



*Ministry for the*  
**Environment**  
*Manatū Mō Te Taiao*

# **Good Practice Guide for Air Quality Monitoring and Data Management 2009**

This report may be cited as:

Ministry for the Environment. 2009. *Good Practice Guide for Air Quality Monitoring and Data Management 2009*. Wellington: Ministry for the Environment.

Published in April 2009 by the  
Ministry for the Environment  
Manatū Mō Te Taiao  
PO Box 10362, Wellington 6143, New Zealand

ISBN: 978-0-478-33166-0 (print)  
978-0-478-33167-7 (electronic)

Publication number: ME 933

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This document is available on the Ministry for the Environment's website:  
[www.mfe.govt.nz](http://www.mfe.govt.nz)



# Acknowledgements

The Ministry would like to thank the following people and organisations for contributing to the development of this guide:

- Clean Air Society of Australia and New Zealand, represented by Paul Baynham
- National Air Quality Working Group members
- National Institute of Water and Atmospheric Research Limited
- regional council air quality scientists
- the practitioners who attended a consultation workshop in December 2008:
  - Teresa Aberkane, Environment Canterbury
  - Robert Chauval, QEMS Ltd
  - Brian Cheyne, Taranaki Regional Council
  - Ross Glubb, Environment Canterbury
  - Sally Gray, National Institute of Water and Atmospheric Research Limited (NIWA)
  - Shane Iremonger, Environment Bay of Plenty
  - Nick Kim, Environment Waikato
  - Brian Mills, BECA
  - Deborah Mills, Otago Regional Council
  - Tamsin Mitchell, Greater Wellington Regional Council
  - Janet Petersen, Auckland Regional Council
  - Jozua Taljaard, Watercare Services Ltd.

# Abbreviations

$\mu\text{g}/\text{m}^3$	micrograms per cubic metre
$\mu\text{m}$	micrometre
AAQG	Ambient Air Quality Guidelines
AS/NZS	Australian / New Zealand Standard
BAM	beta attenuation monitor
BaP	benzo(a)pyrene
BS EN	British Standards Institution European Norm standard
CFR	United States Code of Federal Regulations (40 CFR 51 is the same as Title 40, Part 51 of the CFR)
CO	carbon monoxide
DAS	data acquisition system/datalogger
FDMS	filter dynamics measurement system
$\text{H}_2\text{S}$	hydrogen sulphide
Hi-vol	high-volume sampler
$\text{mg}/\text{m}^3$	milligrams per cubic metre
NAQWG	National Air Quality Working Group
NES	national environmental standards
NIWA	National Institute of Water and Atmospheric Research Limited
NMHC	non-methane hydrocarbon
NO	nitric oxide
$\text{NO}_2$	nitrogen dioxide
$\text{NO}_x$	oxides of nitrogen (eg, nitrogen dioxide and nitrous oxide)
NZST	New Zealand Standard Time
$\text{O}_3$	ozone
PAH	polycyclic aromatic hydrocarbon
$\text{PM}_{2.5}$	particulate matter with an aerodynamic diameter of 2.5 microns or less
$\text{PM}_{10}$	particulate matter with an aerodynamic diameter of 10 microns or less
PMT	photomultiplier tube
ppb	parts per billion
ppm	parts per million
RMA	Resource Management Act 1991
$\text{SO}_2$	sulphur dioxide
TEOM	tapered element oscillating microbalance
TSP	total suspended particulate
USEPA	United States Environmental Protection Agency
UV	ultraviolet
VOC	volatile organic compounds
WHO	World Health Organization

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# 1 Introduction

## 1.1 Purpose of the Guide

The *Good Practice Guide for Air Quality Monitoring and Data Management 2009* provides guidance to help achieve accurate and representative ambient air quality monitoring, using nationally consistent monitoring methods and reporting formats. The Guide also aims to make air quality monitoring information accessible by being a quick reference of methods and new developments.

This document replaces the *Good Practice Guide for Air Quality Monitoring and Data Management* published by the Ministry for the Environment in 2000. It does so by incorporating the significant developments (see section 1.2) that have occurred since the 2000 Guide was published.

This Guide aims to provide guidance for air quality monitoring and data management to ensure these are:

- **correct** – air quality monitoring is of high quality and free from errors
- **representative** – spatial/temporal variations and the extent of human exposure are considered when designing monitoring networks
- **consistent** – air quality data is recorded, analysed, processed, reported and archived following best-practice principles
- **accessible** – suppliers and users of air quality data have quick and easy access to methods, procedures and new developments.

## 1.2 Background

The Resource Management Act 1991 (RMA) requires regional councils / unitary authorities to monitor air quality and the state of the environment. In response, councils have prepared regional air quality plans, which contain objectives for air quality in the region together with policies and rules to achieve them.

Historically, information on New Zealand's air quality was limited to data from a small number of monitoring sites. In recent years, many councils have designed and established air quality monitoring programmes of varying scales and complexities, and since 1993 the number of air quality monitoring sites in New Zealand has increased significantly (Ministry for the Environment, 2003a).

As monitoring programmes were established and existing ones expanded, concerns have been raised about data quality, reliability and comparability. In particular, data gathered by different techniques or to varying levels of quality assurance prevented the development of a reliable picture of air quality across New Zealand. To address these concerns, the *Good Practice Guide for Air Quality Monitoring and Data Management* (2000) was developed by the Ministry for the Environment in close collaboration with air quality specialists.

The objective of that guidance was to provide robust, good-quality monitoring and reporting practices that would ensure:

- the effectiveness of different air quality management options could be evaluated
- the comparability of air quality data between sites and regions
- clear communication of information about air quality and its effects within a region and nationally (eg, through regional and national state of the environment reports).

Since the publication of the 2000 Guide there have been a number of developments.

- Eight additional contaminants have been identified in the *Ambient Air Quality Guidelines* (AAQG) (Ministry for the Environment, 2002), updating the original 1994 document.
- New Zealand's first suite of national environmental standards in the *Resource Management (National Environmental Standards Relating to Certain Air Pollutants, Dioxins and Other Toxics) Regulations 2004* (the regulations) was introduced on 6 September 2004. The regulations include the first ambient air quality standards in New Zealand, covering carbon monoxide (CO), nitrogen dioxide (NO<sub>2</sub>), ozone (O<sub>3</sub>), particulate matter (PM<sub>10</sub>) and sulphur dioxide (SO<sub>2</sub>).
- The Foundation for Research Science and Technology (FRST) programme, Keeping Our Air Clean, provided research and tools to help implement the national environmental standards (NES) for air quality. Specific outputs from this programme have provided additional guidance and resources for monitoring air quality, which are included in this new Guide.
- The national Air Quality Database, developed by the National Institute of Water and Atmospheric Research Limited, was discontinued.
- Annual, web-based national-level reporting of PM<sub>10</sub> in monitored airsheds was introduced in 2005. This includes data on concentration, methodology and exceedences, together with straight-line-path information. This is a web-based update that can be accessed at the Ministry for the Environment's website ([www.mfe.govt.nz/state/reporting/air/nes/index.html](http://www.mfe.govt.nz/state/reporting/air/nes/index.html)).

These developments have led the Ministry to produce this updated guide, *Good Practice Guide for Air Quality Monitoring and Data Management 2009*, to replace the 2000 Guide. The Ministry intends to review and update the Guide as further developments occur (eg, the release of new standards from Standards Australia and Standards New Zealand).

## 1.3 Who will use this Guide?

The Guide is primarily intended to be used by councils, agencies, consultants and researchers when planning and carrying out:

- regional air quality monitoring programmes
- monitoring programmes to collect data for air quality models.

In addition, the Guide will be helpful for agencies planning and carrying out:

- desktop assessments and screening surveys
- various air quality research projects
- other monitoring programmes.

## 1.4 Status of recommendations

The recommendations in this Guide represent best-practice approaches based on expert advice from experienced air quality scientists in New Zealand. They should be used wherever possible. However, the recommendations are not legislative requirements under the RMA or any other legislation.

The recommendations should be closely followed when collecting monitoring data for comparison with standards and guideline values or data from other locations. The methods are consistent with those recommended for use in the NES for air quality and by Standards Australia and Standards New Zealand. Different monitoring techniques may be useful when monitoring for other purposes, such as screening surveys.

## 1.5 What this Guide covers

The Guide provides best-practice guidance for undertaking air quality monitoring for various purposes. It also covers the statutory requirements for compliance monitoring and guidance for monitoring other contaminants listed in the *Ambient Air Quality Guidelines* (AAQG). It deals specifically with *ambient* air quality monitoring.

The Guide also covers the management of air quality data and includes guidelines for the collection, review, storage and dissemination of such data.

Although the focus is on air quality contaminants, some discussion on meteorological monitoring is included given that it plays a major role in the analysis and interpretation of air quality monitoring data.

The Guide is structured as follows.

- Chapter 1 (this chapter) describes the aims of the Guide and sets its scope. It provides information on how the Guide was developed and explains the status of recommendations contained in the Guide.
- Chapter 2 contains guidance on developing an air quality monitoring programme and discusses some types of monitoring.
- Chapter 3 provides information on the contaminants included in the NES for air quality and the AAQG and explains the difference between a standard and a guideline. It also briefly discusses meteorological monitoring.
- Chapter 4 discusses the different methodologies used in monitoring air quality. It lists the required methods for compliance monitoring and the recommended methods for monitoring AAQG contaminants.
- Chapter 5 focuses on particulate monitoring. It describes the different particle size fractions and the most common particle monitoring methods used in New Zealand.
- Chapter 6 contains guidance on the siting of monitoring stations based on the latest Australian / New Zealand standard (AS/NZS 3580.1.1:2007).
- Chapter 7 discusses equipment calibration and maintenance procedures and provides recommendations on proper documentation.

