forest and crop productivity
– leaching of heavy metals from soils and sediments.

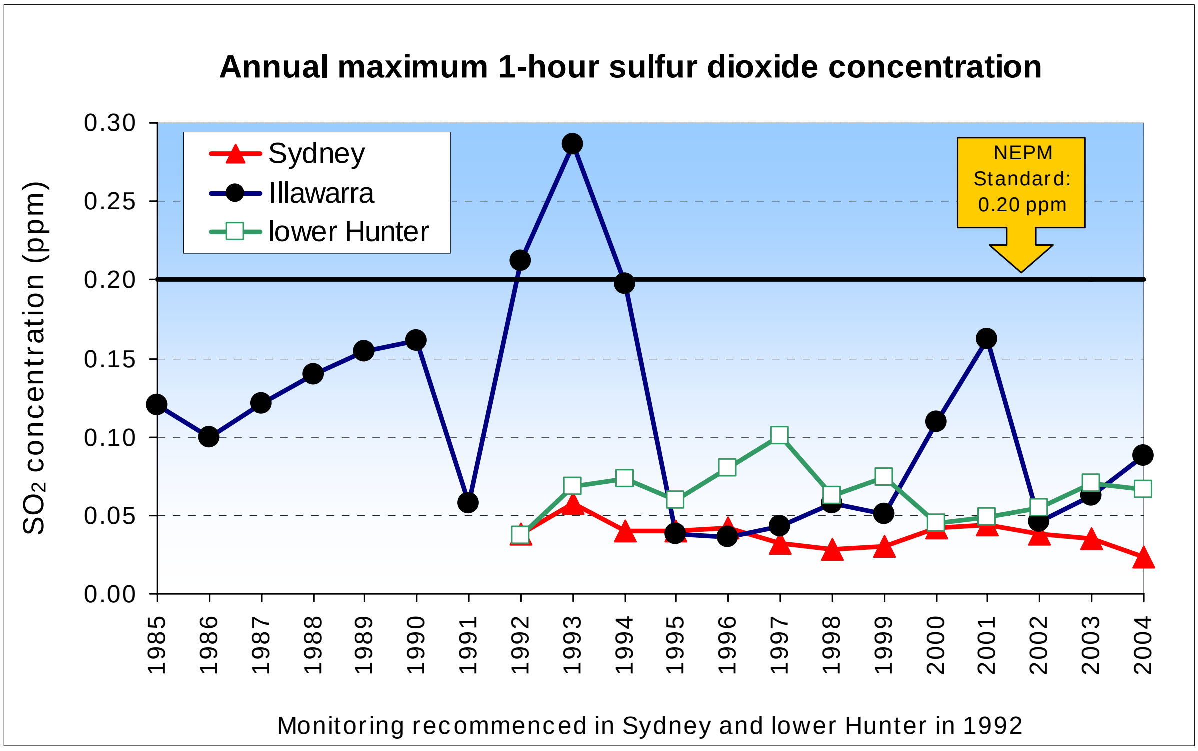
Other problems may include:

– dissolution of metals in water pipes
– the corrosion of exposed metal
– dissolution of surfaces of limestone buildings.



Trends in ambient SO_2 levels

Monitoring data for ambient levels of sulfur dioxide for the Sydney region, the Illawarra and lower Hunter are shown below.



The National Pollutant Inventory

The National Pollutant Inventory (NPI) gives information on the types and amounts of pollutants being emitted to the Australian environment.

There are three main ways that data are obtained for the NPI database:

– medium to large industrial facilities measure and/or estimate and report their emissions to the government

– State and Territory governments estimate generically the emissions from smaller facilities

– State and Territory governments estimate emissions from mobile and non-industrial sources (such as emissions from activities like driving to work and mowing the lawn), and other sources of pollutants.

NPI data can be useful for an overall view of the types of sources responsible for pollutant emissions in a particular area, and the differences between the large urban centres and regional areas. **However, caution is required in using NPI data for air quality assessments.** In assessing potential impacts, consideration must be given to the location and manner in which pollutants are emitted as well as the actual quantity of pollutant emitted. Also, the quality of the data recorded in the NPI is unavoidably variable.

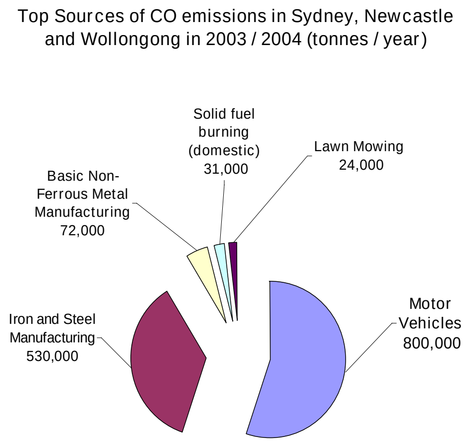
Carbon monoxide

The overall levels of carbon monoxide are now below the NEPM standard, with most of the emissions being from motor transport.

Carbon monoxide (CO) is another of the key air pollutants for which national goals have been set. It is a colourless and odourless gas.

Sources of CO

CO is a product of the incomplete combustion of organic material and its main natural sources are volcanoes and bushfires. Sources associated with human activities are motor vehicle emissions, some industrial activities such as steel making, and stubble burning. Tobacco smoke is one of the main sources of exposure indoors. The greater part of total CO emissions is from motor vehicle usage and this is predominantly in large urban centres.



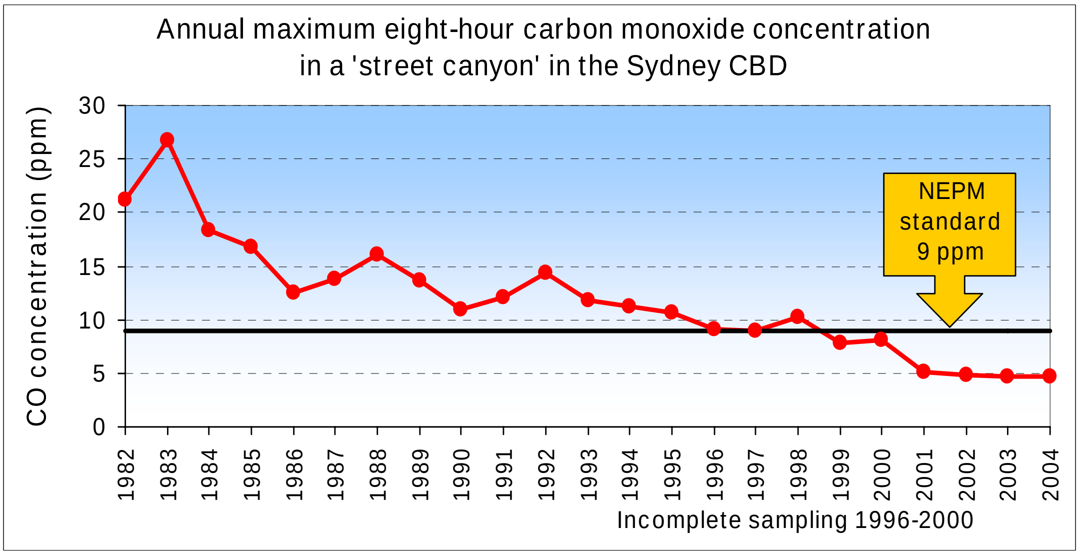
Carbon monoxide data from the National Pollutant Inventory

Impacts of CO

High levels of CO are poisonous to humans, affecting both healthy and unhealthy people alike. It acts by combining with haemoglobin, preventing normal uptake of oxygen and so reducing the oxygen carrying capacity of blood. This means that at high CO levels vital bodily organs may be deprived of oxygen and therefore cannot function properly. Fortunately the effects are reversible when the person is no longer exposed to the gas. People with cardiovascular disease are particularly susceptible to exposure to high carbon monoxide levels.

Trends in ambient CO

In most Australian cities and towns the levels of CO in air are now below those that are hazardous to human health. The NEPM goal of less than 9 ppm set for 2008 was achieved by 2000 through implementing catalytic vehicle emission standards. The highest levels of CO are likely to be experienced in the 'canyons' of city streets and nearby busy roads.

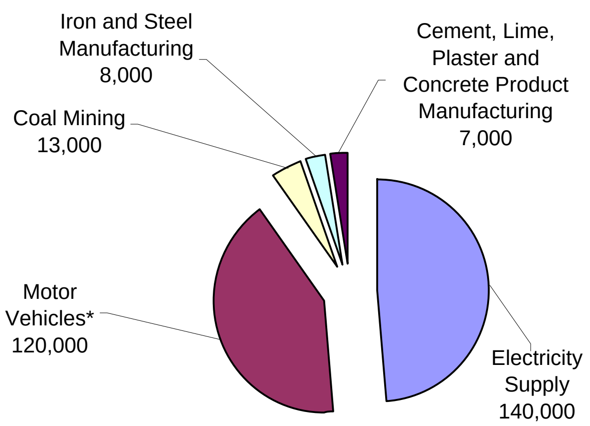


Nitrogen oxides

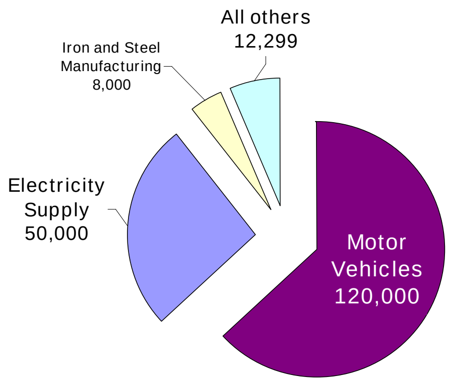
The two nitrogen oxides that are important air pollutants are nitric oxide (NO) and nitrogen dioxide (NO_2), collectively called NO_x. NO is a colourless, odourless gas and NO_2 is a brownish, highly reactive gas with a nasty acrid smell when in very high concentrations. However, it is normally neither smelled nor visible in the atmosphere.

NO is the primary form in which NO_x is emitted, but it is usually converted relatively rapidly in the atmosphere to the more reactive NO_2 which is one of the six key pollutants included in the Air NEPM. Nitrogen oxides are important pollutants because they contribute to the formation of photochemical smog which can have significant impacts on human health. This is treated in more detail in the next section.

NO x emissions in NSW: 2003 to 2004 (tonnes/yr)



Top Sources of NO_2 emissions in Sydney, Newcastle and Wollongong in 2003 / 2004 (tonnes / year)



Nitrogen dioxide data from the National Pollutant Inventory

Sources of NO_x

Some NO is formed naturally in the atmosphere by lightning and some is formed biologically. However these natural sources contribute only about 1% of the NO_2 found in urban air.

When both urban and regional areas in NSW are added together, according to the NPI, coal-fired power stations supplying the electricity grid (46%) and motor vehicles (40%) contribute the majority of NO_x across the State.

However, there are significant differences between the large cities and rural areas. Sydney, Newcastle and Wollongong account for virtually all of the State aggregate from motor vehicle emissions. These emissions contribute 63% of NO_x in these urban areas.

In rural areas motor vehicle emissions are insignificant and the main sources here are electricity generation (80%) and coal mining (11%).

The major impacts of NO_x are:

- reaction with volatile organic compounds (VOCs) to form photochemical smog.
- direct impact on human health as NO_2.

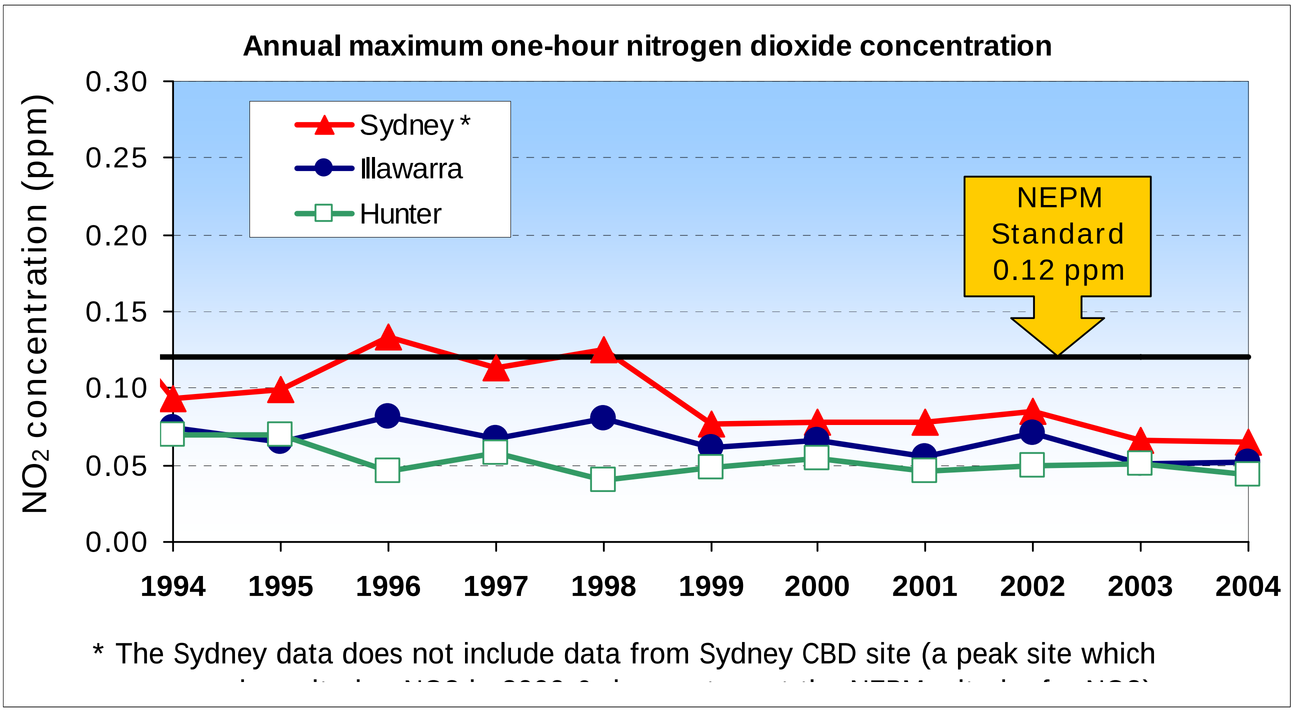
The reaction of NO_x with volatile organic compounds to form photochemical smog is considered in the next section.