- Chapter 8 contains guidance on data quality assurance at all stages of data management. Guidance is also provided for data adjustment and dealing with negative and missing data.
- Chapter 9 provides recommendations on data reporting formats to promote nationally consistent air quality reporting.

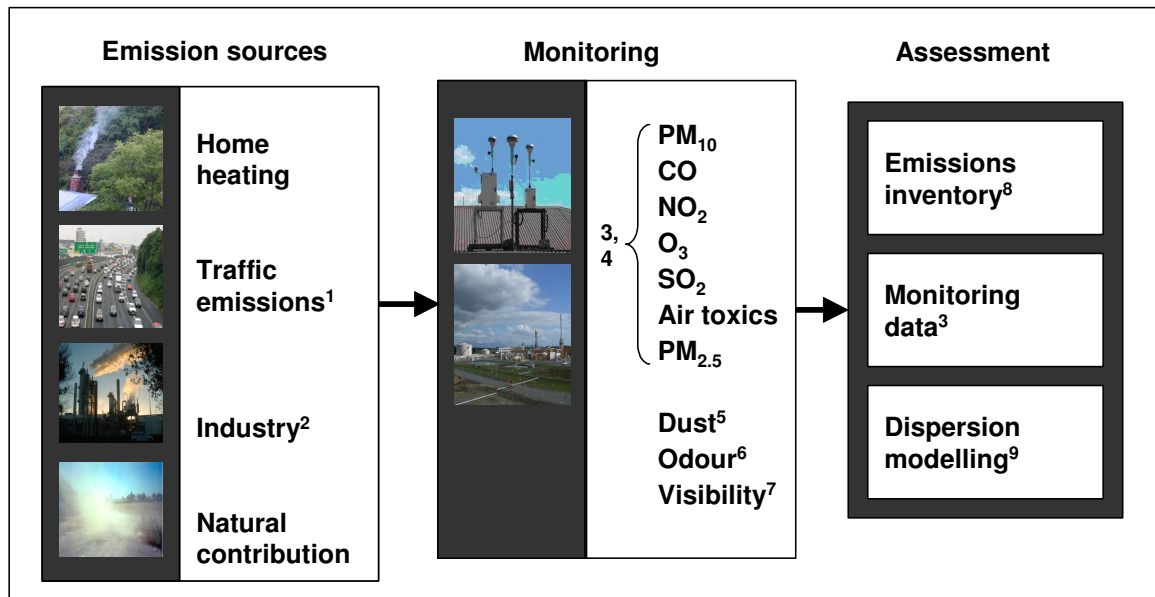
## 1.6 What this Guide doesn't cover

The Guide aims to provide information and recommendations that are neither too specific nor too general. The scope of this Guide does not include:

- equipment-specific guidance – readers are advised to consult the user's manual or contact the equipment vendor for detailed information
- information on monitoring methods already covered by an Australian / New Zealand Standard (AS/NZS), or other relevant standard – readers are advised to refer to the relevant standard
- emissions testing for individual source discharges – information about compliance monitoring and emission testing can be found in the Ministry's *Compliance Monitoring and Emissions Testing of Discharges to Air* (1998)
- monitoring odour – information on this can be found in the Ministry's *Good Practice Guide for Assessing and Managing Odour in New Zealand* (2003).

Figure 1.1 shows the full suite of the Ministry for the Environment's air quality good practice guide publications and their applications.

**Figure 1.1: Applications of the Ministry for the Environment’s air quality good practice guides**



Photograph sources: Ministry for the Environment, Taranaki District Council and Tasman District Council

- 1 *Good Practice Guide for Assessing Discharges to Air from Land Transport* (2008)
- 2 *Good Practice Guide for Assessing Discharges to Air from Industry* (2008)
- 3 *Good Practice Guide for Air Quality Monitoring and Data Management 2009* (2009)
- 4 *Compliance Monitoring and Emission Testing of Discharges to Air* (1998)
- 5 *Good Practice Guide for Assessing and Managing the Environmental Effects of Dust Emissions* (2001)
- 6 *Good Practice Guide for Assessing and Managing Odour in New Zealand* (2003)
- 7 *Good Practice Guide for Monitoring and Management of Visibility in New Zealand* (2001)
- 8 *Good Practice Guide for Preparing Emissions Inventories* (2001)
- 9 *Good Practice Guide for Atmospheric Dispersion Modelling* (2004)

## 2 Why Monitor? – Monitoring Programme Objectives

The fundamental objective of air quality monitoring is to collect data that can be used to make informed decisions to best manage and improve the environment. This section describes an approach for developing an air quality monitoring strategy.

### 2.1 Regional policies and plans

Monitoring programmes should be closely linked to the main issues of concern within a region, as specified in its regional plan. Air quality monitoring provides evidence on the current levels of contaminants and provides policy-makers with information on how to better manage air quality in their regions.

Air quality data is continuously collected to provide information to aid policy development and evaluation. After a regional plan has been put in place, monitoring can confirm if targets are being met and if the rules implemented are producing the anticipated results.

Compulsory monitoring requirements were also introduced when the NES for air quality were implemented in 2004. Regional councils should consider these requirements when drafting their regional plans and monitoring programmes.

### 2.2 Regional monitoring objectives

To quantify ambient air quality in a region and note spatial and temporal variations, the monitoring should:

- provide comprehensive data to judge the significance of actual and perceived regional issues
- be related to the issues, objectives and methods of implementation specified in the regional air plan
- supply sufficient data to determine geographical patterns in air quality over various time scales (eg, seasonally)
- lead to an understanding of whether national or regional air quality standards, guidelines, objectives and environmental outcomes are being met, and whether areas of concern are being identified
- develop a picture of representative concentrations in areas of high population density where air quality is known, or suspected, to be poor
- provide sufficient data to determine trends in air quality over time and the background levels of contaminants
- supply enough information to determine the population at risk from exposure to poor air quality in order to evaluate the potential and actual health effects in a region (eg, personal exposure assessments).

## 2.3 Developing an air quality monitoring programme

The intended use of data from a monitoring site should be identified before a site is established.

Usually, the general objective of an ambient air quality monitoring programme is to determine air quality in a region to assess its effects on human health. However, programmes may have different specific objectives (eg, to establish long-term trends and patterns, or validate dispersion modelling).

There are many factors to consider in developing a monitoring programme, but the following are of fundamental importance.

- **Why monitor?**

Why is monitoring being undertaken? What is the expected outcome of the monitoring? Establishing a monitoring objective is the fundamental step in developing a monitoring programme because all subsequent decisions will be based on why the monitoring is being undertaken. The most common reasons for monitoring include:

- determining the level of contaminants in an airshed to compare with standards and guidelines
- reporting on the state of the environment
- obtaining exploratory data
- conducting air quality research
- obtaining data for air quality modelling
- providing air quality information for policy or strategy development
- assessing the effectiveness of policy based on air quality trends.

- **Which species to monitor?**

In many cases this may be obvious, based on known emission sources in the area, but in other cases it merits careful consideration. Once the target contaminant has been identified, in what form should it be monitored? For example, total hydrocarbons or individual (speciated) hydrocarbons? Total particulate matter or a specific size fraction? Is further analysis required?

- **How to sample?**

Both the type of sampling and the analytical end method need to be considered. Method selection involves an appraisal of cost versus performance; the latter includes the limits of detection, sensitivity, speed of instrument response, susceptibility to interfering species and the overall uncertainty of the measurement. Consider the aim of monitoring and choose appropriate methods and equipment. When using a screening method for exploratory testing, is the level of accuracy and precision suitable to measure contaminant levels?

- **Where to sample?**

The decisions around where to locate a monitoring site are based on the objectives of monitoring. The siting of an air quality monitor has a profound effect on the resulting measurements of contaminant levels and on achieving monitoring objectives. Will the site measure peak or background concentrations? What atmospheric reactions affect the formation/destruction of the contaminant to be monitored?

- **How to calibrate and maintain equipment?**

Calibration and maintenance of monitoring equipment is an important part of every monitoring programme. How frequently should calibration be undertaken? What documentation is required? What procedures will ensure the efficient and smooth operation of monitoring equipment?

- **What data management protocols should be used?**

It is important to ensure that air quality data is properly validated and managed after it is obtained. What data quality assurance processes are in place? What supplementary data needs to be collected? Other information may be relevant to the study (eg, meteorological conditions, process data and traffic flows). Meteorological conditions are important in assessing the impacts of sources on surrounding areas because they dictate the transport and dispersion of contaminants in ambient air.

- **How will data be stored and reported?**

What time format should be used? How will exceedences be determined and reported? Following the recommended format in the reporting of monitoring results is a step towards achieving national consistency in air quality reporting.

These factors are discussed in greater detail in the following chapters.

## 2.4 Desktop assessments

In the early stages of establishing a regional monitoring programme little may be known about the air quality of the area under investigation. Initially, it will be necessary to assess where air quality in the region is likely to be at risk of exceeding standards for each contaminant. This can often be done by a desktop assessment.

The following factors need to be investigated to determine areas at risk within a region:

- emissions sources (eg, domestic, industrial, transport, agricultural and natural) and the contaminants emitted
- meteorology (eg, areas prone to temperature inversions)
- topography
- geography
- population centres (especially where domestic fires and traffic emissions occur)
- historical monitoring data (where available)
- areas with high natural environmental values (eg, in and around natural parks, forests, wilderness areas and wetlands)
- the location of sensitive areas particularly vulnerable to air pollution (eg, hospitals, schools, child- and aged-care facilities)
- areas planned for development (eg, to get a picture of background concentrations)
- any public complaints or issues of concern relating to air pollution
- any epidemiological studies on air quality effects on health already carried out.



This information should provide a good basis to determine which contaminants should be monitored and where contaminant levels may be elevated. Should any risks be identified, preliminary screening surveys may need to be established to better identify risk areas and potential contaminant levels, particularly if no historical monitoring data is available. Even with a well-established regional monitoring programme, emission sources within an air quality management area can change significantly over time (requiring an efficient approach to updating emission inventories), and may result in the need for further screening surveys.