Impacts of NO_x

Acute exposure to NO_2 is harmful to human health. Fatalities have been reported due to gases containing NO_2 being inhaled when celluloid is burning. Also, in the case of ‘silo fillers disease’, NO_2 poisoning has occurred because fodder containing nitrate has fermented and produced NO_2.

Trends in NO_2 levels

Monitoring data for regional areas in NSW and other States shows that the maximum values are low by comparison with the Air NEPM. The graph shows data for the Sydney, Hunter and Illawarra regions.

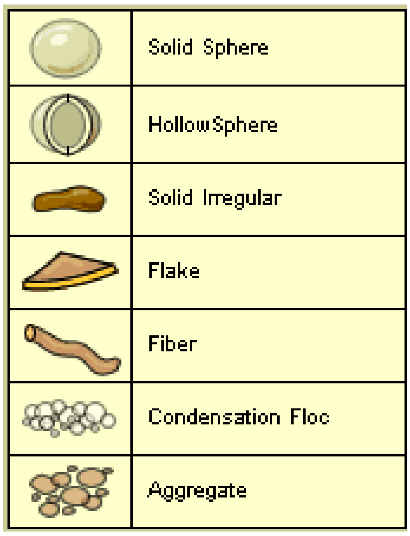


Volatile organic compounds

Volatile organic compounds (VOCs) enter the atmosphere from many diffuse sources including petrol vapour from unburned fuel from motor vehicles, service station pumps, spills from lawn mowers and evaporation of solvents in industrial activities. Their significance in the generation of photochemical smog and ground level ozone is described in section 3.4 below.

3.3 Particulate matter

Particulate matter is the term used to describe the particles that remain suspended in the air for periods longer than about a minute because of their small size. The particles may be solid or liquid and as haze over a region or city are one of the most obvious forms of air pollution.



Adapted from the website of the US EPA

Size and shape of airborne particles

Particles emitted from air pollution sources and formed by natural processes have many different sizes and shapes, and a range of densities, from that of water (1 g/cm^3) to more than that of rocks (about 3 g/cm^3). Unlike the other criteria pollutants which can be unambiguously defined in terms of their chemical composition, 'particles' can be composed of a diversity of elements and compounds which may be of natural or anthropogenic origin.

In managing air quality involving particulates it is necessary to use a definition of particle size that relates directly to how the particles behave in moving and still air, and so how they penetrate into the lungs. The idea of 'aerodynamic diameter' has been developed to provide such a definition. It takes account of the particle's physical size, its density and its shape.

Particles of different shapes and densities can have the same aerodynamic diameter and so be grouped in the same size category. In the same way, particles that look very similar in size under a microscope may be in different size categories.

Atmospheric particulates are microscopic, so a very small unit of length is needed to indicate their size.

In the metric system the unit that is the right size is the 'micrometre' which is one millionth of a metre and has the symbol 'µm'

It used to be called the 'micron' and this name still appears in many documents.

1 µm = 1 micron = 10^{-6} m

Whenever a particle 'size' is specified in air quality management it refers to the aerodynamic diameter of the particle.

The 'aerodynamic diameter' of a particle of any size, shape and density is the diameter of a spherical particle with a density of one g/cm^3 which behaves the same way in air.

Particle size terminology

The terminology used to describe and categorise particles of concern for air quality management is somewhat complex. The US EPA uses two classification schemes that break up the wide range of particle sizes into smaller categories that relate to their potential impact on human health.

A descriptive categorisation is given in the table below:

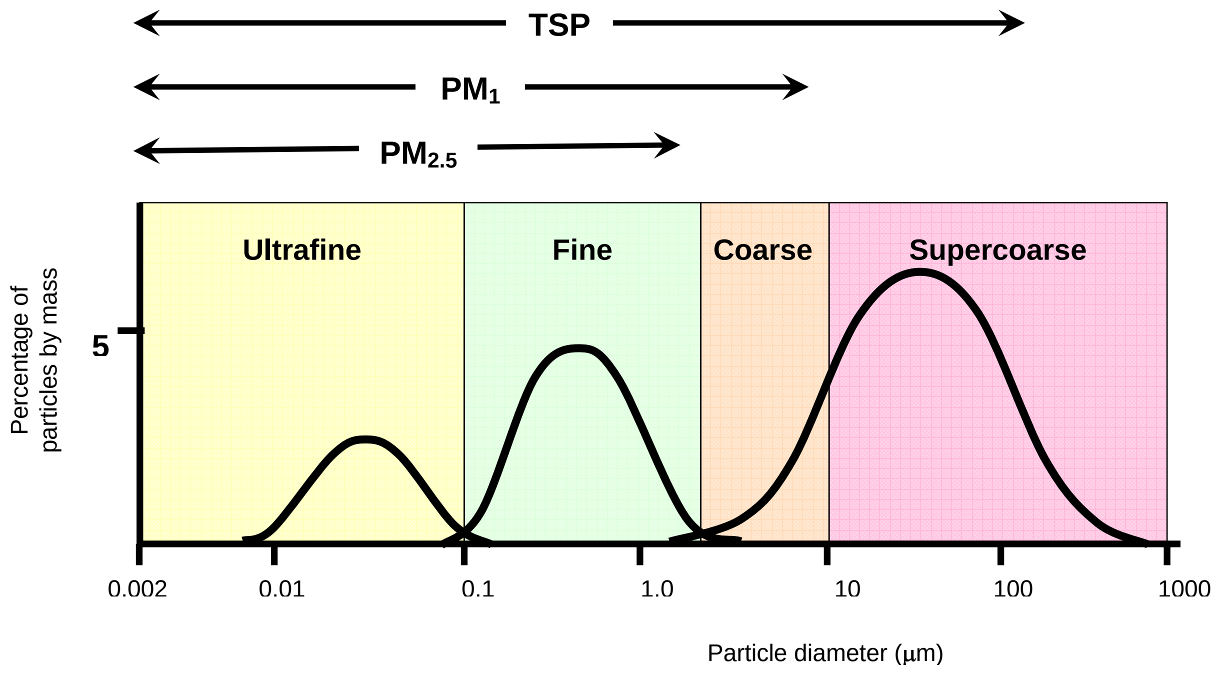
US EPA description	Particle size
Supercoarse	10 µm–100 µm
Coarse	2.5 µm–10 µm
Fine	0.1 µm–2.5 µm
Ultrafine	less than 0.1 µm

In addition to this descriptive categorisation there is a **regulatory categorisation** based on how particulate matter is regulated and tested for under the NEPM. These categories also relate to how far they typically penetrate the human respiratory system and so have potential health impacts.

Category	Description
TSP (total suspended particulate matter)	All particles from 0.1 µm up to about 100 µm or more in diameter—in practice the major contribution to TSP is from particles significantly less than 100 µm.
PM_{10} (particulate matter less than 10 µm)	All particles with an aerodynamic diameter less than or equal to 10 µm (sometimes called 'inhalable' particles).
$PM_{2.5}$ (particulate matter less than 2.5 µm)	All particles with an aerodynamic diameter less than or equal to 2.5 µm (sometimes called 'respirable' particles).
Particles less than 0.1 µm	These can be clusters of as few as 20 to 50 individual molecules but tend to agglomerate rapidly to larger particles.
Condensable particulate matter	Formed by chemical reactions and physical condensation within a few seconds of emission from a stack.

Distribution of particles in the atmosphere

The graph below shows an idealised size distribution of ambient atmospheric particulate matter that relates the two classification schemes (adapted from the US EPA *Basic Concepts in Environmental Sciences*). In practice the size distributions can overlap to a greater extent, depending on the type of sources.



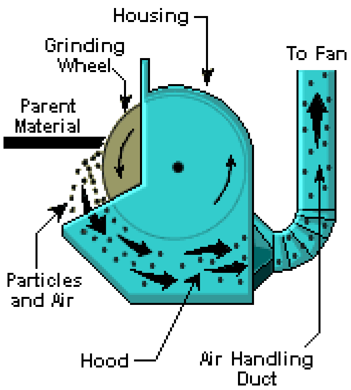
The **larger PM_{10} particles** stay in the air for minutes or hours and travel as little as 100 metres or as much as 50 kilometres.

The **smaller $PM_{2.5}$ particles** persist in the air for days or weeks and can travel for hundreds of kilometres.

Sources of particulate matter

Some typical sources of PM_{10} and $PM_{2.5}$ are summarised in the table below:

PM_{10}	$PM_{2.5}$
Smoke	Secondary formation from gaseous pollutants, e.g. photochemical smog
Dirt and dust	Motor vehicle emissions (diesel)
Factories, farming, roads	Inefficient burning
Construction sites	Smelting and purifying metals
Mould, spores and pollens	
Crushing and grinding rocks and metals	



Grinding wheel showing exhaust ducting (US EPA)

Processes and particle size

The range of particle sizes that are formed in any process largely depends on the sort of particle formation mechanisms that are present in the process. The significant mechanisms in air pollution sources are:

- physical abrasion (attrition) and mechanical dispersion
- combustion particle burnout
- nucleation (homogeneous and heterogeneous) and chemical reaction
- droplet evaporation.

> The general size range of emission particles is characterised by the particle formation mechanisms in the process being evaluated and managed.

Physical abrasion or attrition occurs when two hard surfaces rub together. Examples that may be encountered in premises or activities within a local government authority's responsibility are dust from vehicular abrasion and construction sites, metal grinding and tertiary stone crushing.

The dust particles formed in these sorts of operations range from less than 10 µm to almost 1000 µm with little in the PM_{10} category. Thus physical attrition generates predominantly moderate to large-sized particles that have short retention times in the air and typically only travel several hundred metres in moderate wind conditions. Their impacts are mostly restricted to the immediate vicinity of the premises or activity.

Pulverizing or atomizing of fossil fuels are both done to increase the surface area of fuel that is exposed to the oxygen in air to enhance combustion at high temperatures. In most cases these processes take place in premises regulated under DECC licences.

For any given amount of pulverized or atomized fuel, a decrease in particle diameter by a factor of ten results in a 1000-fold increase in the number of particles, and a ten-fold increase in the total surface area of all of the particles.

Combustion particle burnout is the term used to describe the process whereby a fuel is burned leaving only the incombustible ash and char particles. These particles are typically in the 1 to 100 µm size range and will be emitted in the exhaust of wood-fuelled domestic heaters as well as furnaces or boilers that use fossil fuels such as oil or coal, and from motor vehicles. If the combustion is incomplete then other particulate matter will also be emitted, a problem associated with woodsmoke from domestic heaters.

Nucleation is the conversion of materials in the vapour phase to particulate form as the vapour-containing gas streams cool to temperatures low enough for each to become liquid or solid. This may occur due to condensation alone or may be as a result of chemical reactions between pollutants in the atmosphere.

Homogeneous nucleation is the formation of new particles composed almost entirely of one compound from the vapour-phase material.

Heterogeneous nucleation is the accumulation of vapour-phase material on the surfaces of existing particles so that the resulting particulate matter is made up of more than one compound.

Each vapour phase material has a different temperature at which it becomes liquid or solid. Thus some materials nucleate in relatively hot gas zones while some remain as vapour until the gas stream is cold.

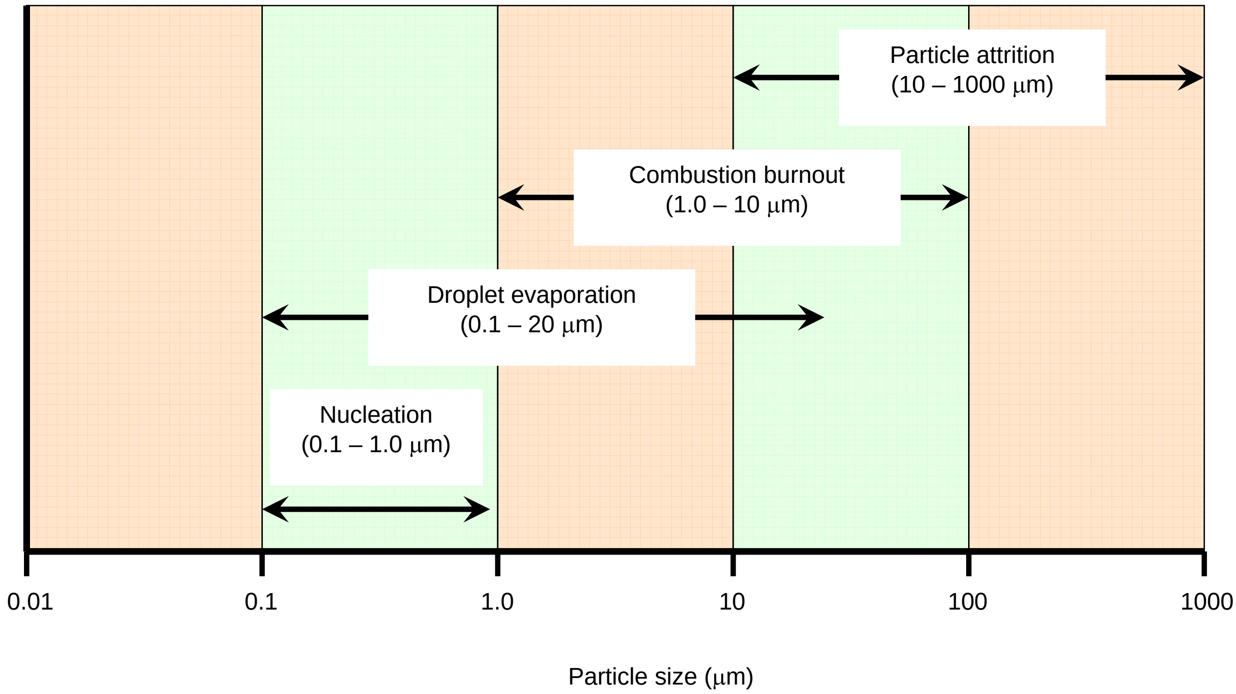
The two main types of vapour phase materials that can nucleate in air pollution source gas streams are organic compounds and inorganic metals or metal compounds.