## 2.5 Types of monitoring

### 2.5.1 Screening surveys

Screening surveys using local knowledge and simple monitoring techniques can provide a quick and cost-effective picture of contaminant concentrations over a wide spatial distribution. They are usually intended to assess air quality at a particular location to determine indicative ambient concentrations and identify whether more permanent monitoring is needed. Screening surveys can include non-standard methods such as passive samplers for gases and volatile organic compounds (VOCs) and low-volume gravimetric samplers for PM<sub>10</sub>. However, the use of standard methods housed in a mobile air quality monitoring station may be more appropriate where decisions on establishing permanent sites (at considerable financial investment) are involved.

Consideration should be given to ensuring the monitoring period is representative of pollution levels throughout the year. Screening should ideally be undertaken for at least a six-month period to include summer and winter conditions. Screening surveys should cover particular seasons in which contaminant peak levels occur.

### 2.5.2 Continuous monitoring

Screening programmes should only be used to provide an indication of where detailed monitoring is required. Data derived from screening surveys must not be used to determine whether an airshed complies with the NES for air quality or air quality guidelines. When there is an indication that national standards are likely to be breached, it will be necessary to select sites where contaminants will be monitored using the methods in Schedule 2 of the NES for air quality. This is likely to require commitment to a long-term site in order to measure the effects of management strategies in the airshed.

Two examples of continuous monitoring sites are:

- *permanent ambient site* – a site established for long-term monitoring of contaminant levels and trends using standard monitoring methods
- *compliance monitoring site* – a site established for long-term monitoring of contaminant levels and trends over time for the purposes of determining compliance with the NES for air quality in a particular airshed. The use of standard monitoring methods is compulsory.

### **2.5.3 Monitoring for research purposes**

Air quality monitoring is often undertaken for research purposes to address specific issues such as local dispersion characteristics using tracer gases, or the collection of particle samples for speciation analyses and source apportionment work. This work is usually carried out using non-standard methods and specialised sampling equipment.

## 3 What to Monitor? – Choosing Contaminants

This chapter describes the ambient air quality standards and guidelines and discusses how air quality monitoring fits into the regulatory framework.

New Zealand has national environmental standards for five air contaminants as well as 15 ambient air quality guidelines. Guidelines that apply over the same averaging period for a particular contaminant have been effectively superseded by the standards. This is not simply a change in designation from guideline to standard. The following summarises the basic differences between standards and guidelines.

- Ambient air quality **standards** are concentration limits set to protect New Zealanders' health. They have the force of regulation under the Resource Management Regulations 2004 and have *mandated* monitoring methods and reporting requirements. Some ambient air quality standards incorporate a specified number of allowable exceedences in any 12-month period.
- Ambient air quality **guidelines** are concentration limits recommended to protect human health and the environment under the Resource Management Act 1991 (RMA). They may be incorporated into regional plans as objectives or targets. The ambient air quality guidelines do not specify allowable exceedences.

*Note:* Guidelines for contaminants not covered by standards still apply. Guidelines should be followed as closely as possible for the sake of good practice and national consistency.

From a regulatory viewpoint, regional air quality plans are statutory instruments under the RMA and have equal status with the standards. If the air quality objectives in a regional air quality plan are more stringent than the NES for air quality, then the regional plan takes precedence. Regional air quality objectives, however, cannot be more lenient than the NES for air quality (Ministry for the Environment, 2008).

### 3.1 Monitoring for standards and guidelines

The term 'airshed' as used in the regulations is more akin to an 'air quality management area' rather than being a strictly science-based concept of an airshed (although in many instances the two are equivalent). These airsheds were designated through recommendations made by regional councils and unitary authorities to the Minister for the Environment. They extend upwards from ground level, including coastal marine areas, and have no specified upper limit. In most cases they represent areas that are known, or likely, to exceed the fine particle ambient standard. The exception to this is the Marsden Point airshed, which is based on its likely or known breaches of the sulphur dioxide standard.

### 3.1.1 National environmental standards (NES) for ambient air quality

The NES for air quality apply at any place in the open air where a person might reasonably be expected to be exposed to the contaminant over the relevant averaging period. This does not include tunnels, indoor areas or outdoor workplace sites, whose emissions are covered by Occupational Safety and Health regulations.

The standards are based on the 'no observable adverse effect' level or 'lowest observable adverse effect' level in relation to human health. Where epidemiological studies and international guidelines have been unable to determine such a threshold, a judgement has been made as to what constitutes an 'acceptable' health risk.

Table 1 shows the airborne contaminants included in the NES for air quality which are considered to be of greatest concern and most likely to exist in New Zealand.

**Table 1: National environmental standards for ambient air quality**

Contaminant	Threshold concentration	Time average	Permissible excess per year
Carbon monoxide (CO)	10 mg/m <sup>3</sup>	Running 8-hour mean	1
Nitrogen dioxide (NO <sub>2</sub> )	200 µg/m <sup>3</sup>	1-hour mean	9
Ozone (O <sub>3</sub> )	150 µg/m <sup>3</sup>	1-hour mean	0
PM <sub>10</sub> (fine particles)	50 µg/m <sup>3</sup>	24-hour mean	1
Sulphur dioxide (SO <sub>2</sub> )	350 µg/m <sup>3</sup> 570 µg/m <sup>3</sup>	1-hour mean 1-hour mean	9 0

The ambient standards came into effect on 1 September 2005. The standards include permissible exceedences for CO, NO<sub>2</sub>, PM<sub>10</sub> and the 350 µg/m<sup>3</sup> SO<sub>2</sub> standards. There are no permitted exceedences for O<sub>3</sub> or the 570 µg/m<sup>3</sup> SO<sub>2</sub> standards.

Certain human activities are associated with the emission of particular groups of contaminants. Emissions from domestic fires monitored at a neighbourhood site may require the monitoring of CO in addition to PM<sub>10</sub>. In areas where high sulphur content solid fuel is burnt, SO<sub>2</sub> may be another contaminant to monitor.

Refer to appendix A for Schedule 1 of the NES for air quality.

### 3.1.2 Ambient air quality guidelines

The *Ambient Air Quality Guidelines* (AAQG) are health-based guidelines that set the minimum requirements that outdoor air quality should meet in order to protect human health and the environment.

Table 2 outlines the existing 15 ambient air quality guidelines for a range of contaminants. This includes guidelines with different values and time averages to the standards for carbon monoxide (CO), nitrogen dioxide (NO<sub>2</sub>), ozone (O<sub>3</sub>), particulate matter (PM<sub>10</sub>), and sulphur dioxide (SO<sub>2</sub>). These guidelines have not been superseded by standards because they measure a different time average, and therefore provide an indication of human exposure on a different time scale. It is important to assess air quality in terms of both short-term (eg, peak) exposure and long-term exposure (eg, annual averages).

**Table 2: Ambient air quality guidelines (2002)**

Contaminant	Guideline value <sup>a</sup>	Time average
Carbon monoxide	30 mg/m <sup>3</sup>	1-hour mean
Nitrogen dioxide	100 µg/m <sup>3</sup>	24-hour mean
Ozone	100 µg/m <sup>3</sup>	8-hour mean
PM <sub>10</sub>	20 µg/m <sup>3</sup>	Annual mean
Sulphur dioxide <sup>b</sup>	120 µg/m <sup>3</sup>	24-hour mean
Hydrogen sulphide <sup>c</sup>	7 µg/m <sup>3</sup>	1-hour mean
Lead <sup>d</sup>	0.2 µg/m <sup>3</sup>	3-month rolling mean (calculated monthly)
Benzene (2002)	10 µg/m <sup>3</sup>	Annual mean
Benzene (2010)	3.6 µg/m <sup>3</sup>	Annual mean
1,3-butadiene	2.4 µg/m <sup>3</sup>	Annual mean
Formaldehyde	100 µg/m <sup>3</sup>	30-minute mean
Acetaldehyde	30 µg/m <sup>3</sup>	Annual mean
Benzo(a)pyrene	0.0003 µg/m <sup>3</sup>	Annual mean
Mercury (inorganic) <sup>d</sup>	0.33 µg/ m <sup>3</sup>	Annual mean
Mercury (organic)	0.13 µg/ m <sup>3</sup>	Annual mean
Chromium IV <sup>d</sup>	0.0011 µg/m <sup>3</sup>	Annual mean
Chromium metal and chromium III <sup>d</sup>	0.11 µg/m <sup>3</sup>	Annual mean
Arsenic (inorganic) <sup>d</sup>	0.0055 µg/m <sup>3</sup>	Annual mean
Arsine <sup>d</sup>	0.055 µg/m <sup>3</sup>	Annual mean

## Notes:

- a All values apply to the gas measured at standard conditions of temperature (0°C) and pressure (1 atmosphere).
- b The sulphur dioxide guideline values do not apply to sulphur acid mist.
- c The hydrogen sulphide value is based on odour nuisance and may be unsuitable for use in geothermal areas.
- d The guideline values for metals are for inhalation exposure only; they do not include exposure from other routes such as ingestion. These other routes should be considered in assessments, where appropriate.

Monitoring PM<sub>2.5</sub> is recommended if resources are available (see section 5, Particulate Monitoring, for further details). Results may be compared with the World Health Organization's annual PM<sub>2.5</sub> guideline of 10 µg/m<sup>3</sup> (World Health Organization, 2006) or the monitoring guideline of 25 µg/m<sup>3</sup> (24-hour average) stated in the AAQG.

Additional guidance and information on the NES for air quality and the AAQG can also be found in the following documents.