Wood-fired domestic heaters provide an example of the importance of both combustion burnout and nucleation for the management of air pollution.

When operating properly, the wood both burns directly to form incombustible ash and volatilises to organic vapours that are substantially oxidised completely to carbon dioxide and water. However, if the combustion process is incomplete, a portion of these organic vapours and their partial combustion products remain in the gas stream, as well as the particles from the unburned matter entrained in the stream.

Droplet evaporation may occur if water containing solids is used to cool gas streams. The cooling water is 'atomised' and as the small droplets evaporate, the suspended and dissolved solids are released as small particles, typically with sizes between 0.1 and 20 µm.

The diagram below (adapted from the US EPA) summarises the ranges of particle sizes arising from the four different processes.



A simple summary of particles and sources

Particle size	Activities
Coarse particles	Crushing Grinding Quarrying
Fine particles	Combustion Smelting Process industries Traffic

The impacts of particulate matter

Health effects

The human respiratory system in a healthy person normally is able to deal with most inhaled particles without long-term effects or undue stress. However, in cases of extreme exposure and more generally for sensitive individuals, the presence of airborne particles is associated with increased rates of respiratory illnesses and symptoms.

When particulate matter is breathed in it then travels into the respiratory system. Generally the smaller the particles the further they penetrate into the lungs and the worse their effect.

If the smaller $PM_{2.5}$ particles contain **more toxic substances** like trace metals and carcinogenic organic compounds, then these may be carried deeper into the lungs than the normal bronchio-pulmonary defences would allow—with adverse effects.

Epidemiological studies have shown that exposure to particulate matter leads to increased use of medication, more visits to doctors or hospital outpatient services and more deaths of medically-at-risk individuals.

The **known health effects** of exposure to particulate matter include:

- coughing, wheezing and shortness of breath
- aggravated asthma
- damage to the lungs that results in decreased function
- lifelong respiratory disease such as chronic bronchitis and emphysema
- premature death in people with existing heart or lung conditions.

Asthma: this is caused by the periodic constriction of the bronchi and bronchioles making breathing more difficult. It is triggered by airborne irritants and chemicals.

Chronic bronchitis: any small particle reaching the bronchi and bronchioles in the lungs stimulates increased secretion of mucus to try and remove the irritation. In chronic bronchitis these air passages become clogged with mucus leading to a persistent cough.

Emphysema: when very small PM2.5 particles penetrate deep into the lungs they are trapped and cause the delicate walls of the alveoli to break down. This progressively reduces the gas exchange area of the lungs which in turn forces the heart to pump ever larger volumes of blood to the lungs in order to satisfy the body's needs. The added strain can lead to heart failure. Emphysema is now mainly a result of cigarette smoke.

Other effects

Particulate matter in the air can cause a range of damage to surfaces and materials, as well as being a significant nuisance problem. The simple requirement for more frequent cleaning and the associated abrasion of surfaces by dust particles can speed up deterioration. Over the years many car yards adjacent to dust-generating premises have been badly impacted leading to costly reparation.

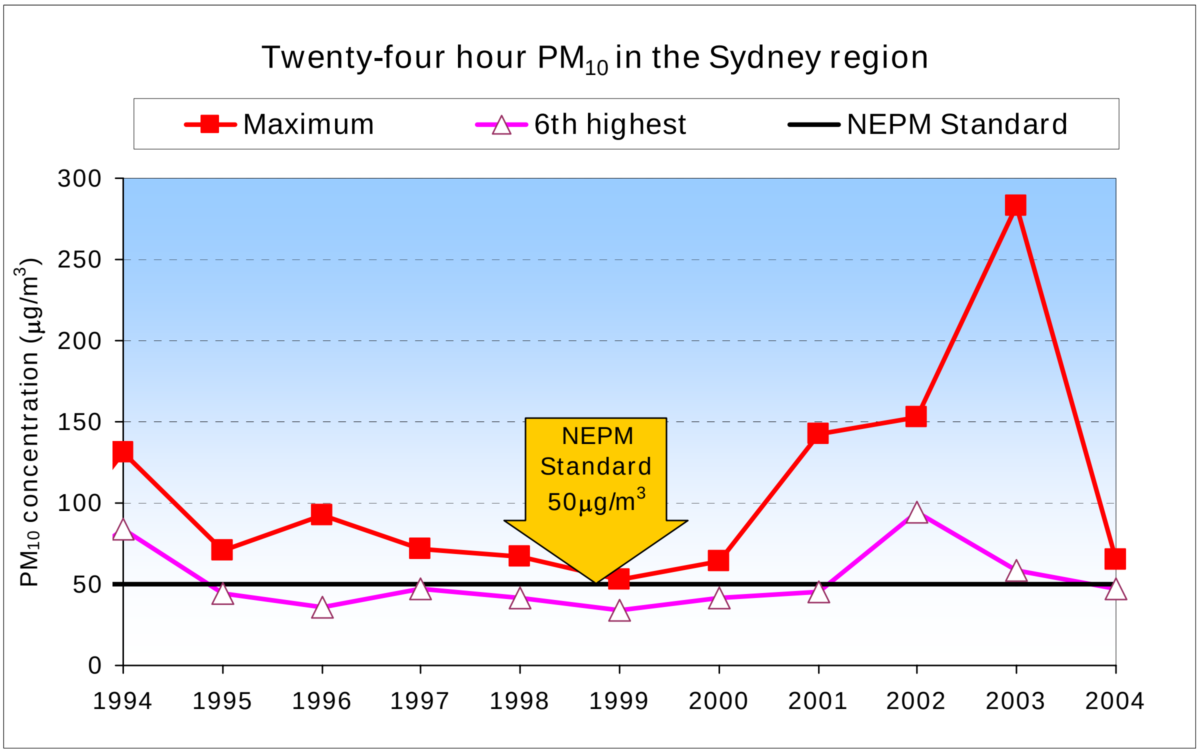
Additionally, if the particles are themselves corrosive or have other pollutants, such as SO_2/sulphate, attached to them, they may corrode sensitive surfaces (paint work, duco, etc.) to which they adhere, especially if there is overnight condensation on the particles lying on the sensitive surfaces.

In coastal areas wind-blown suspended **sea salt particles** are corrosive. They usually require particular attention to exposed metal surfaces such as external plumbing in roof gutters and other structures.

Local government can help manage particles by:

- making sure premises within their control are operating and maintaining their air pollution control devices satisfactorily
- managing woodsmoke from domestic heaters
- strategic planning for the location of new industrial and commercial facilities within their area—in relation to local roads, residential areas and schools
- consent conditions on emissions for new premises and activities
- consent conditions on developments to influence motor vehicle use associated with new developments.

Trends in ambient concentrations of PM_{10}



Events where concentrations of PM_{10} exceed the NEPM standard can occur in the Sydney region as can be seen in the figure below.

Concentrations of PM_{10} near to or exceeding the NEPM standard are widespread in the Sydney region. The more moderate of these generally occur during the cooler months of the year with the highest concentrations observed during the early evening and early morning. They tend to be associated with stable atmospheric conditions that are conducive to clear cold nights and the development of inversions and drainage flows which can result in the trapping of pollutants close to the surface and their transport within the Sydney region.

Extreme episodes of particle pollution are generally associated with large-scale hazard reduction burning or wildfires. These sorts of events account for most of the exceedences of the PM_{10} standard in the Sydney region.

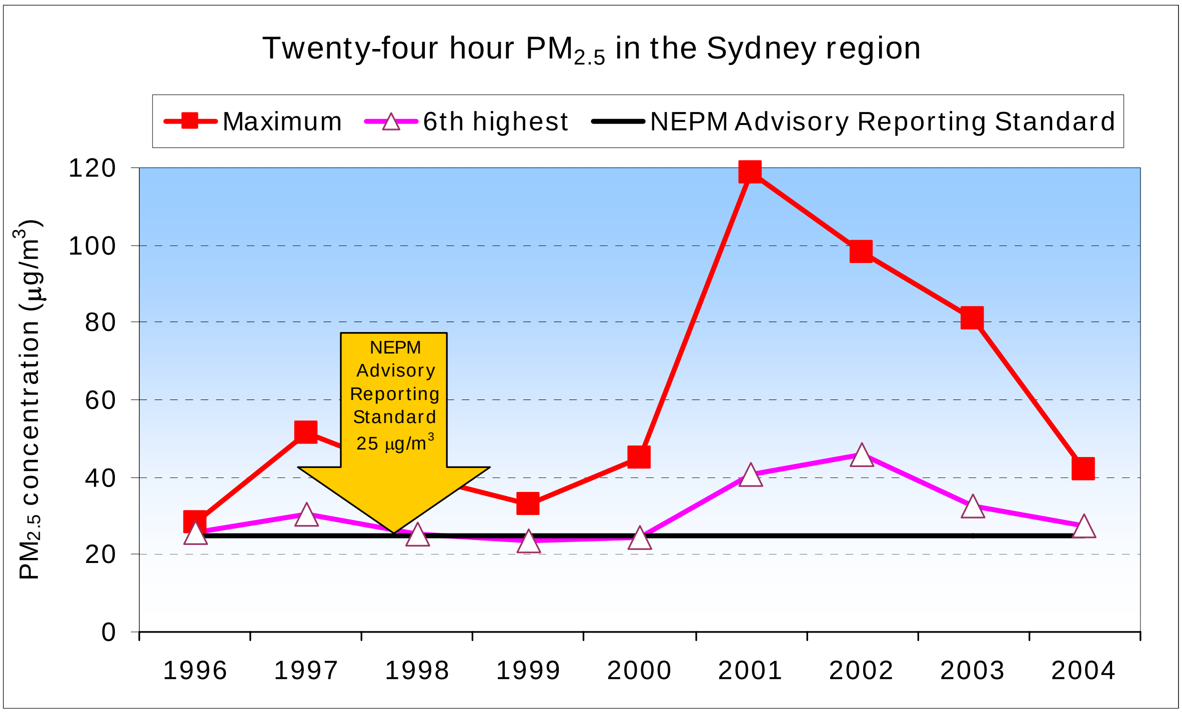
The distribution of elevated concentrations of PM_{10} during these events is governed by the location of the fire and the prevailing winds on that day. The combination of these two factors has meant that on different occasions, all of the monitoring stations in the Sydney region have recorded elevated concentrations of PM_{10}.

Severe dust storms can also contribute to particulate pollution.

Trends in ambient concentrations of $PM_{2.5}$

With the growing understanding of the health impacts of the smaller respirable particles in the $PM_{2.5}$ category there is an increasing emphasis on managing their emissions. The figure below shows recent trends in $PM_{2.5}$ concentrations in Sydney.

Bushfires, hazard reduction burning and dust storms in recent years are also believed to have contributed to the observed very high levels of $PM_{2.5}$.



3.4 Ozone and photochemical oxidants

Ozone

Ozone is important at two levels in the atmosphere: in the troposphere (the air layer next to the earth's surface) and in the stratosphere (a higher air layer, above the troposphere).

In the troposphere high concentrations of ozone are detrimental to health, vegetation and materials. It is the main constituent of photochemical air pollution and is a very reactive gas causing deterioration of all types of organic materials it contacts. Gaseous ozone is the measured indicator of photochemical air pollution and is used to set the ambient standard for this type of pollution in the Air NEPM goal.

In the stratosphere high concentrations of ozone are beneficial for health, biota and materials. It shields the earth's surface from damagingly high levels of ultraviolet radiation from the sun. Ozone is also a greenhouse gas.

Upper-level (stratospheric) ozone is destroyed by the release of ozone-depleting substances such as chlorofluorocarbon refrigerants. The release of these materials is internationally controlled under the Montreal Protocol and locally controlled in NSW under the *Ozone Protection Act 1989*.

Ozone is an ephemeral gas at both the tropospheric and stratospheric levels, being continually formed and destroyed by dynamic, photocatalysed reactions. The concentration at any time depends on the competing rates of destruction and formation. It is more difficult to measure accurately than most other gaseous pollutants, since standard calibration gases cannot be stored.

Impacts of tropospheric (low-level) ozone

Ozone is a very strong oxidising agent. It causes damage to sensitive tissues of the body, such as in the lungs and their airways and the eyes. It is used as a surrogate for other products of the oxidant reactions, including polyacetyl nitrates (PAN) and fine particles.

The health effects appear as shortness of breath and chest pains, especially in people exercising or working hard in the open, increased incidence of asthma and eye irritation. Fine particles and aerosols are also created during the formation of photochemical smog and have an impact as particles on health and visibility.

It is difficult in health studies to isolate the effects of ozone gas from the other constituents of the smog. PAN, for example, is probably the main promoter of eye irritation. While the effects of ozone exposure tend to be short-term, laboratory studies of animals have also shown effects on lung tissue for longer-term and repeated exposures.

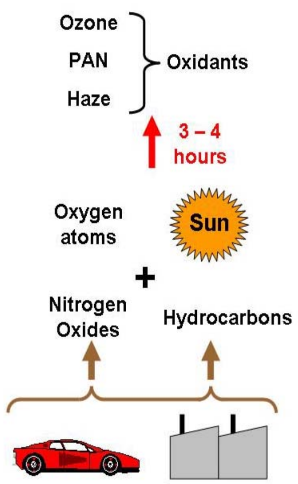
The strong oxidising capability of ozone also causes **damage to vegetation**. Some commercial and ornamental plant species are particularly sensitive to ozone damage. Likewise many modern products exposed to the atmosphere such as rubbers and polymers suffer deterioration when exposed to the oxidants of this smog.

The Air NEPM set the goal for ozone exposure at 0.1 ppm for a 1-hour exposure and 0.08 ppm for a 4-hour exposure, neither to be exceeded more than once per year.	Consideration is being given to the introduction of an 8-hour standard for ozone.

Photochemical air pollution

Photochemical oxidants are products of the reaction of **volatile organic compounds** (VOCs) and **nitrogen oxides** (NO_x) in the atmosphere. The reaction is promoted by exposure of the mixture to strong sunlight. It is a seasonal phenomenon, since concentrations of ozone and oxidants only reach levels of concern in summer, when the sun's radiation is strongest.

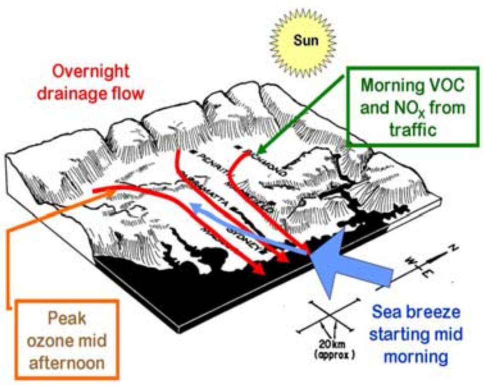
Photochemical oxidant pollution was first studied as an urban problem in Los Angeles, where it became famous as photochemical 'smog'. The term tends to be identified primarily with car and vehicle pollution, but there is a significant contribution from industry and other urban activities, both commercial and individual.



Oxides of nitrogen

Oxides of nitrogen are released from motor vehicles and industry. The largest proportion comes from motor vehicles.

As discussed earlier in section 3.2 'Gaseous impurities', the two forms occurring in the atmosphere are nitric oxide (NO) and nitrogen dioxide (NO_2). Fresh emissions are mostly in the form of nitric oxide. This is oxidised to nitrogen dioxide in the atmosphere as part of the photochemical process. The photochemical reactions between the two oxides of nitrogen occurs naturally in sunlight, but does not result in levels of ozone being formed above concentrations of concern **if no significant concentrations of VOCs are present**.



Emission of VOCs in urban areas

In urban and industrial atmospheres VOCs are emitted in large quantities from many sources, including motor vehicles, and consequently high concentrations of ozone can be generated in these situations. But the reactions usually take 3–4 hours for the concentrations of oxidants (as indicated by ozone) to build up to troublesome concentrations. So smog is only formed on days with appropriate meteorological conditions, such as morning trapping of NO_x and VOC pollutants, relatively light air movements and strong sunlight.

Smog in the Sydney basin

The outstanding example in NSW is the accumulation of VOCs and NO_x from the morning traffic peaks in Sydney, especially in the western areas of the basin where the overnight inversion drainage flow traps and transports the reactant pollutants to the east over the city. When the mid-morning sea breeze pushes this brew of pollution back over the urban land, peak oxidant concentrations tend to be formed in the south-western regions of the basin from early to late afternoon.

Monitoring ozone

$$NO + O_3 \rightarrow NO_2 + O_2$$

Care is needed in monitoring ozone. If the monitors are located too close to concentrated sources of nitrogen oxide emissions, such as heavy traffic lanes or near large industrial combustion sources or in CBDs, then low values are likely to be measured. This is because the dominant form of nitrogen oxides from combustion is nitric oxide (NO), as discussed above. This reacts very rapidly with ozone already formed to convert it to oxygen. In the longer time needed for full development of oxidants this effect passes and a realistic concentration of ozone will be measured relating to the emissions.

This was the main cause of an unfortunate prediction about photochemical air pollution made in the late 1960s, namely, that even without any control of vehicle air pollution in Sydney, Los-Angeles-type smog was not likely to be a problem until 1997. When measurements were taken well away from the Sydney CBD in the early 1970s, high ozone values quickly made it apparent that there was an urgent need for control.

Control of photochemical oxidants

There are possibilities for controlling the VOC and NO_x precursors to greater or lesser extents to achieve desired ozone outcomes. Throughout Australia and in NSW an approach of controlling both NO_x and VOCs has been adopted:

- **Motor vehicle emissions are regulated nationally** for both NO_x and VOCs, the latter from both tail pipes and evaporative emissions. Modern catalyst-equipped vehicles using lead-free petrol are the cornerstone of this control. **This regulation is on a vehicular basis**; that is, the amount of pollutant for a kilometre travelled is limited, not the distance the vehicle travels in a day.
- **Evaporative emissions of VOCs** from distribution of petroleum products and some solvents is controlled in large storage facilities.
- **Combustion emissions of NO_x** from large industrial facilities and power plants are controlled by POEOCAR.

Traffic management

To the extent that local government has an influence on traffic congestion and generation, it can have a significant impact on the potential for ozone and oxidant pollution within the air basin in which it is located. But the pollution effect may not be a local one for the particular local government area in which the control is undertaken.

> Traffic generation and congestion can be influenced by planning for walking and cycling facilities; and by planning to reduce local trips—e.g. for shopping or schools. These can all contribute to the reduction of vehicle kilometres travelled (VKT) in the air basin.
>
> Emissions of the ingredients of photochemical smog in one local government area have regional impacts and will impact on the air quality in other local government areas.

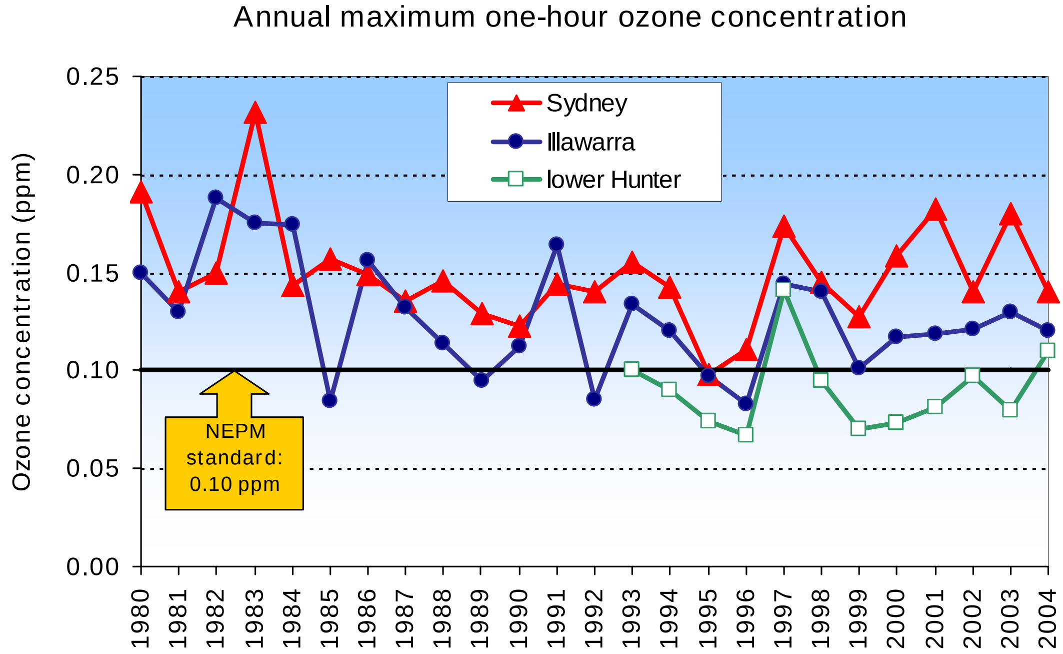
Small to medium-sized sources

There are thousands of small to medium-sized sources which are not specifically controlled for NO_x and VOCs as such, although such activities may be controlled to achieve clean combustion and to minimise organic emissions so as to reduce impacts of odours or air toxics.

Under the POEO Act local councils are the ARA for most of the small to medium-sized sources which remain to be controlled. Specific action to tighten controls on ozone precursors from these sources may be required in future.

Present levels of ozone pollution

While significant improvements have been achieved in the Sydney, Illawarra and Lower Hunter air basins following early vehicular and industrial controls, and the introduction of catalyst equipped vehicles and lead-free petrol in 1986, the AAQ NEPM standard is still exceeded in Sydney and the Illawarra more often than allowed under the goal.

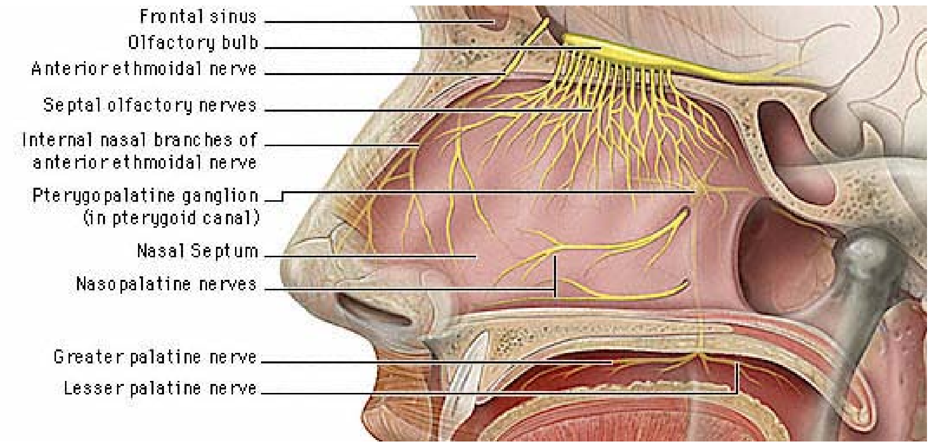


3.5 Odours

The community complains about odours more frequently than any other type of air pollution. The majority of the air quality problems associated with local-government-controlled industries and businesses relate to odours. There is great subjectivity associated with odour assessment. These facts make odours a significant problem for local government.

The sense of smell

Certain volatile substances and mixtures stimulate the olfactory nerve in the nose so as to produce a sensation of odour or smell.



The olfactory epithelium (Yale University Medical School website)

Odours are transported from source to nose by air movement, the wind. Many odours are not toxic at readily detectable concentrations. Each citizen is equipped with a sensitive detector. So the primary issue is amenity.

Easily recognisable odours

Some substances have distinctive odours as the pure compounds, such as hydrogen sulfide (H_2S, or ‘rotten egg’ gas), acetone (or nail polish remover) and hypochlorous acid (from swimming pool chemicals). These are quite familiar to many people even if they do not know their chemical names.

Most odours, both pleasant and unpleasant, result from mixtures of many compounds.

That odours come from mixtures of many compounds is especially true of the **food and waste treatment industries** where biological processes characteristically generate families of odorous compounds rather than one or two such compounds. Most **rotting material** contains hydrogen sulfide, although it is not recognisable as such in the mixture. Surprisingly, hydrogen sulfide is also found in small quantities in pleasant odours, such as coffee.

Human sensitivity to odour

To complicate matters further, human sensitivity to odour perception varies widely. **So odours are difficult to measure reliably**.

Where only one compound is present the chemical concentration can be determined and related to odour strength as defined below. When multiple compounds are present, the more common situation, one cannot simply add up the odour strengths of the individual components to arrive at the strength of the mixture.

Odours:

– are pure compounds or mixtures of compounds which stimulate the olfactory nerve causing a sensation of smell

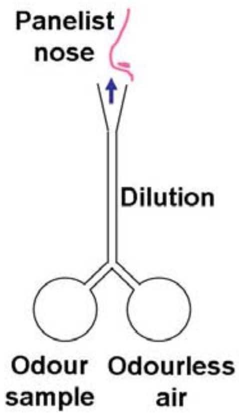
– are not easily defined as chemical compounds

– are transported by air from source to nose

– are detected with differing sensitivities

– impact on amenity, and

– are often not toxic at the strength they are detectable (even if a 'nasty smell').



Olfactometry

Measurement of odour

Odour strength is usually measured by quantitatively diluting a sample of odorous air with non-odorous air and presenting it according to set protocols to a panel of representative subjects, or 'sniffers'.

The **mean or average dilution value** at which the panel just detects the presence of the odour is called the **threshold value**.

Panel response may be either to the **detection threshold** or the **recognition threshold**.