- The *Updated User's Guide to Resource Management (National Environmental Standards Relating to Certain Air Pollutants, Dioxins and Other Toxics) Regulations 2004 (Including Amendments 2005)* (Ministry for the Environment, 2005) is aimed at practitioners in local government implementing the first suite of national environmental standards. Chapter 3 of the User's Guide deals with ambient air quality standards from an air quality management and consent perspective.
- *Ambient Air Quality Guidelines* (Ministry for the Environment, 2002) pre-dates the introduction of the NES for air quality and includes guideline values for contaminants not covered by the standards. Chapter 2 contains useful information on health effects and sources of airborne contaminants. Although the NES for air quality has mandatory considerations for the processing of resource consents, chapter 3 of the guidelines still provides useful general guidance on regional air quality management.

## 3.2 Meteorological monitoring

Weather has a profound influence on contaminant dispersion and concentrations. For example, meteorological effects such as temperature inversions can dramatically increase contaminant levels. It would not be possible to gain a clear picture of the air quality in an area without meteorological monitoring. Good-quality meteorological data is necessary, and may require a number of stations depending on topography. Basic meteorological monitoring at some air quality monitoring sites may prove very useful, especially when trying to assess the validity of data. Meteorological data is also critical in the use of dispersion modelling.

A detailed set of guidelines for meteorological monitoring has been prepared by the United States Environmental Protection Agency (USEPA, 2000). The Australian standard, AS 2923:1987, *Measurement of horizontal wind*, provides guidance on the measurement of wind speed and direction. Additional guidance can also be sourced from the *Guide to Meteorological Instruments and Methods of Observation* (World Meteorological Organization, 1996).

## 4 How to Monitor? – Monitoring Methods

This chapter describes a range of methods for monitoring ambient air quality and outlines the level of precision required for different monitoring purposes. Required methods for ambient air quality standards and recommended methods for ambient air quality guidelines are discussed. The chapter also includes a brief section on meteorological monitoring.

### 4.1 Using appropriate monitoring methods

A wide variety of methods are available for measuring contaminants in ambient air, with an equally wide variation in cost and precision. Specific monitoring methods should be chosen taking into consideration the purpose, objectives and budget of the monitoring programme.

Monitoring for the purposes of national environmental standards can only be carried out with the high-precision instrumental methods in accordance with Schedule 2 of the regulations. High-precision instrumental methods would also be generally used for research studies or other specific investigations, where there is a need to understand the ways in which contaminant levels fluctuate over short time periods (hours or days).

Ambient air quality guidelines carry recommended monitoring methods that should be used for the assessment of the contaminants covered by the guidelines. These are based on Australian / New Zealand and USEPA standards.

There is still a place for monitoring methods that fall outside the specifications for standards and guideline assessments. Methods that involve lower resolution instruments can be used for an initial screening survey, where a detailed study is not warranted. These may be used as a prelude to more detailed monitoring. If contaminant levels are found to be low, then the same method(s) could be used for repeat surveys over subsequent years. Low resolution methods are also useful for prioritising a number of different areas that have already been selected for detailed monitoring programmes.

It should be stressed that **screening methods cannot be used to determine compliance with national standards or guidelines**. A screening method is any non-standard method that is used on an exploratory basis and provides indicative data for a particular contaminant. Despite this, the method still needs to have a level of accuracy and precision suitable for the purpose of monitoring (eg, Occupational Health and Safety equipment is *not* suitable for ambient air quality monitoring).

Screening methods are purely indicative methods and any results must be treated with caution. For example, a one-day-in-three monitoring regime of PM<sub>10</sub> may indicate that there have been no breaches of the ambient air standard. However, this does not necessarily mean that exceedences were not occurring during the two days that were not sampled. A number of exceedences detected by this method would indicate detailed monitoring for national environmental standards is warranted.

### **Recommendation 1: Screening methods**

Screening methods cannot be used to determine compliance with the NES for air quality or to establish whether an airshed meets the ambient air quality guidelines. They may, however, be used to provide indicative data for other monitoring purposes.

A screening method's level of accuracy and precision must be suitable for the purpose of monitoring (eg, occupational health and safety equipment is not suitable for ambient air quality monitoring).

## **4.2 Using existing monitoring for national environmental standards**

Regional monitoring programmes conducted since the introduction of the RMA should, at least in the case of PM<sub>10</sub>, provide a good indication of where national environmental standards are likely to be breached. However care must be taken when considering whether such ambient air quality monitoring can be used for the regulatory requirements of national environmental standards. The following points should be considered:

- Is the data capture sufficient and is there an appropriate time average?
- Are monitoring methods appropriate for standards?
- Are the appropriate contaminants being monitored?
- Is it at an appropriate location?

Earlier PM<sub>10</sub> monitoring in New Zealand traditionally adopted a one-day-in-three or one-day-in-six approach. This approach is not suitable for national environmental standards because continuous monitoring of 24-hour averages from midnight to midnight is required. It may be found that some analysers that require manual filter changes are not practical for midnight changeovers, unless these analysers can have automated samplers retrofitted. Regional councils have shifted to continuous monitors since the NES for air quality came into effect.

It is not only necessary to *choose* analysers that are compliant with the relevant Australian / New Zealand standards or USEPA standard; it is also necessary to *operate* the analyser in accordance with that standard. Simply ensuring an analyser's specifications are compliant with the standard is not sufficient.

A large proportion of PM<sub>10</sub> monitoring in New Zealand is conducted at residential neighbourhood sites (see section 6.2 on site classifications). While these may not exactly align with the 'worst location' requirement in the NES for air quality, careful consideration should be made concerning relocation of the site. There may be little to gain by relocating a current site within the same general vicinity of an airshed if it will end a useful record of long-term data.



## 4.3 Choosing appropriate monitoring equipment

Choosing the appropriate monitoring equipment is important for achieving the aims of the monitoring programme. Equipment that does not measure the contaminant in the required measurement range clearly will not provide useful data.

The following factors should be considered before purchasing monitoring equipment.

- **Purpose of monitoring:** ie, screening, compliance monitoring or research. Different sensitivities may apply to different types of monitors. For example, compliance monitoring may require a higher level of sensitivity and resolution than a monitor used for screening purposes.
- **Duration of deployment:** if the instrument is to be used for short-term screening surveys then portability, size, weight and robustness may be factors to consider.
- **Detection limit, precision and measurement range:** will the instrument be able to measure within the required range, based on the monitoring objective?
- **Consumables:** how frequently do parts need to be changed or replaced?
- **Ability to conform to relevant monitoring standards:** does the instrument conform to monitoring standards such as those required in the NES for air quality?
- **Frequency of calibration:** the time taken to complete automatic zero and span checks, and operational and multipoint calibrations. Instruments that spend significant time on an automatic zero and span checks will reduce your percentage data recovery. An instrument that requires frequent calibration in order to comply with a particular standard will impose costs on an organisation (time and resources).
- **Ease of use:** some instruments can be extremely difficult to operate, which imposes costs in terms of training and person-hours spent resolving problems.
- **Communication:** ideally instruments should have ethernet/IP ports, analogue and RS232 connectivity to allow connection to dataloggers and telemetry.
- **Ability to interface remotely:** most modern instruments will allow an operator to remotely operate an instrument.
- **Environmental requirements:** does the instrument require air conditioning, temperature or humidity control?
- **Cost:** consider both the cost of the instrument and the cost of consumables.
- **Reliability:** find out who else has operated similar instruments and discuss the pros and cons with other organisations before committing to a purchase.
- **Memory or on-board storage capacity:** determine if memory capacity is sufficient for your current and future needs (eg, memory expansion features).
- **Instrument parameters that may be recorded in addition to output concentration:** can the instrument record any other parameters (eg, temperature)?

Do your homework before making a purchase. For organisations that make decisions primarily based on price, consider imposing instrument specifications and/or standards as conditions of purchase.

## 4.4 Methodology types

Monitoring methodologies can be divided into three categories according to cost and the level of accuracy and precision.

- **Continuous monitoring methods**

These are high-resolution methods that provide continuous records of contaminant levels. They can operate over extended periods (weeks or months) with minimal operator intervention. Remote communication is possible by telemetry. They have a high degree of measurement precision, and have detection levels around one order of magnitude or more below typical background levels. As might be expected, these are the most expensive monitoring methods. A high standard of maintenance, calibration, and operational and quality control procedures are required for good data quality.

- **Gravimetric particulate methods**

In the past, gravimetric particulate methods have formed the mainstay of particulate monitoring in New Zealand. The implementation of the NES for air quality, however, has shifted the use of these methods to the analysis of airborne lead, co-location studies and screening surveys.

Monitoring starts when a known volume of air is pumped through a pre-weighed filter for a known length of time (typically 24 hours). The filter is reweighed after exposure and a concentration determined. Most systems used in New Zealand require manual changes of the sampling filters between each sample, although a number of semi-automated systems are also available. This can be done on consecutive days. Manually changing filters at midnight, however, is operationally impractical when compliance monitoring (the regulations by definition require filter changes to take place at midnight; see Appendix A).

- **Passive monitoring methods (diffusion tubes and badges)**

Diffusion tubes work when a contaminant is diffused into a tube containing either an adsorbent or reactive material. Analysis of the tubes following a known exposure time (typically two to four weeks) will provide a time-averaged contaminant concentration. Badges work in a similar way, the difference being the sampler configuration. Badges typically have higher uptake rates and are used more widely in New Zealand.

Because these methods are simple and cheap, they can provide a good picture of spatial variation over a large area. They are particularly useful in screening surveys and during the initial stages of an air quality monitoring programme.

Though a cheap screening tool, there are a number of limitations to this method, such as lower accuracy and no indication of peak levels. Quality control and assurance during laboratory analysis must be of the highest standard to attain consistent results. The results from passive samplers can be used in conjunction with high-resolution instruments to determine spatial variation across an airshed over a relevant averaging period. This method can also be useful for comparison with annual guidelines.

Historically, wet chemical methods were used to monitor levels of gaseous contaminants. These methods are no longer recommended due to interferences and the low resolution of data. High-resolution instrumental methods are now recommended.

Low-level instrumental methods using optical sensors are commonly used for monitoring occupational exposure. While such analysers may occasionally be useful for incident investigations, they should not be used for routine compliance monitoring due to their low sensitivity.

## 4.5 Mandatory ambient air monitoring methods

The following are mandatory monitoring methods under the NES for air quality. Note that these Australian / New Zealand and USEPA standards apply to monitoring *methods*. It is not sufficient to simply use an analyser that conforms to a standard: it is also necessary to operate the analyser in accordance with the operational requirements of that standard.

### 4.5.1 Carbon monoxide (CO)

CO monitoring instruments are predominantly gas filter correlation infrared (GFC-IR) absorption analysers. This is the recommended CO monitoring method, although AS 3580.7.1 also allows for a non-dispersive infrared gas chromatograph with flame ionisation detector, or electrochemical sensor systems. These alternative methods, however, suffer from a variety of interfering species and are considered less robust than GFC-IR analysers.

In a GFC-IR analyser, ambient air is continuously sampled using a pump unit and the CO concentration in the sample air is measured by the absorption of infrared radiation at 4.5 to 4.9 nanometre (nm) wavelength. A reference detection system is used to alternately measure absorption due to CO in the ambient air stream and absorption by interfering species. An infrared detector and amplification system produce output voltages proportional to the CO concentration. The concentration is derived from the Beer–Lambert relation:

$$I_1 = I_0 e^{-alc}$$

where the sample passes through a cell tube of length ‘l’. The analyser alternately measures the absorption  $I_0$  of the air path with no CO present and the absorption  $I_1$  of the ambient sample, with ‘a’ being the absorption coefficient, to provide the CO concentration, ‘c’.

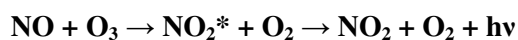
GFC instruments use a filter wheel to allow alternate measurement of total IR absorption. The analyser continually displays current CO concentrations, and, depending on the make and model of analyser, other parameters can be selected as necessary.

#### **NES for air quality: Mandatory method for CO**

Australian Standard **AS 3580.7.1–1992**, *Methods for sampling and analysis of ambient air – Determination of carbon monoxide – Direct-reading instrumental method*.

## 4.5.2 Nitrogen dioxide (NO<sub>2</sub>)

Nitric oxide (NO) in the sample air stream reacts with ozone (O<sub>3</sub>) in an evacuated chamber to produce activated NO<sub>2</sub>:



The intensity of the chemiluminescent radiation (hν) produced is measured using a photomultiplier tube (PMT) or photodiode detector. The detector output voltage is proportional to the NO concentration. The ambient air sample is divided into two streams; in one, ambient NO<sub>2</sub> is reduced to NO using a molybdenum catalyst before reaction. The molybdenum converter should be at least 95 per cent efficient at converting NO<sub>2</sub> to NO. This gas stream gives total NO<sub>x</sub>. The second stream measures NO directly by not passing through the molybdenum converter.

Separate measurements are made of total oxides of nitrogen NO<sub>x</sub> (= NO + NO<sub>2</sub>) and NO. The ambient NO<sub>2</sub> concentration is calculated from the difference (NO<sub>2</sub> = NO<sub>x</sub> – NO). This is an important point to remember, because the contaminant of interest (NO<sub>2</sub>) is actually measured by inference rather than directly, and the efficiency of the molybdenum converter should be checked on a regular basis.

In a chemiluminescent analyser, ambient air is drawn through the system via a pump and permature drier unit. NO<sub>x</sub> analysers are equipped with either a single or a double reaction chamber and PMT system. A solenoid valve is used to alternately switch between NO and NO<sub>x</sub> measurements, typically at 15-second intervals. The analyser continuously displays current NO, NO<sub>2</sub> and NO<sub>x</sub> concentrations, and, depending on the make and model of analyser, other parameters can be selected as necessary.

### **NES for air quality: Mandatory method for NO<sub>2</sub>**

Australian Standard **AS 3580.5.1–1993**, *Methods for sampling and analysis of ambient air – Determination of oxides of nitrogen – Chemiluminescence method.*

## 4.5.3 Ozone (O<sub>3</sub>)

In an O<sub>3</sub> analyser, ambient air is continuously sampled using a pump unit. O<sub>3</sub> concentrations are calculated from the absorption of ultraviolet (UV) light at 254 nanometres (nm) wavelength. The absorption is measured using a UV detector. An O<sub>3</sub>-removing scrubber is used to provide a zero reference intensity. The concentration is calculated using the Beer–Lambert equation:

$$I_1 = I_0 e^{-alc}$$

where the sample passes through a cell tube of length 'l', and the analyser alternately measures the absorption I<sub>0</sub> of the air with no O<sub>3</sub> present and the absorption I<sub>1</sub> of the ambient sample, with 'a' being the absorption coefficient (at 254 nm), to provide the O<sub>3</sub> concentration, 'c'.

The analyser continually displays current O<sub>3</sub> concentrations, and, depending on the make and model of analyser, other parameters can be selected as necessary.

#### **NES for air quality: Mandatory method for O<sub>3</sub>**

Australian Standard **AS 3580.6.1–1990**, *Methods for sampling and analysis of ambient air – Determination of ozone – Direct-reading instrumental method.*

#### **4.5.4 PM<sub>10</sub>**

The USEPA standard is described as a reference method (eg, gravimetric); 40 CFR Part 53 ([www.epa.gov/ttn/amtic/criteria.html](http://www.epa.gov/ttn/amtic/criteria.html)) contains a full list of equivalent methods. The most commonly used methods for the measurement of PM<sub>10</sub> in New Zealand are discussed further in chapter 5.

#### **NES for air quality: Mandatory methods for PM<sub>10</sub>**

Australian/New Zealand Standard **AS/NZS 3580.9.6:2003**, *Methods for sampling and analysis of ambient air – Determination of suspended particulate matter – PM<sub>10</sub> high-volume sampler with size selective inlet – Gravimetric method.*

or

**United States Code of Federal Regulations, Title 40 – Protection of Environment, Volume 2, Part 50, Appendix J** – *Reference method for the determination of particulate matter as PM<sub>10</sub> in the atmosphere.*

Note: The following Australian / New Zealand standards were released after 2000 for the continuous monitoring of PM<sub>10</sub>.

Continuous sampling in accordance with **AS 3580.9.8-2008**, *Methods for sampling and analysis of ambient air – Determination of suspended particulate matter – PM<sub>10</sub> continuous direct mass method using a tapered element oscillating microbalance analyser.*

Australian / New Zealand Standard **AS/NZS 3580.9.11:2008**, *Methods for sampling and analysis of ambient air – Determination of suspended particulate matter – PM<sub>10</sub> beta attenuation monitors.*

#### **4.5.5 Sulphur dioxide (SO<sub>2</sub>)**

SO<sub>2</sub> monitoring instruments are predominantly molecular UV fluorescence analysers. This is the recommended SO<sub>2</sub> monitoring method. AS 3580.4.1 also allows flame photometric detector and electrochemical sensor systems.

UV fluorescence systems operate on the principle that an ambient air sample stream exposed to UV light excites SO<sub>2</sub> molecules in the sample to higher, but unstable, excited states. These excited states decay, giving rise to the emission of secondary (fluorescent) radiation:



The fluorescent radiation is detected by a PMT, causing an output voltage proportional to the SO<sub>2</sub> concentration. A permeable membrane ‘kicker’ is used to remove interfering hydrocarbons (aromatic hydrocarbons also fluoresce) before reaction. Ambient air is drawn through the system via a pump unit, and the analyser continuously displays current SO<sub>2</sub> concentrations. Depending on the make and model of analyser, other parameters can be selected as necessary.

#### **NES for air quality: Mandatory methods for SO<sub>2</sub>**

Australian standard **AS 3580.4.1–2008**, *Methods of sampling and analysis of ambient air – Determination of sulphur dioxide – Direct reading instrumental method*.

The above standard supersedes Australian standard **AS 3580.4.1-1990**, *Methods for sampling and analysis of ambient air – Determination of sulphur dioxide – Direct-reading instrumental method*.

## **4.6 Recommended ambient air monitoring methods**

The following methods are recommended for the measurement of contaminants for comparison with the New Zealand ambient air quality guidelines.

### **4.6.1 Hydrogen sulphide (H<sub>2</sub>S)**

The recommended method is based on the Australian standard method for sulphur dioxide, with the addition of a catalyst to convert H<sub>2</sub>S to SO<sub>2</sub>.

#### **Recommendation 2: Hydrogen sulphide**

The recommended method for hydrogen sulphide is fluorescence monitoring, in accordance with **AS3580.4.1–2008**, *Methods of sampling and analysis of ambient air – Determination of sulphur dioxide – Direct reading instrumental method*.

### **4.6.2 Lead content of PM<sub>10</sub>**

#### **Recommendation 3: Lead content of PM<sub>10</sub>**

The recommended method for lead content of PM<sub>10</sub> is high-volume gravimetric sampling in accordance with **United States Code of Federal Regulations, Title 40 – Protection of Environment, Volume 2, Part 50, Appendix J and Appendix G**.