Measured odour concentrations can vary by an order of magnitude depending on how the test is conducted. Some of the variations in the results from odour testing include:

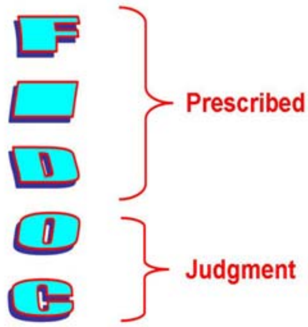
- **Forced choice versus yes/no response**—the panellist is asked to choose the strongest of multiple odour dilutions presented to them versus the panellist's ability to smell anything in the dilution presented.
- **Dynamic versus static exposure**—the panellist is exposed to a continuous flow of odour dilutions versus being exposed to discrete parcels of odour dilutions.
- **Recognition versus detection threshold**—the panellist can detect a recognisable smell versus any smell sensation.

There can also be variations in the method of panel selection. Most panels are selected to be representative of the 'typical community' and to be reliable in their response to varying odour dilutions. They should not be dominated by panellists on the extremes of the range of sensitivity or insensitivity.

> The number of **odour units** in a sample is the number of dilutions required for the sample to reach the chosen threshold of detection.

There are Australasian (AS/NZS 4323.3:2001) and European (CEN:/TC264/WG2/N222/e(OM-7)) standards for odour measurement by **dynamic olfactometry**, both of which are recommended by DECC for odour assessment.

Sampling for odour measurement is a difficult and specialised process because of the tiny quantities of odour material involved—the 'odour' can end up being stuck to the sampler walls.



Factors in odour assessment

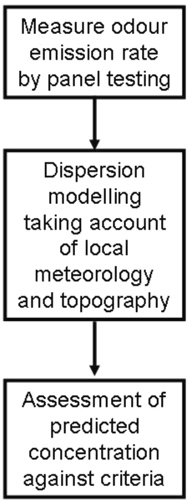
The key factors which have been identified as determining community responses to an odour are:

- **F**requency of exposure
- **I**ntensity of exposure
- **D**uration of exposure
- **O**bjectionableness of the odour (the so-called 'hedonic tone')
- **C**ircumstances in which the exposure occurs (work, relaxing at home, attempting to sleep).

F I D O C is the acronym.

No reliable means of scientifically measuring **O** or defining **C** has been developed. Thus many odour assessment techniques involve a compromise of specifying **FID**, which can be assessed scientifically, and either not assessing **OC** or assuming it is loosely related to **FID**. This tends to be a 'safe' approach, in that it assumes no odour is preferable to any odour, even a normally pleasant one, in most circumstances.

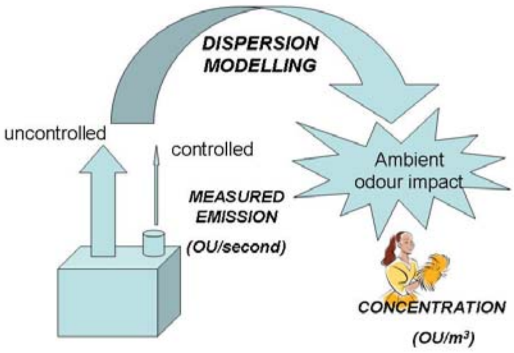
Despite these shortcomings, considerable progress has been made in odour assessment and control. The DEC draft policy, *Assessment and management of odour from stationary sources in NSW* (2001), provides extensive guidance for odour assessment and control.



Assessment of odour

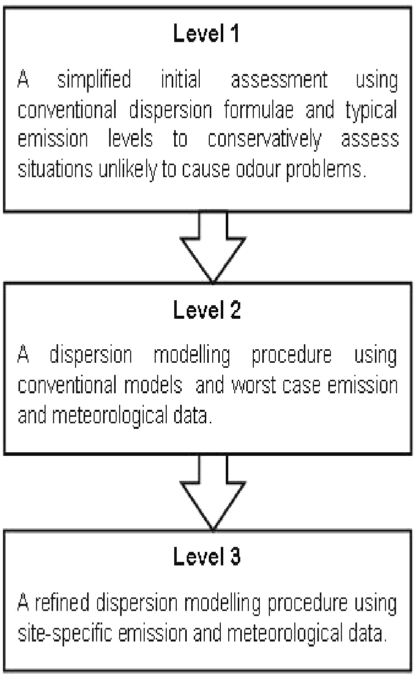
In essence the assessment technique relies on three things:

- measurement (sampling and testing) of odour strength by dynamic olfactometry
- prediction of ambient concentrations at sensitive receptors using dispersion formulae or air quality models
- assessment of the predicted strength against odour exposure criteria.



Size of the population exposed

To allow for the likelihood of more sensitive individuals being present in larger populations, the DEC draft criteria take account of the size of the population exposed. They are based on a 0.1 to 1 second averaging time, the typical response time of the olfactory nerve to a stimulus. They also assume that the ambient odour exposure criteria are met for 99% of the time.



Recommended odour levels

The recommended odour concentrations range from two odour units per cubic metre (2 ou/m^3) for urban areas with a population of more than 2,000 people exposed, to 7 ou/m^3 for a single dwelling.

Three-tiered exposure assessment

The DEC draft method allows for a three-tiered exposure assessment (illustrated here on the left) using simple dispersion calculations at the initial assessment level, and increasingly sophisticated emission inputs and dispersion modelling techniques at the higher levels.

Council officers should also be aware that measuring emission rates from **diffuse sources** such as smelly solid or liquid surfaces is problematic.

This is a serious qualification to general application of the methodology, since diffuse sources are fairly common in many industries with an odour problem.

Even at the initial assessment level this technique is difficult and demanding to apply, and it is unlikely that council officers would attempt it directly.

Responding to odour from existing premises

In response to a complaint of odour from existing premises, council officers may specify in a Prevention or Clean Up Notice that an assessment be undertaken according to the methodology. In so doing they should be aware of the following:

- the likely expense—a study involving both odour testing and dispersion modelling could cost more than $20,000 per assessment
- the qualifications on the accuracy of the sampling and analysis
- the difficulty of accounting for diffuse sources
- the limitations on modelling in the sort of topography and building interference often encountered in urban situations.

Another way of assessing some odours

A lower cost option is available under the DEC *Odour Policy* and *Approved Methods for Modelling and Assessment of Air Pollutants in NSW* for certain odorous chemicals. For over 20 years Victoria has used a set of design criteria for the ground-level concentrations (glc) of a number of chemical compounds. These criteria were formulated on the basis of providing protection against exposure to toxicity and avoidance of odour. They have been adopted as the NSW methods and provide a means of modelling without the need for odour testing **for those compounds listed**. However, this method can only be used for odorous materials **which are not mixtures**. This is not the situation typically encountered in local government.

A practical approach to odour management for local council officers

A practical approach is recommended as the first step for local council officers, especially for small-sized installations. Careful use of documented odour observations by officers and others, coupled with an analysis of the suspect process and complaint patterns, can sometimes lead to practical solutions at a cost comparable to the cost of a scientific assessment. This approach is explained further in Module 3.

Ambient monitoring of odours is not practicable since assessment panels have difficulty in assessing low concentrations of odour. In addition, the sampling itself is problematical. It is possible that odorous compounds can be lost entirely from the sampled air through adsorption onto the container walls before the sample reaches the panel.

Much progress has been made on odour assessment over the last 50 years. However, there is still not the same degree of consensus on managing this frustrating aspect of air quality as that which exists for most other forms of air pollution.

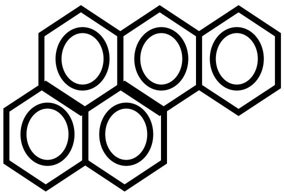
3.6 Toxic air pollutants

Of the air pollutants currently prescribed under the Ambient Air Quality NEPM, only lead and carbon monoxide are considered to be 'toxic'. However, there is long-standing concern about toxic pollutants in the atmosphere.

Two general types of impact are addressed under the category of 'air toxics':

- – directly toxic air pollutants
- – carcinogenic air pollutants.

The Commonwealth Government has published several documents under its Air Toxics Program including the *State of knowledge report on air toxics and indoor air quality*. NEPC released an *Information bulletin* and an *Impact statement for the National Environment Protection (Air Toxics) Measure (2003)*.



Benzo(a)pyrene

Air Toxics NEPM

The EPHC issued an Air Toxics NEPM in 2004 addressing five individual or sets of air toxic compounds:

- benzene
- formaldehyde
- benzo(a)pyrene as a marker for polycyclic aromatic hydrocarbons (PAHs)
- toluene
- xylenes (as a total of ortho, meta and para isomers)

While the NEPM sets monitoring investigation levels for these toxic compounds, it has not set goals. In anticipation of setting goals it has prescribed a monitoring regime with a view to setting goals by 2012.

The Environment Protection and Heritage Council (EPHC) has also identified **other air toxics** which it has prioritized for further investigation at a later stage:

- 1,3 butadiene
- acetaldehyde
- arsenic and compounds
- cadmium and compounds
- methyl ethyl ketone
- methyl isobutyl ketone
- nickel and compounds
- styrene
- tetrachloroethylene
- trichloroethylene
- polychlorinated biphenyls (PCBs)
- polychlorinated dioxins and furans.

Dioxins and furans

Dioxins and furans have been an issue of public concern in Australia for some time. Dioxins and furans are an extensive family of cyclic organic chemicals containing varying amounts of chlorine. There are hundreds of different members of the family, depending on chemical structure.

Dioxins have been shown to be extremely toxic to humans, but they are only found in the environment in very small (trace) quantities. The concentrations usually found are a million or more times less than other common air pollutants in the atmosphere. The toxicity of the many isomers varies widely and so test results are converted to a **toxic equivalent** (TEQ) value, based on accepted ratios of toxicity of the family members to the most toxic member: 2,3,7,8 tetrachloro dibenzo-p-dioxin (usually called simply ‘TCDD’). The corresponding furan is ‘TCDF’ or 2,3,7,8 tetrachloro-dibenzo-furan.

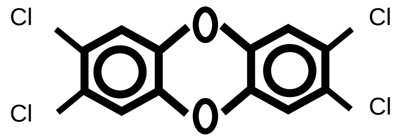
Research on sources of dioxins and furans

Research in the last 20 years has revealed that polychlorinated dioxins and furans can be formed in many combustion processes where organic materials and chlorine containing materials are present. Given the ubiquitous distribution of these materials in nature, it is not surprising that trace quantities of dioxin can be found in many situations involving traditional forms of burning. The first cave dwellers were almost certainly exposed to dioxins.

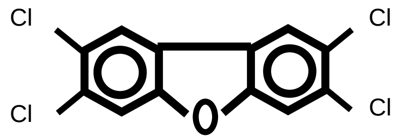
Environment Australia funded and published a series of 12 reports as part of the National Dioxins Program between 2001 and 2004. These addressed many issues related to dioxins and furans in Australia, including a useful inventory of emissions from all sources.

Burning of biomass such as in bushfires, metallurgical processing (ferrous and non-ferrous) and burning of wastes and accidental fires emerge as the three largest categories of dioxin emissions in Australia. For local government domestic wood burning for heating and cooking, and operations such as cremation, are dioxin sources warranting close attention.

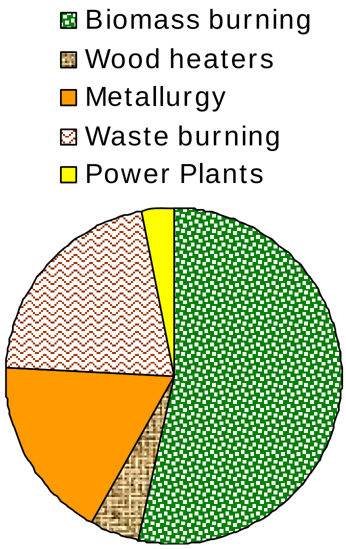
Dioxins and furans are families of cyclic organic chemicals. The toxic ones contain chlorine and in popular usage the term ‘dioxins and furans’ is applied in the environmental context to the many chlorine-containing compounds in these families.



TCDD—the most toxic dioxin



TCDF—the most toxic furan



Sources of dioxin emissions in Australia

Addressing dioxins in Australia

The EPHC has recently issued a draft *National Action Plan for Addressing Dioxins in Australia* (July 2005). This Plan is intended to address Australia's obligations under the Stockholm Convention 2004 for management of persistent organic pollutants (POPs).

On the basis that dioxin levels in Australia appear to be low, emphasis is placed on the following management strategies:

- enshrining the widely used emission standard of 0.1 ng TEQ/m^3 as a national combustion emission limit.
- reducing emissions from burning of wood fuels
- better understanding emissions from bushfires (the major source in Australia)
- adopting the Stockholm Convention best practice guidelines for assessing proposals for new and upgraded facilities in Australia.

> ng is the nanogram; that is, 10^{-9} gram or just one thousandth of a microgram.

Local government and toxic air pollutants

Local councils will not often be required to make decisions about or to regulate emissions of toxic air pollutants other than those already covered by the existing AAQ NEPM, or those in relation to minimising odours or smoke emissions (e.g. from spray painting, coating or domestic wood burning).

On the few occasions that this is required, the design criteria specified in *Approved methods for modelling and assessment in NSW* (2005) can be adopted for any assessment.

> It would be wise for local councils to consider obtaining expert advice if they need to consider an emission involving toxic pollutants.

Ambient design criteria for some air toxics

A Victorian list of ambient design criteria for air toxics has existed since 1980. The latest revision of this list has been adopted in NSW. It covers 90 chemicals and related substances, both inorganic and organic. [See *Approved methods for modelling and assessment of air pollutants in New South Wales* (2005).]