### 4.6.3 Benzene and 1,3-butadiene

#### Recommendation 4: Benzene and 1,3-butadiene

The recommended methods for benzene and 1,3-butadiene are:

**USEPA method TO-1** – *Method for the determination of VOCs in ambient air using Tenax<sup>®</sup> adsorption and gas chromatography / mass spectrometry (GC/MS)*

**USEPA method TO-14A** – *Determination of VOCs in air using specially prepared canisters with subsequent analysis by gas chromatography*

**USEPA method TO-15** – *Determination of VOCs in air collected in specially prepared canisters and analysed by gas chromatography / mass spectrometry (GC/MS)*

**USEPA method TO-17** – *Determination of VOCs in air using active sampling onto sorbent tubes*

**BS EN 14662-1:2005** – *Ambient air quality – Standard method for measurement of benzene concentrations – Pumped sampling followed by thermal desorption and gas chromatography*

**BS EN 14662-2:2005** – *Ambient air quality – Standard method for measurement of benzene concentrations – Pumped sampling followed by solvent desorption and gas chromatography*

**BS EN 14662-3:2005** – *Ambient air quality – Standard method for measurement of benzene concentrations – Automated pumped sampling with in situ gas chromatography*

**BS EN 14662-4:2005** – *Ambient air quality – Standard method for measurement of benzene concentrations – Diffusive sampling followed by thermal desorption and gas chromatography*

**BS EN 14662-5:2005** – *Ambient air quality – Standard method for measurement of benzene concentrations – Diffusive sampling followed by solvent desorption and gas chromatography.*

### 4.6.4 Formaldehyde and acetaldehyde

#### Recommendation 5: Formaldehyde and acetaldehyde

The recommended method for formaldehyde and acetaldehyde is **USEPA method TO-11A** – *Determination of formaldehyde in ambient air using adsorbent cartridge followed by high performance liquid chromatography (HPLC).*

#### 4.6.5 Benzo(a)pyrene (BaP)

##### **Recommendation 6: Benzo(a)pyrene**

The recommended methods for BaP are:

**USEPA method TO-13A** – *Determination of polycyclic aromatic hydrocarbons (PAHs) in ambient air using gas chromatography / mass spectrometry (GC/MS)*

**BS EN 15549:2008** – *Air quality – Standard method for the measurement of the concentration of benzo(a)pyrene in ambient air.*

#### 4.6.6 Mercury, chromium and arsenic

##### **Recommendation 7: Mercury, chromium and arsenic**

The recommended method for mercury, chromium and arsenic is:

PM<sub>10</sub> sampling in accordance with **40CFR Part 50, Appendix J**, followed by analysis using atomic absorption spectroscopy or an equivalent method.

For mercury:

**Method IO-5** (*Sampling and analysis for vapour and particle phase mercury in ambient air utilising cold vapour atomic fluorescence spectrophotometry*)

**BS EN 15852** – *Ambient air quality – Standard method for the determination of total gaseous mercury.*

The monitoring methods for the above air contaminants are based on procedures recommended by Standards Australia, the USEPA and the British Standards Institution (BSI). Detailed specifications for these methods can be obtained from the following websites:

- Standards Australia publications site (<http://www.standards.org.au>)
- USEPA site (<http://www.epa.gov/ttn/amtic>)
- BSI site (<http://www.bsi-global.com>).

More information on recommended monitoring methods for hazardous air contaminants can also be found in the reports prepared for the review of the AAQG. These reports are available from the Ministry's website (<http://www.mfe.govt.nz/publications/air/11-hazardous-air-oct00.pdf>).



## 4.7 Open-path monitoring systems

Open-path monitoring systems measure a range of contaminants based on absorption of a light beam transmitted over distances of up to several kilometres. As such, they are totally different from most other monitoring methods in common use. The main difference is that the open-path system records the average concentration simultaneously for a number of contaminants over the full measured distance rather than at a specific point. The measured results will therefore be lower than those at some points along the path and higher than at others. This method is particularly suitable for measuring along site boundaries of industrial processes, but is not often used for measuring ambient air quality at discrete points. In New Zealand, these methods are usually only used for research purposes.

One of the main attractions of the open-path systems is that they can be used for a wide variety of different contaminants, including most of the volatile organics. The main disadvantage is their cost, which is typically three to five times the cost of any of the more traditional instruments. Furthermore the concentration of a particular contaminant is averaged over the beam length, which can underestimate the ground-level concentration where there are one or more point sources of contamination present.

## 4.8 Meteorological monitoring

As mentioned in section 3.2, it is important to monitor meteorological conditions at the air quality monitoring site since weather is a significant factor which influences air contaminant concentrations. Measurements of wind speed, wind direction and air temperature are the minimum meteorological parameters to be monitored. Additional measurements that would provide an improved picture of weather conditions during monitoring are: relative humidity, solar radiation, rainfall, and a temperature profile at two heights.

Wind direction, by convention, is the direction the wind is blowing *from* and is quoted with reference to true north (not magnetic north). An exception to this is meteorological data collected for oceanographic monitoring purposes. In this case, the wind is recorded in the direction it is blowing *towards*. Care should be taken to determine the meteorological wind convention when using data collected from the marine environment.

Wind speeds are often quoted in different units. The preferred reporting unit is metres per second (m/s). A wind speed conversion table is shown in Appendix B.

## **Recommendation 8: Meteorological monitoring**

The minimum monitoring required is as follows:

- mast, 6 m minimum, 10 m preferable
- wind speed (resolution 0.1 m/s, accuracy  $\pm 0.2$  m/s, start-up 0.2 m/s)
- wind direction (resolution 1°; accuracy  $\pm 2^\circ$ , referenced to true north)
- air temperature (resolution 0.1 °C, accuracy 0.2 °C)
- automated logging system, reliable power, with battery back-up.

The use of the Cartesian coordinate system is recommended, whereby data is converted to its x and y components. This data can then be accumulated in a vector form. This solves averaging and unweighted direction problems. Results may subsequently be converted to polar coordinates, if required.

Desirable measurements are:

- humidity (or dew point) (resolution 1% relative humidity (rh), accuracy  $\pm 5\%$  rh)
- solar radiation (for stability estimates) (resolution 1 W/m<sup>2</sup>, accuracy 10 W/m<sup>2</sup>)
- rainfall (resolution 1 mm)
- temperature profile (T at two heights, 1.5 m and 10 m, needs 0.1 °C accuracy) using identical sensors at both heights.

Specific siting requirements:

Must be free of influence of trees, buildings, structures – should be at least two times the height away from the obstacle, and for wind sensors it should be at least 10 times the height away from obstacles (refer to Part I, sections 5.9.2 and 6.2 of the *Guide to Meteorological Instruments and Methods of Observation* (World Meteorological Organization, 1996; Oke TR, 2006).

Required time resolution:

- data should be collected at the same minimum time resolution as air quality data
- resolution should be at least hourly.

Period of monitoring:

For atmospheric modelling and trend analysis, a minimum of one year's data is recommended.

## **4.9 Monitoring agencies and training**

### **4.9.1 Monitoring agencies**

Air monitoring services are provided by a number of environmental consultancies, Crown research institutes and universities. A number of regional councils also carry out monitoring in their own regions, as do many industries. Other organisations have taken the option of purchasing their own equipment but contracting consultants to run it. Equipment can also be leased from a number of suppliers. Names of suppliers and consultants can often be found in journals and magazines or by talking to other councils.

It is strongly recommended that agencies/firms undertaking ambient air quality monitoring for assessing compliance with the NES be accredited by an independent and approved accreditation organisation such as International Accreditation New Zealand (IANZ) or the Joint Accreditation System of Australia and New Zealand (JAS-ANZ). As a minimum, accredited staff should be used to audit and verify the data collection, validation and quality assurance processes at least every two years. For more information on the accreditation process, visit [www.ianz.govt.nz](http://www.ianz.govt.nz) or [www.jasanz.com.au](http://www.jasanz.com.au)

## 4.9.2 Training

Local training courses in ambient air quality monitoring are periodically offered in New Zealand by the Clean Air Society of Australia and New Zealand (CASANZ). More frequent training is held in Australia. Information on upcoming courses can be obtained from CASANZ ([www.casanz.org.au](http://www.casanz.org.au)). If equipment is being purchased, the manufacturer should provide initial training in its use. Conferences also provide a useful opportunity to view and discuss monitoring equipment with suppliers.

The National Air Quality Working Group (NAQWG) convenes biannually to discuss air quality issues from a regional council perspective. Presentations are given on various initiatives being undertaken by regional councils in air quality management and research.

### **Recommendation 9: Independent accreditation**

Accreditation of agencies/firms undertaking air quality monitoring by an independent and approved accreditation organisation is strongly recommended.

# 5 Particulate Monitoring

This chapter describes the wide range of methods available for particulate monitoring and provides guidance on the suitability of methods for different purposes.

## 5.1 Monitoring for different fractions

There are a number of approaches and methods for measuring particulates in the air, and many of these have been used in New Zealand. Different approaches measure different properties of atmospheric particulates, and therefore care must be taken before selecting a monitoring method or attempting to compare the results of different methods.

### 5.1.1 PM<sub>10</sub>

PM<sub>10</sub> is atmospheric particulate matter less than or equal to 10 micrometres (µm) in diameter. This is the fraction of atmospheric particulates that are small enough to penetrate deep into the human lung. To monitor PM<sub>10</sub>, the sample air enters a size-selective inlet which has at least 50 per cent efficiency cut-off at a 10 µm aerodynamic diameter. The resulting air stream contains particulate matter generally less than 10 µm (with a small proportion of particulate matter greater than 10 µm).

PM<sub>10</sub> can arise from a wide range of sources, but can generally be separated into three categories:

- primary combustion particulates – produced directly from combustion, such as domestic heating, road transport, power stations and industrial processes
- secondary particulates – aggregates in the atmosphere following their release as gases (include nitrates and sulphates)
- coarse particulates – from non-combustion sources such as re-suspended road dust, construction work, mineral extraction, wind-blown dust and soil, and sea salt.

### 5.1.2 PM<sub>2.5</sub>

PM<sub>2.5</sub> is particulate matter less than or equal to 2.5 µm in diameter. PM<sub>2.5</sub> is emitted from primary combustion processes and requires the appropriate size-selective inlet for sampling.