These are relevant to the assessment of all sources of air pollution in NSW, including non-scheduled premises.

Emission limits for some toxic chemicals

Emission limits have also been set for 39 toxic chemicals in the POEOCAR. However, there are no emission limits for toxic pollutants applicable to non-scheduled premises in NSW.

Further information on air toxics

Detailed information on air toxics can be found in the following sources:

- *Impact assessment criteria for principal toxic air pollutants* (Victoria, 2001)
- *Approved methods for the modelling and assessment of air pollutants in NSW* (2005)
  Table 7.2 (lists design criteria for 90 toxic materials)
- *NEPM (Air Toxics) Impact Statement* (2003)
- *National Environment Protection (Air Toxics) Measure* (2004):
  benzene, benzo(a)pyrene, formaldehyde, toluene, xylenes
- National Dioxins Program:
  12 reports (2001–2004)
- *National Action Plan for Addressing Dioxins in Australia* (2005) pursuant to the Stockholm Convention on Persistent Organic Pollutants.

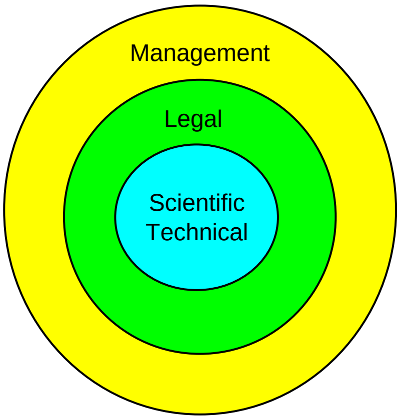
4 Management of air quality

4.1 General management of air quality

Management framework

The ideal air quality management objective is to avoid all air pollution and maintain pristine air quality. Such a goal is not feasible in the presence of human activities relying on energy from fuels and involving biological and manufacturing processes.

Our practical objective becomes to manage air quality to the best level possible and to ensure that pollutants are kept at or below acceptable levels. In pursuit of this overall objective we use various tools or instruments:



General management tools ensure that we pursue our objectives systematically and efficiently.

Legal instruments are the primary compliance tools governments use to achieve air quality outcomes. These instruments are reviewed in detail in Module 2. Our secondary objective, within the overall management framework, is to use our legal instruments effectively.

Scientific and technical understanding serves the tertiary objective of providing the physical means by which air pollution is controlled and the legal and management objectives are attained.

These three objectives can be viewed as a conceptually nested framework within which we pursue our management role in government, whether at the national, state or local level.

National level

Under the Australian Federal Constitution air quality was originally the sovereign responsibility of each State. However, issues such as needing a consistent response to protecting health, a uniform requirement for controlling vehicle emissions and addressing global pollution have necessitated a national approach.

The **National Environment Protection Council** (NEPC) was formed by agreement between the Commonwealth Government and the eight State and Territory governments in 1994 to set standards for environmental quality and for motor vehicle emissions. The standards are set as ambient concentration goals to be complied with by a nominated future time. NEPC is now under the general aegis of the **Environment Protection and Heritage Council** (EPHC) of Environment Ministers.

NEPC establishes National Environment Protection Measure (NEPMs) for the environmental standards and goals it sets. There are several NEPMs for air quality as outlined in the introductory section of this Toolkit.

Air quality is historically and constitutionally the sovereign responsibility of States and Territories.

Since 1994 the Commonwealth, States and Territories have designated NEPC to set ambient air quality standards as goals for the whole of Australia.

Controlling emissions

Except for the unique case of motor vehicles—which is the preserve of the Commonwealth Government—agreed national policy leaves controlling emissions to achieve the national ambient air quality goals to the States and Territories.

Control of **greenhouse gases** such as carbon dioxide and methane is also guided at a national level by the Commonwealth Government. However, in varying degrees, State and Territory governments, and in some cases local councils, have taken significant initiatives in this area. Responsibilities for managing greenhouse gases are not yet well defined.

In contrast, the **stratospheric ozone depleting gases** are regulated in an agreed manner by the Commonwealth, States and local government in pursuance of Australia's national responsibility under the Montreal Protocol for Ozone Protection.

State level

Each State continues to carry the responsibility for managing the release of air pollutants in its jurisdictional territory.

This is achieved through **planning legislation** in terms of new developments. The *Environment Planning and Assessment Act 1979* (EP&A Act) is the relevant planning law in NSW. The recently updated EP&A Act and Regulations provide tools for managing the location of polluting sources.

> State environmental planning legislation governs the location of industry and business.
>
> Location, in turn, affects the impacts of air pollutants.

Pollution control is achieved through **environment protection legislation** by regulation of emissions. The *Protection of the Environment Operations Act 1997* (POEO Act) is the relevant law in NSW.

Through this legislation and its derivative regulations, the States and Territories control emissions of air pollution to achieve the national ambient goals in their jurisdictions.

> State protection of the environment legislation regulates all emissions, except emissions from motor vehicles.

Air pollution controls at the State level

Air pollution controls at the State level often go beyond the defined NEPC goals. In fact, a wide range of pollutants are defined for control at the State and Territory level because legal responsibility for air quality management rested at this level until the last decade.

For example, there are State limitations and guidelines for a wide range of toxic air pollutants (including mercury, dioxins and cadmium etc.), for pollutants where damage to vegetation is more important than impacts on health (for example fluorides) and for odours, for which there is no national position.

> Goals and emission limits for many air pollutants not covered by the national NEPM goals are set in State and Territory laws, regulations, policies and guidelines.

State controls, requirements and objectives are set out in regulations, policies and guidelines. For example, in NSW they are set out in:

- Protection of the Environment Operations (Clean Air) Regulation 2002 (POEOCAR)
- *Action for Air* (1998)
- *Approved methods for sampling and analysis of air pollutants in NSW* (2005)
- *Approved methods for modelling and assessment of air pollutants in NSW (*2005)
- *Draft Policy: Assessment and management of odours from stationary sources in NSW* (2001)

When using State laws, regulations and guidelines in the local government context it is important to avoid confusion between controlling pollutant emissions and meeting ambient air quality goals. The two are related but are regulated differently.

Local government level

The **EP&A Act** and its instruments designate the responsibility for granting consents to new industrial and commercial developments. In general local government is the consent authority, but other authorities may be designated for important situations, such as the Minister for Planning, advised by the Department of Planning (DoP), for any 'State Significant Development'. Local government also has a key role in locating sources of air pollution through its powers under the EP&A Act to make Local Environment Plans (LEPs) within the context of State and Regional Environmental Plans (SEPPs and REPs).

The **POEO Act** defines responsibility for environment protection, including control of air pollution, through a schedule of industrial activities with a potential environmental impact (see Schedule 1 of the POEO Act).

The list of activities includes thresholds for activity size, above which the activity is licensed by the EPA and below which the activity is the responsibility of local government. The responsible body is called the Appropriate Regulatory Authority (ARA). This delegation of power under the POEO Act makes local government the ARA responsible for managing the environmental performance of most small to medium-sized businesses and industries in NSW.

Local government is therefore one of the agencies required to participate in meeting the national goals for air quality. In NSW, although the Minister for Planning/DoP and DECC take responsibility for most major pollution sources, local councils in fact manage most of the planning and control relevant to emission sources. This is because they have responsibility for many more factory and business sites than the Minister for Planning/DoP and DECC. They also significantly influence the disposition and flow of traffic and hence the impacts of motor vehicle air pollutants on the environment.

The EP&A Act & its instruments designate the responsibility for planning and location of air pollution sources generally to local government, but with other authorities, including the Minister under the Act, designated in important situations.

The schedule to the POEO Act divides responsibility for controlling air pollution from sources between the State agency (DECC in NSW) and local government.

Local councils have a significant responsibility for meeting the national goals for air quality—since they control most of the air pollution from small to medium industry and have some influence over road traffic and hence vehicular emissions.

Responsibilities for air quality management according to level of government

Level of government	Direct responsibility	Influence
National/Federal	Ambient goals Fuel standards	
Commonwealth	Motor vehicle emissions Greenhouse policy Ozone-depletion policy Air, shipping and national highway deployment and patterns	Sustainability
State/Territory	Emissions from large polluting industries Ozone-depleting emissions Some ambient goals, not regulated nationally Regional traffic deployment and patterns	Sustainability Greenhouse policy
Local government	Emissions from small-to-medium sized industries Ozone-depleting emissions Local traffic deployment and patterns	Sustainability Greenhouse policy

4.2 The management cycle and air quality

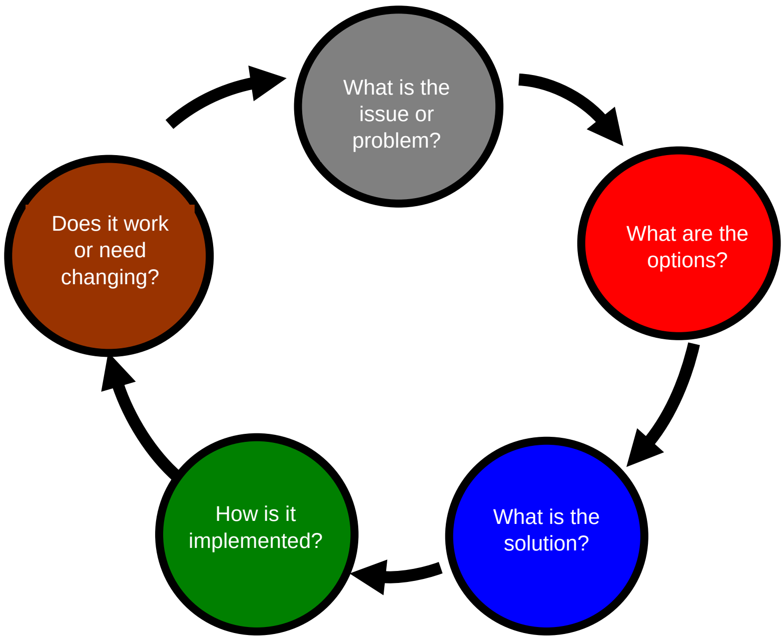
Examining the management cycle for air quality can help to illustrate what might be realistically achievable at local government level.

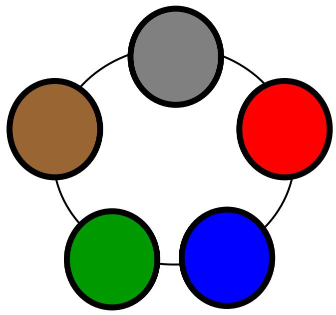
The 5-step management cycle is represented in simple terms in the diagram below.

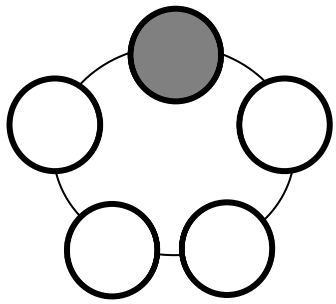
Five-step cycle

The five key steps are:

- defining the problem
- exploring options for its solution
- deciding on a solution by analysis—including costs and benefits
- implementing the chosen solution
- checking and, if necessary, reviewing the outcome.





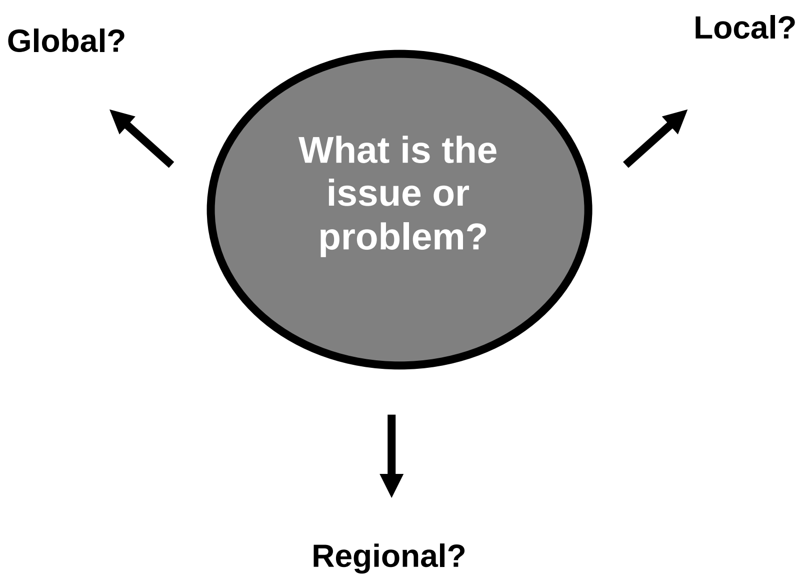


Defining the management problem

The first step is problem definition: what is the issue or problem from a management point of view?

Regional and local impacts

A key consideration in defining the management issue from a local government perspective is whether the impact of the air pollution is local, regional or global—or a combination of these—as this will influence the degree of control a local council has over managing the issue.



If the issue is to manage air quality **comprehensively** in the local government area to meet the NEPM standard or goal, then this may be beyond the capacity of many councils acting alone. For example, few local councils in large metropolitan areas can possibly manage all the factors which contribute to air quality in their local government area. There are two reasons for this:

- air pollutants cross council boundaries, and
- not all pollution sources in a local government area (LGA) are under the council's regulatory control.

Conversely, **councils in rural areas** may be in a position to effectively achieve this outcome because their areas are larger and most sources tend to be council-controlled.