Current research indicates that it has a greater effect on health than PM<sub>10</sub>. The AAQG include a monitoring guideline of 25 µg/m<sup>3</sup> as a 24-hour average for PM<sub>2.5</sub>. This is equivalent to the World Health Organization (WHO) ambient air quality guideline for PM<sub>2.5</sub> as a 24-hour average. WHO further provides an ambient air quality guideline of 10 µg/m<sup>3</sup> as an annual average for PM<sub>2.5</sub>.

Standards for monitoring PM<sub>2.5</sub> include:

- AS/NZS 3580.9.10:2006, *Methods for sampling and analysis of ambient air – Determination of particulate matter – PM<sub>2.5</sub> low volume sampler – Gravimetric method*
- US Code of Federal Regulations Title 40, Part 50 Appendix L, *Reference method for the determination of fine particulate matter as PM<sub>2.5</sub> in the atmosphere.*

Systems complying with the US specification are notified in the Federal Register, v. 63, p. 18911, 16 April 1998, and v. 63, p. 31991, 11 June 1998. These cover a variety of 24-hour average, low-volume systems fitted with a PM<sub>2.5</sub> inlet. Some of the units are fitted with automated filter-changing systems, which allow for unattended operation over extended periods of time.

### 5.1.3 Total suspended particulate (TSP)

TSP can be considered as anything smaller than 100 µm in diameter. A considerable quantity of inhaled TSP can be removed quite effectively from the human body, although only particles smaller than 10 µm (eg, PM<sub>10</sub>) achieve any significant degree of lung penetration. For this reason TSP concentrations are not suited to monitoring in relation to health effects, but are more suited to the appraisal of dust nuisance. A detailed approach to monitoring dust nuisance can be found in the *Good Practice Guide for Assessing and Managing the Environmental Effects of Dust Emissions* (Ministry for the Environment, 2001) and *Amenity Effects of PM<sub>10</sub> and TSP Concentrations in New Zealand* (Ministry for the Environment, 2003b).

### 5.1.4 Dust deposition

Deposited dust can cause significant nuisance effects at locations close to sources such as unpaved roads, railways, site works, quarries and various industrial sites. Simple deposition gauges usually measure it, with results presented as deposited mass per unit area per time period (usually grams per square metre per 30 days). Monitoring methods used in New Zealand include the AS/NZS 3580.10.1:2003 *Methods for sampling and analysis of ambient air – Determination of particulate matter – Deposited matter – Gravimetric method.*

Deposition monitoring is a cheap and easy method for monitoring dust nuisance. However, the results can be difficult to interpret because of the poor time resolution of the method (typically 30 days). There is usually too much variation in weather conditions and other factors such as source emissions over this time to allow any sensible correlation with the monitoring results. The method is best used as a means of comparing overall nuisance dust levels in different locations.

There are several variants to the deposition gauge, including:

- directional gauges
- frisbee gauges
- alternative dust measurement techniques (eg, dust deposition (soiling) meter and the use of sticky plates).

More information about methods for monitoring ambient dust is provided in the Ministry's *Good Practice Guide for Assessing and Managing the Environmental Effects of Dust Emissions* (Ministry for the Environment, 2001). This report can be downloaded from the Ministry's website: <http://www.mfe.govt.nz/publications/air/dust-guide-sep01.pdf>

## 5.2 Methods for particulate monitoring

The USEPA categorises particulate monitoring methodologies as either reference or equivalent methods. Reference methods are gravimetric (eg, direct measurement by weight), and equivalent methods are alternative methodologies that have been granted (following stringent inter-comparison studies) equivalency to the reference methods.

### 5.2.1 Beta attenuation monitor (BAM)

Particle mass density is measured using beta radiation attenuation. A pump draws ambient air through a paper-band filter and the reduction in intensity of beta radiation measured at the detector is proportional to the mass of particulate deposited on the filter. As the mass of PM<sub>10</sub> increases, the beta count is reduced. The relationship between the decrease in count and particulate mass is computed according to a known equation (the Beer–Lambert law, as for CO and O<sub>3</sub>).

Monitors can be set to operate for 15-minute to 24-hour cycles, with intermediate averages if selected. Some samplers will automatically take a measurement and feed the filter tape if the filter loading reaches a predetermined level.

This method allows for unattended operation over extended periods of time, with a time resolution of about 0.5 to 2 hours. The response of the instrument depends on the beta absorption coefficient of the particulate, and this can vary with chemical composition. As with the tapered element oscillating microbalance (TEOM, see section 5.2.2), the requirement to heat the air inlet also results in the loss of some semi-volatiles. However, because the collected material does not remain on the filter for long periods before being measured, the volatile loss is not normally as significant as for the TEOM.

Under-reporting of approximately 23–24 per cent at 50 µg/m<sup>3</sup> has been recorded by BAM monitoring at Taupo and Tokoroa when compared with gravimetric results.<sup>1</sup> Most comparisons were under-reporting by around 6 per cent when compared with gravimetric methods at 50 µg/m<sup>3</sup>. The variation in semi-volatile components, both across an airshed and even within an airshed on a seasonal basis, means that correcting data to gravimetric equivalent is *not* presently recommended.

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<sup>1</sup> Minutes from the Beta Attenuation Monitor Workshop, Hawke's Bay Regional Council, Napier, 17 March 2008.

### Recommendation 10: Operation of a beta attenuation monitor

- Enclosure temperatures should be maintained at 25 °C ± 3 °C to avoid moisture collecting on filter paper.
- Regular maintenance in accordance with the operation manual is critical. Irregular and/or inadequate maintenance can result in up to 20 per cent variation.
- The sample heater should be switched off for at least one hour before calibration.
- The condition of the radioactive source should be checked twice a year (R2 count). It may be necessary to adjust after two to three years due to decay in the radioactive source.
- Inlet temperature should be set to 40 °C.
- Equipment should be maintained in accordance with the operation manual (refer also to AS/NZS 3580.9.11:2008).
- Data correction to gravimetric equivalent is *not* generally recommended.
- Where possible, humidity should be logged along with appropriate meteorological data.

## 5.2.2 Tapered element oscillating microbalance (TEOM)

The TEOM is a proprietary system that determines particulate concentration by continuously weighing particles deposited on a filter. The filter is attached to a hollow tapered element, which vibrates at its natural frequency of oscillation, 'f'. The frequency changes by an amount proportional to the mass deposited, 'm', as particles progressively collect on the filter:

$$m = k/f^2$$

where k is a constant determined during calibration of the TEOM. The mass measurement system is also known as the mass transducer. The flow rate of air through the system is controlled using thermal mass flow controllers and automatically measured to determine mass concentration. The TEOM analyser consists of a sample inlet head attached to the sensor unit, a control unit containing the mass flow controllers and system software, and a carbon vane pump. The total flow of 16.67 litres per minute through the sampling head is divided using a flow splitter to give 3 litres per minute through the filter cartridge and an auxiliary flow of 13.67 litres per minute. This provides direct mass measurement (USEPA, 2002) and, in conjunction with measured flow rate, concentration can be calculated, providing 10-minute averages.

The mass concentration, oscillation frequency, filter loading, flow rates, temperature and other diagnostic information can be displayed on the controller's liquid crystal display (LCD) screen. In addition, mass concentration and filter loading, and possibly other parameters, are output to the datalogger as analogue voltages or through the RS232 interface.

The system allows for continuous unattended monitoring over extended periods of time, and has a high level of precision. It is classified as an equivalent method for PM<sub>10</sub> monitoring (but not PM<sub>2.5</sub>) when operated in accordance with 40 CFR Part 50, Appendix J. Alternatively, TEOMs can be operated in accordance with AS/NZS 3580.9.6:2003 (*Methods for sampling and analysis of ambient air – Determination of suspended particulate matter – PM<sub>10</sub> high volume sampler with size selective inlet – Gravimetric method*).

Comparative studies of the TEOM against gravimetric methods have shown that the heated inlet, designed to remove unwanted water vapour from the sample, inadvertently causes the loss of volatile particulates (such as ammonium nitrate), both in the sample train and on the filter itself. This effect can be reduced by operating the sampler at 40°C instead of 50°C. This is standard recommended practice in New Zealand.

For the measurement of PM<sub>10</sub> a high-volume sampler should be co-located with the TEOM for one year to establish an adjustment factor for volatile loss. The difference between TEOM and gravimetric methods varies with season and location. Greater differences are likely to occur where wood smoke comprises a large portion of the PM<sub>10</sub>. Wood smoke contains a significant fraction of low molecular weight volatile organic compounds, which are volatilised by the TEOM's heated inlet.

It is not necessary to determine an adjustment factor if the TEOM is fitted with an FDMS (filter dynamics measurement system). In simple terms, the FDMS alternates between sampling aerosol-laden and aerosol-purged air. Any decrease in filter mass as a result of being purged of aerosols is added back to the unpurged mass to take account of the volatilised component.

It is strongly recommended that TEOMs be fitted with FDMS when used for compliance monitoring. FDMS can be retrofitted to Series 1400a analysers. Data should be annotated to show that it is from a TEOM-FDMS monitor. Alternatively, the TEOM could be used without the FDMS by using a correction factor. This factor is determined by co-locating the TEOM with a gravimetric monitor for at least one year.

**Recommendation 11: Operation of a tapered element oscillating microbalance (TEOM)**

It is recommended that TEOMs be fitted with a filter dynamics measurement system (FDMS) when monitoring for national standards.

Alternatively, TEOMs can be used without the FDMS by using a correction factor that is determined by co-locating the TEOM with a gravimetric monitor for at least one year.

### 5.2.3 Partisols

Partisols are available as sequential gravimetric samplers with size-selective inlets that can monitor different particle size fractions (PM<sub>10</sub> and PM<sub>2.5</sub>). Some partisols have reference method designation (USGPO, 1998a and 1998b) making them suitable for compliance monitoring. Other samplers may be used when operated in accordance with US 40 CFR Part 50, Appendix J.