Air pollution comes from many sources, and the multitude of small sources make a major contribution to the regional air quality problem in cities like Sydney. Therefore councils almost always have some part to play with the State and Commonwealth governments in the management of regional air quality.

Global impacts of emissions

Many councils have adopted policies aimed at reducing 'greenhouse gas' emissions in their LGA, from council activities and from the industries, businesses and dwellings under their control and influence.

See Module 2 for information on Cities for Climate Protection and other initiatives.

Councils and regional air quality

The extent of council involvement in addressing regional air quality problems will depend on:

- the extent of the sources which council controls in its area (that is, for which **council is the ARA** under the POEO Act)
- any **partnerships between councils and DECC** in air quality management
- the **resources available to council** to manage air pollution from sources, through legal instruments and technical tools.

Some regional air quality issues, such as photochemical smog, can be significantly influenced by sources which are located throughout the region and are regulated by individual local councils.

Impacts separated from pollution source

An example where the impacts of pollution are experienced some distance from the source is the emissions of volatile organic compounds (VOCs) from many small sources. These react with emissions of nitrogen oxides (NO_x) in the presence of strong sunlight over a period of several hours to form a brew of photochemical oxidants, measured as ozone (O_3), and commonly called **photochemical smog**.

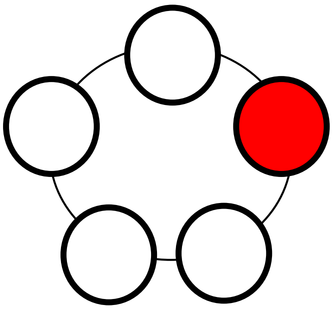
Because of the time delay in the reaction, air carrying the reacting mix of pollutants can travel many kilometres from the source of emissions before forming the smog. Some local government areas contributing significantly to the problem may only rarely experience the effects. Yet many of the sources, of VOCs for example, may be small local industries, such as car smash repairers, which are subject to local government control.

Another example would be **domestic wood fires** in the north west of the Sydney air basin or parts of the Southern Highlands or Northern Tablelands. Fine particles and aerosols from wood fires are trapped in the early-morning winter drainage flow in Sydney, Armidale and the Southern Highlands. They accumulate in the stable air moving slowly eastwards, exposing the suburbs it crosses to high levels of particulate air pollution.

Local air quality impacts

For local impacts caused by activities for which council is the ARA, council often has effective control over all parts of the management loop. For example, an industry or activity causing a local odour or dust problem where council is the ARA is a management issue for council alone.

Exploring options



There are usually many ways of reducing air pollution. Module 3 of the Toolkit outlines some of the important techniques for the types of industries commonly controlled by local government.

In general the management options fall into three categories:

- changes to practices
- changes to materials used
- changes to equipment.

Often a combination of two or even three of these categories can be used together.

Changes to practices

Changes to practices might be, for example, ensuring paper or carbon filters are changed regularly in food preparation establishments. This will mean their containment capacity does not become overwhelmed, rendering the removal of fatty and smelly aerosols ineffective. Another change to practice might be applying adequate water to dusty surfaces on a construction site or within industrial premises.

Changes to materials

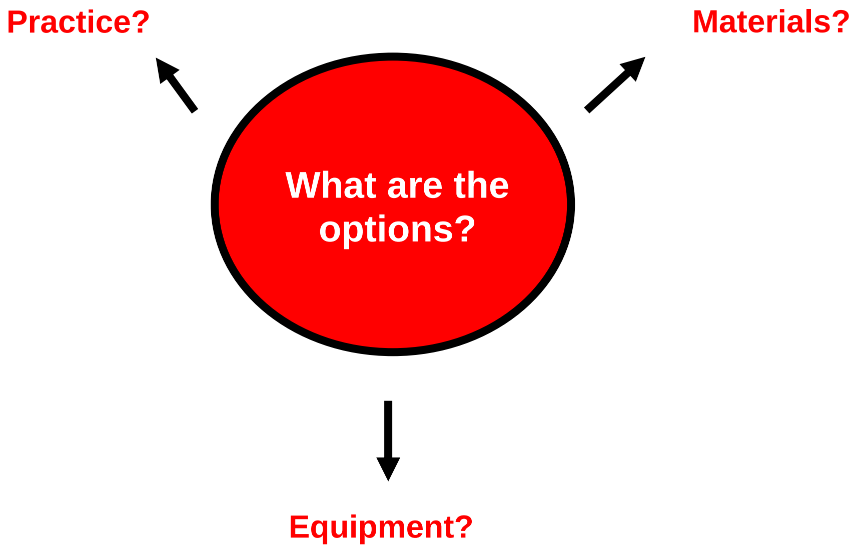
Changes to materials might be, for example, substituting an effective but less odorous or low solvent-content surface coating for a more odorous high solvent-content one in a smash repair shop, or on a white goods finishing line. This would reduce both odours and VOC contribution to photochemical smog. Another example would be ensuring wood used for domestic combustion is well seasoned and dry.

Changes to equipment

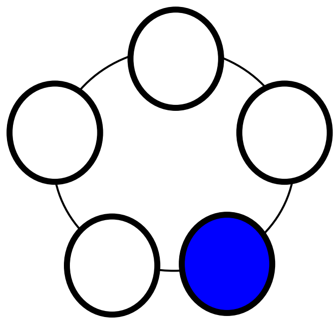
Changes to equipment might involve, for example, using high-pressure low-volume applicators in the car repair trade to minimise overspray, or installing a catalytic oxidiser on the exhaust of a coffee bean roaster.

Another common equipment change is to **raise the height of the exhaust point** of the pollutant in the interests of better dispersion. While this can give real relief locally, it is ineffective for regional impacts.

However, even to achieve the local benefits, the change in height has to be enough to overcome building and topographic effects. It is not uncommon for these factors to defeat the purpose of raising stacks at small to medium sources that are surrounded by other high buildings and hills.



Deciding on a solution



Once a range of options has been developed to address the issue, the options are analysed, quantitatively if possible, to determine the optimum solution. The analysis should look at:

- costs
- effectiveness
- acceptability.

Options may not be easy to assess in situations where there has been extensive or prolonged public disquiet and solutions have been difficult to find.

The guidance notes in Module 3 provide a range of detailed solutions to specific types of industries which present problems for local government.

The cost of a solution

The **cost of options** is the most readily defined of the three factors. This task belongs to the person or organisation managing the pollution source, although care should be taken to make sure the costs claimed are reasonable.

The effectiveness of a solution

Effectiveness can sometimes be assessed quantitatively using *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (2005). However, the modelling prescribed in this guideline is expensive to carry out and for small-to-medium enterprises may not always be warranted. Also, in some situations, the results (predictions) may not provide enough certainty on which to base a management decision. Furthermore, it may not be appropriate to incur this cost simply to provide comfort in decision-making when exercising a fairly obvious judgement would suffice.

In some situations, an **expert judgment** (without expensive modelling) may be adequate to guide the decision-making process and make a recommendation about likely effectiveness for smaller installations, especially where the cost of a modelling study could become a significant component of the total cost of the solution. This Toolkit, and the associated training, aims to help council officers develop this expertise. An additional option, always available to councils, is to require the businesses in question to provide expert reports addressing the issues of uncertainty.

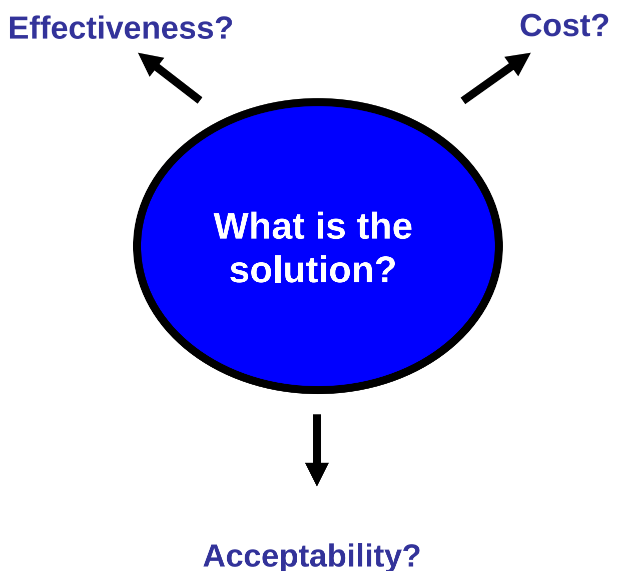
Acceptability of a solution

Council must determine which of the possible solutions to the problem is the most acceptable, based on the consideration of the costs, the effectiveness and the benefits associated with each option.

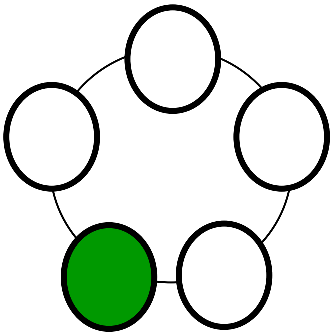
Some **exercise of practical judgment** is usually warranted, especially for dealing with amenity impacts which may be a significant proportion of complaints to council. The amenity of the people affected by the pollution may need to be weighed against the capacity of the neighbouring source of air pollution to pay for the mitigation measures.

Acceptability will be more difficult to assess, especially for amenity pollutants such as dust and odour.

For example, it is not uncommon for complainants against odour sources to become so sensitised to the odour over a period that a significant improvement, even to the level of industry best practice, will not satisfy them. Putting up with a smell for a considerable time can leave an emotional scar which is not easily healed. Added to this, political factors can sometimes become entwined in the problem.



Implementation



The tools and resources needed for implementation of the chosen solution need to be carefully assembled and applied. Depending on the nature of the problem or issue different tools will be required.

Essentially there are three tools used in implementation:

- legal instruments
- technical resources
- education.

In many cases problems can be avoided in the development assessment process by anticipating impacts and using siting or the incorporation of appropriate controls at that stage.

To manage an emission source that is presenting problems (external to council's own operations), the solution will generally require the management of the polluting source to undertake the work.

The **legal instruments** available for imposing these requirements are outlined in Module 2. They are generally Prevention or Clean Up Notices under the POEO Act. Occasionally variations to or enforcement of planning consent provisions or measures under the LG Act may be used.

The **technical information** needed can be generated by or elicited from the source factory or business, either voluntarily in response to council recommendations, or in response to a Prevention or Clean Up Notice.

Persuasion

The preferable way to implement change is by persuading the factory or business management that they need to solve the problem, since development undertaken willingly is always more likely to succeed than development undertaken by constraint. There can also be problems for council officers in drafting technical notices in terms which avoid the risk of the recipient of the notice evading its purpose.

Even when a solution is developed voluntarily by a business, it is advisable for a council to issue a notice to formalise any agreement with the occupier of the premises or business.

An issued notice should clearly set out any requirements relating to the investigation of a problem, monitoring or operational changes and the timeframe for completion of each step, so that all parties know where they stand. A **realistic time** is needed for compliance with equipment design and installation. A notice which is unrealistically short, i.e. a standard '30 days to comply' typically used with domestic premises and shops, may render the notice ineffective if the actions required involve designing equipment, specialised installation or raising capital. For longer processes it might be appropriate to set milestones.

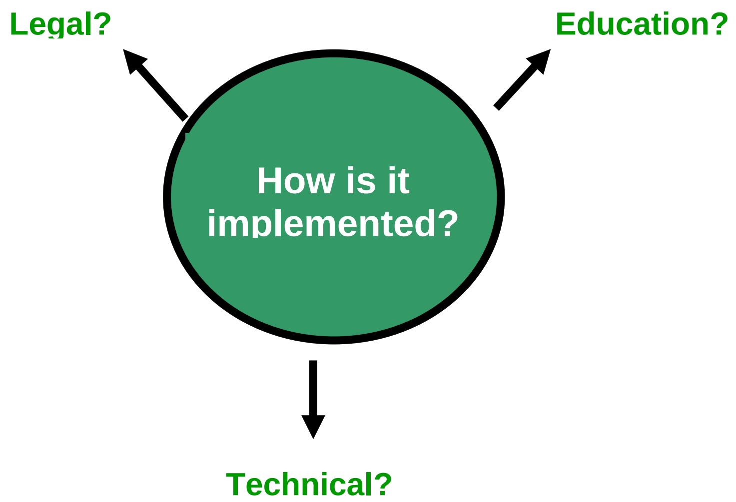
Community education campaigns

On the other hand, a council campaign aimed at reducing a widespread local problem (for example), requires a different approach to implementation. An example might be a campaign to reduce woodsmoke from domestic premises.

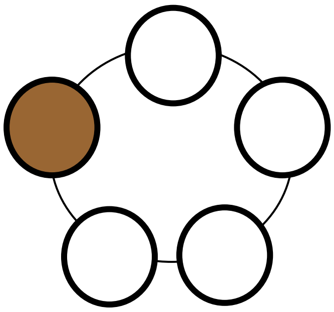
Council would need to make sure the technology is applicable and practical in the situation, that enforcement is feasible if necessary and that financial, personnel and expert resources are available for promoting and implementing the campaign.

Education

Education may be the principal means of addressing some problems, either as a broad issue-specific campaign or on an individual premises level. Planning would need to take account of the need for sustained advice and follow-up for effective implementation.



Checking and review



Any management program needs a checking or review step to ensure the outcomes satisfy the objectives.

This holds whether the program is a broad action, such as reducing woodsmoke in a local government area over a period of years, or a specific action, such as reducing odours from the local ‘takeaway chook shop’.

There are two benefits to checking and review:

Firstly, to make sure the action undertaken and the effort expended do in fact achieve their intended outcomes.

To continue with the example, without some checking it may seem as if the complaints about ‘chook shop’ odours have gone away, whereas in fact the complainants may have just given up on council ever solving the problem.

> Mere disappearance of the complaints may seem an adequate outcome from an officer’s perspective. But if this results in an ineffective solution being applied in another situation, the outcome will not have been satisfactory.

Secondly, reviewing programs leads to continual improvement and is the path to sustainability in environment protection.

This approach can be adopted for all programs, from the smallest action to a council’s overall environmental performance.

The formalised techniques for checking and review are

- monitoring
- auditing
- reporting.

Simple air pollution monitors on a large construction site

Monitoring

Monitoring can span a full range of actions from checking for odours on a 'sniff patrol', through emission testing of a source on completion of its installation, to ambient scientific monitoring to ensure that air quality goals have been achieved. The expense increases across this range.

Ambient scientific monitoring, the most expensive, is rarely warranted in local government situations involving small to medium industries and businesses, even for limited periods.

Emission or **source performance monitoring** may sometimes be warranted, although it is also expensive. For example, an emission test for particles could cost the operator from several thousand dollars to $20,000 depending on the ease of access and the difficulty of the test. If toxic emissions are involved such testing may indeed be warranted.

Finally, some sort of **physical checking by observation** is obviously the cheapest method and is frequently adequate to confirm performance, e.g. the dust can no longer be seen or the odour can no longer be smelled.

> Consistent pre- and post- monitoring (scientific or by simple observation) is essential for the adequate assessment and management of new developments and changes to premises.
>
> 'Monitoring' may be anything from intelligent observation to specialised, scientific measurement. Wherever it lies on the spectrum it should be:
>
> – systematic
> – documented
> – subject to careful analysis.

Auditing

Auditing is a systematic and thorough checking of operations and equipment to make sure they are performing as intended. There are various techniques for auditing which are described on the DECC and related web sites and in various standards produced by organisations such as Standards Australia and the ISO standards.

Audits may take many forms. The purpose of an audit might be to address:

- compliance
- program effectiveness
- due diligence.

> Audits are most successful when their objectives have been carefully and precisely defined before any measurements or checks are undertaken.

Audits may be carried out by accredited or general auditors, or may be independent or internal to the organisation involved.

The acceptability of these variations will depend on the objectives. For example, for **auditing contaminated land** only DECC accredited auditors may be used, whereas there are fewer situations in which accredited auditors are likely to be required in air pollution situations.

Finally, the term 'monitoring' is also applied in a management sense to the overall process of checking that a program or policy is being implemented satisfactorily.

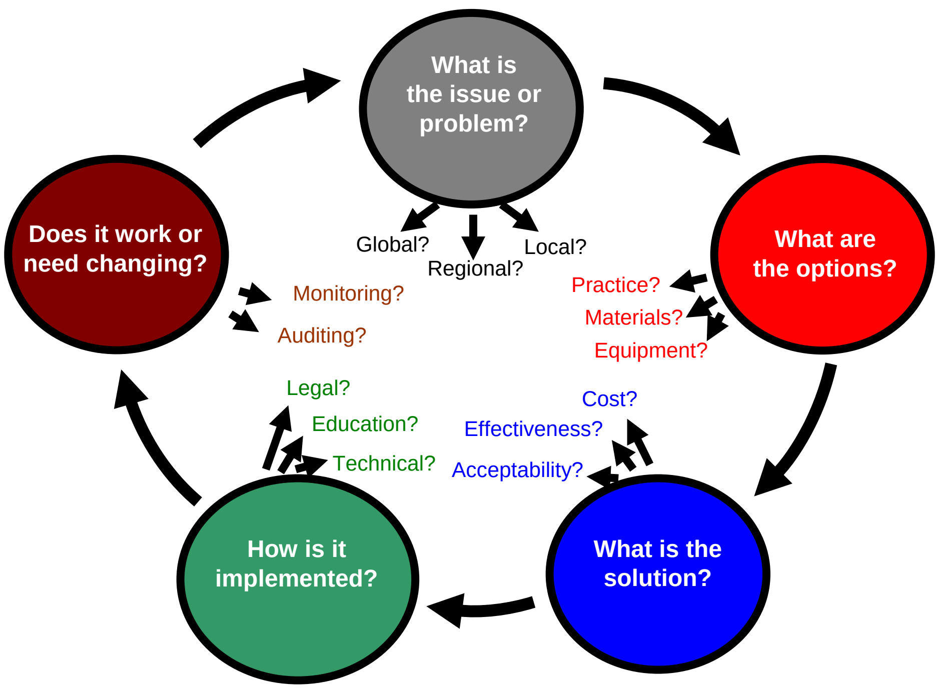
Reporting of monitored and audited results should take account of who needs to know and who might be interested in knowing.

The feedback process should also be open, and ideally there should be a willingness to consider critical comment in order to improve management.

Overview

This management cycle, widely used for managing many activities in business and government, is appropriate for local government management of air quality.

The full cycle is shown combined in the following diagram.



4.3 Assessing air quality issues

Some practical techniques that can be used by councils for identifying air quality issues in their local areas include:

- any DECC or large-industry **monitoring** in or adjacent to the local government area
- **inventories of air pollutants** emitted in the local government area from sources such as the National Pollutant Inventory or DECC special purpose inventories
- **GIS data** held by council on the spatial distribution of industries with potential for air emissions, looking especially for clustering of common types, for example, smash repairers
- **council-generated data** including analysis of complaint patterns relating to 'hot spots' and routine field officer observations.

Monitoring ambient air quality

Collecting and maintaining ambient air quality monitoring data is demanding and expensive. Scientific accuracy, consistency and continuity are essential for reliable assessment of air quality and trends. It is not feasible or warranted for DECC to monitor air quality in every local government area.

In the old days of high fallout, deposit gauges were maintained in many local government areas across the State, but this form of gross pollution monitoring has now been reduced to a typical uniform minimum across similar areas and is no longer carried out. Processes for monitoring of PM_{10} or ozone, for example, are much more sophisticated and complicated.

In polluted air basins, reliable interpolations on air quality can be made between monitoring stations by using modelling techniques. However, this is rarely critical for local government purposes, since the nearest air quality monitor within the same air shed will usually give an adequate indication of air quality in the local government area.

Monitoring by industries

Some industries are required to undertake specific ambient monitoring around their operations and to make the information publicly available. This can be usefully accessed and reviewed by local government for general air quality trends, although these large industries are not regulated by local government.

The National Pollutant Inventory

The National Pollutant Inventory (NPI) provides information on releases of toxic and other key air pollutants by local government and postcode areas. This can be a useful starting point for developing priorities for dealing with air quality in a region. However, caution is needed in interpreting some of the NPI data, especially where reporting is not complete.

GIS databases

Often a council's own GIS database of its industries and businesses can be a useful starting point in developing a priority program for air quality management. For example, the location of poultry operations, small piggeries or mushroom growers in relation to residential areas and likely prevalent wind directions might provide useful inputs to land use planning and the formulation of Local Environment Plans (LEPs) and Development Control Plans (DCPs).

Council-generated information

Complaints usually represent a substantial database in councils, and careful analysis of the complaints can provide useful pointers for practical management as discussed further below. Skilled observations by council officers in the course of normal field duties can also provide valuable data inputs.

4.4 Planning

Although regional planning for air quality is primarily the province of DECC and the Department of Planning, local government planning for local facilities can have significant impacts on air quality. For example, the development of a new shopping complex has obvious implications for traffic flow and vehicle emissions and certain types of commercial emissions. Similarly, the development of a new industrial area can have significant impacts on air quality—both locally and regionally. For example, the development of marina-based businesses could result in increased emissions of VOCs as a result of boat maintenance activities.

> The best management of the regional and amenity impacts of air pollution is achieved at the planning stage, in which local government is an active partner with State government.

Local land use planning

At the local level, the air amenity issues most commonly faced by local government—odour and dust—are best dealt with initially by separating the sources of air pollution and the sensitive receptors such as homes, hospitals, schools, etc. Sensible planning provisions can contribute immeasurably to maintaining good air quality at the local level.

Some local councils include provisions relating to air quality management into Local Environment Plans (LEPs) and Development Control Plans (DCPs), while others rely on regional air quality planning at the State level and concentrate primarily on local air pollution issues. This depends on circumstances, but the need for local government to be involved in regional aspects is becoming more relevant with growth in population and increasing density of housing and traffic.

These exhaust stacks are located on a relatively new food processing premises. The dust screen in the foreground is shielding a proposed multi-storey residential development. Is this a problem waiting to develop?

4.5 Consents, notices and enforcement

The principal legal instruments available to councils for air quality management at specific premises are **conditions attached to consents** granted under the EP&A Act and **requirements attached to notices** under the POEO Act.

The legal aspects of these instruments are outlined in Module 2 of the Toolkit. Guidelines for conditions in various industries are covered in Module 3 of the Toolkit.

Enforcement

Enforcement will be needed from time to time, when industries, businesses or householders are tardy and recalcitrant in complying with Council's requirements to control or eliminate air pollution.

Penalty Notices under the EP&A Act and the POEO Act are useful tools for achieving compliance. Prosecution is a more demanding measure, but one which may be warranted in difficult cases. The approach taken will depend on circumstances and council policies and attitudes to enforcement.

Clean-Up Notices under the POEO Act where there has been an incident or persistent damage to the environment can serve both the dual purpose of remediating damage to the environment and being a costly deterrent to repeat offences.

Warning letters following inspections are used by some councils as the first formal action against offending premises, before applying the law formally. While this can be effective, it needs to be publicly demonstrated that more formal legal action will indeed follow if warnings are not heeded.

Industrial or commercial campaigns

Some councils have found that **planned campaigns in selected industrial areas** have beneficial effects. Some of the techniques used include:

- **Short 'audits' by experienced council officers on a 'walk-though-and-note' basis**, often using check lists for specific industry types. These may be planned on a precinct or industry-type basis. Such audits will rarely be confined to air pollution matters alone, since it tends to be an inefficient use of resources to visit premises only for air pollution where water, noise and waste issues are also likely to be involved.
- **Blitz-type intensive inspections on selected troublesome industries**, with widely publicized follow-up action.
- **Development of partnerships with industry groups**, e.g. smash-repairers, wherein industry members participate in campaigns and competitions for best practice with the support and encouragement of council officers.

4.6 Complaints and community feedback

Unfortunately much air quality management at the local level tends to be complaint driven. The officers rarely have time for planning since they are forever chasing down and acting on complaints. This is a common fact of life in environmental work.

The DECC information and complaints service receives 80,000 calls a year, many of which relate to local government responsibilities under environmental legislation. The community provides dynamic and active feedback to its government authorities on the environment!

Using complaints constructively

Rather than bemoaning complaints, a more productive approach is to **use phenomenon as an indicator of community feedback.** Members of the public can be enlisted in problem solving by collecting information on occurrence, times, weather conditions, etc. and even fallout samples. However, experience has shown that this information should only be supplementary to more definitive observation and sampling by trained officers.

> Long-term experience has shown that public descriptions of smells and fallout are not generally reliable. What is reliable is that complaints are more often than not an indication that a real problem of some sort does exist.

Most local government councils have a system for recording and following up on complaints. It is wise to review this periodically to see if there are patterns of complaints which could be dealt with in other ways—for example by providing information via council’s website or brochures, and so on.

> Persistent complaint patterns may point to a need to make concerted efforts to achieve efficient solutions for particular premises or industries.

Public exhibition of development applications

Feedback during the consultation and exhibition periods of development applications can be useful in identifying issues for both the applicant and council. It can also point to the need for community follow-up to provide assurance that fears and concerns have been addressed in the consent process.

4.7 Resources

Many council environmental officers have received training at university or college level, and are generally equipped to understand the basic principles of air quality science without being experts in the area. However, the air quality issues which arise, even with medium to small installations, can be quite complex. For example, crematoria, a local council responsibility, emit mercury and dioxins and complex risk assessment may be needed in their assessment and management.

From time to time, when complex issues arise, councils will need access to more skills than available through their staff. Consultants can be used to supplement council skills, either employed by council or by the businesses posing the problems.

Use of consultants

Some councils retain consultants to advise them on specific matters of planning or development consent assessments. However, this can strain council budgets if the costs cannot be passed on to the developers.

Existing premises and activities

Dealing with existing industries and businesses presents a real problem in terms of the cost of advice, since the recovery of costs from issuing notices will not usually be adequate to buy expert advice. A notice can require industry to obtain the necessary expert advice, but it needs to be carefully drafted to make sure that the advice obtained is balanced and does not start from inadequate or unsuitable pre-suppositions on the part of the business. Also, advice from consultants needs to be subject to careful scrutiny by council officers, taking account of the consultant’s experience and qualifications for providing the advice.

Ongoing training of council officers is highly desirable. This Toolkit and associated training is a contribution to such training. It should be regarded as a resource to be developed and adapted to specific council needs, with the training as a seeding exercise. Council officers should be encouraged to engage in real, lifelong training such as many professions now require of their members.

In-service training for council officers

Short courses are offered periodically by:

- DECC e.g. the training accompanying this Toolkit
- professional associations, such as the Clean Air Society of Australia and New Zealand, Inc.
- industry associations, such as the Australian Industry Group.

Some professional training providers also offer in-house specialised training for council officers.

Many universities and TAFE colleges offer postgraduate or advanced-certificate training in environmental science and management which are suitable for council officers.