Partisols operate with either a hub (and satellite) or filter cassette system. Hub systems incorporate two or more filters and can switch sample flow to a new filter to allow daily sampling. The filter cassette system is capable of loading up to 16 filters, which are changed automatically at a predetermined time (AEA Technology plc, 2003). The conditioning of the filters and calculation of results is the same as for a hi-vol sampler (see below). This system can be left unattended up to two weeks and its progress can be monitored remotely by telemetry.

Some samplers are also able to store meteorological parameters such as average ambient temperature, pressure and relative humidity.



## 5.2.4 High-volume (hi-vol) gravimetric method

A hi-vol sampler draws ambient air at a constant flow rate (66–68 m<sup>3</sup>/hour) onto a glass-fibre filter, which has been pre-weighed after being conditioned at constant relative humidity and temperature for at least 24 hours. The filter is exposed for a 24-hour period and then reweighed after being conditioned again under the same conditions of relative humidity and temperature. The total volume of air sampled is determined from the flow rate and the sampling time. The mass concentration is calculated as the mass of the sample collected, divided by the volume of air sampled.

Hi-vols either have a mass flow controller or volumetric flow control, which maintains a constant flow rate as the filter loading increases during sampling. Care must be taken to use appropriate filters that will not become overburdened during the sampling period. For the purposes of PM<sub>10</sub> monitoring a size-selective inlet is required.

Under Schedule 1 of the NES for air quality, a 24-hour mean is calculated every 24 hours at midnight for the preceding 24 hours. While hi-vols can be used for compliance monitoring when operated in accordance with US 40 CFR Part 50, Appendix J, the requirement to manually change filters at midnight makes this impractical.

### **Recommendation 12: The importance of filter conditioning**

Manual methods for particulate monitoring are all based on weighing material collected on a filter. It is therefore important to recognise that the pre- and post-conditioning of the filter and the filter weighing techniques are just as important as the selection and use of the sampling equipment.

Most filters will absorb moisture from the atmosphere, so filter weight will vary in accordance with the surrounding humidity. Particulate matter collected on the filters will also behave in the same way. It is therefore essential that the filters be carefully conditioned and weighed under conditions of constant temperature and humidity, both before and after sampling.

Detailed procedures for filter handling, conditioning and weighing are given in the relevant standard method specifications. For example, the USEPA recommends that filters be conditioned for at least 24 hours at a humidity between 20 to 45%,  $\pm$  5%, and a temperature of 15 to 30 °C,  $\pm$  3 °C (40 CFR Part 50, Appendix J).

Appendix C lists various types of sampling filters and their applications.

## 5.2.5 Light-scattering instruments

Light-scattering instruments have been available for many years, but mainly for use in monitoring workplace dust exposures. Over the past few years some of these instruments have been adapted for ambient monitoring, with variable degrees of success. The ‘workplace’ units are relatively cheap and portable, and give a direct readout of particle concentrations. Their measurement precision and sensitivity, however, are not appropriate for compliance monitoring (see section 4.1). As such, they are more suitable for research or low-level survey work.

The main limitation with light-scattering instruments is that the instrument response depends on both the size distribution and the number of particles, rather than the total mass of airborne particulate. This can be overcome to some extent by carrying out periodic calibrations using manual filter sampling.

Ultimately, there is no direct relationship between light scattering and mass, and the method is not suitable for compliance monitoring. Some light-scattering instruments also give an indication of particle size distributions, which may be of value in specific investigations.

### **5.2.6 Low-volume (low-vol) gravimetric method**

There are a number of low-vol methodologies available. These are designed with specific flow rates sufficient for the size-selective inlet to collect the particle size fraction being monitored. Low-vol systems include:

- minivol (with a flow rate of 5 litres/minute)
- microvol (with a flow rate of 3 litres/minute).

Minivols and microvols do not comply with US 40 CFR Part 50, Appendix J, and are not suitable for compliance monitoring. However, they are useful screening tools, being small, portable, battery powered and easy to deploy. It should be noted that special care needs to be taken when handling the particulate filters for minivol and microvol samplers. The weighing of these filters requires a five decimal place microbalance, and it may also be necessary to install vibration isolators and take special anti-static precautions. At low concentrations (below  $15 \mu\text{g}/\text{m}^3$ ), it is not unusual for minivol samplers to be  $\pm 50$  per cent of the reported concentration (Northland Regional Council, unpublished).

Appendix D summarises the widely used particulate monitoring instruments in New Zealand.

## 6 Where to Monitor? – Selecting Monitoring Sites

Monitoring sites are established for different reasons based on the monitoring objectives. Improperly located sites will provide unsuitable results for the intended purpose of monitoring and will in turn lead to incorrect decisions.

This chapter provides good-practice guidance on properly siting monitoring equipment. This Guide recommends the use of the Australian / New Zealand siting standard (AS/NZS 3580.1.1:2007, *Methods for sampling and analysis of ambient air – Guide to siting air monitoring equipment*) when establishing monitoring sites.

### 6.1 The Australian / New Zealand Siting Standard

The AS/NZS 3580.1.1:2007 is the new siting standard released in August 2007. It has superseded AS2922 – 1987, *Ambient air – Guide for the siting of sampling units*. The new standard provides useful guidance on siting individual monitoring stations.

AS/NZS 3580.1.1 recommends minimum distances of sites from roads so that the site is not unduly influenced by roadside emissions. It also recommends heights of sample inlets for monitoring specific contaminants at different site classifications. The importance of these considerations is discussed in section 6.3.

### 6.2 Site classification

This Guide recommends a combination of New Zealand, Australian and USEPA (USGPO, 2008) site classifications. The purpose of the site classification system is to distinguish between different types of monitoring sites and to allow data sets to be compared nationally and internationally.

The site classification should be recorded in the site metadata (see section 8.8). Site classifications are described in Table 3.

**Table 3: New Zealand monitoring site classification and scales**

Recommended site category	Site scale equivalent	Typical area
Traffic	Peak (metres to 10s of metres)	Typically very close to high-traffic-use roads and intersections. Site should be between 2 to 5 m from the roadside.
Industrial	Peak (metres to 10s of metres) or Neighbourhood (10s of metres to 0.5 km)	Peak – close to one large point source or fugitive emissions. Typically used for compliance monitoring. Neighbourhood – with large and varied point source industry emissions and high population density. Such areas may contain heavy commercial and processing industries.
Residential	Peak (metres to 10s of metres) or Neighbourhood (0.5 to 10s of kilometres)	Peak – a monitoring site located somewhere not truly representative (so it is not neighbourhood scale) but does not exactly fit the 'traffic' or 'industrial' peak site descriptions. Neighbourhood – suburban areas in larger cities with a relatively high population density, but not in the immediate vicinity of congested roads or industry. This category also includes residential areas in smaller towns in rural areas.
Special (site description)	Regional (10s to 100s of kilometres)	Airsheds that are distinct in their geographical, meteorological and emissions characteristics. Included are the effects of any point sources or urban plumes on the regional air quality. Could include places where natural emissions are significant (eg, Rotorua), in which case the category would be <i>Special (Geothermal)</i> .
	National	National background sites that contribute to the global network; eg, <i>Special (National)</i> .

## 6.3 Considerations for site selection<sup>2</sup>

Various factors can severely affect the validity of data from a monitoring site. The following issues should be thoroughly considered before selecting a site.

- **Sites with restricted air flows in the vicinity of the sample inlet**

Sites should not be adjacent to walls, buildings or trees that impede or distort the air flow. AS/NZS 3580.1.1 recommends a minimum clear sky angle of 120 degrees. The site must not be under overhanging foliage. In some cases, such as monitoring in urban canyons, these issues may prove difficult to avoid.

- **Sites prone to the effects of absorption and adsorption**

Some building materials may absorb some of the contaminant being monitored. Deposition of PM<sub>10</sub> may occur on nearby leafy vegetation.

- **Sites where chemical interference may occur**

It is prudent not to monitor for ozone at roadside sites due to the possible interference of motor vehicle emissions with ozone measurements – unless their effect is what you are wanting to measure. Ammonia from refrigeration plants may interfere with sulphur dioxide monitoring.

<sup>2</sup> Reproduced from AS/NZS 3580.1.1:2007 with the permission of Standards New Zealand under Licence 000713.

- **Sites where physical interference can occur**

Avoid overhead high-voltage cables to prevent electrical interference with sampling equipment.

- **Sites affected by extraneous local emissions**

Do not choose sites where emissions from other sources will affect monitoring (eg, standby generators, unsurfaced roads, nearby boiler).

- **Sites that are vulnerable to vandalism**

This can be a major restriction to the available sites. Sample inlets are often the most vulnerable (since ideally they should be at breathing height to best assess exposure). The fabrication of a wide-gauge steel mesh enclosure with a lockable mesh lid for maintenance can be an effective way around this problem. If space is available, putting up a security fence is another option.

- **Sites that have poor access**

Consideration must be given to easy transportation of calibration cylinders, instrument repair and the movement of other bulky equipment to and from the site. Schools are often ideal sites in terms of security and power supply, but arrangements may be necessary to ensure access when the school is closed. This can pose problems during holidays.

- **Locating a suitable power supply**

This can be another obstacle, particularly with roadside sites. Sometimes it is possible to use a power supply from a nearby streetlight, running armoured cable under the pavement. Public safety is paramount when routing cables.

- **Changes around the monitoring site**

Demolition or construction activities, road works resulting in diversion of traffic or congestion can all have a considerable effect on data. A record of these events should be kept, including the date/s and intensity of the activity. It may be necessary to consider whether data during these periods is valid and representative.

If the nature of a site becomes permanently changed, it may be necessary to consider a new location (if the site is no longer representative of the monitoring objectives). Another thing to take into account for long-term sites is the presence of small trees close to the site, which could grow to be very large over the period of monitoring.

Site selection for compliance monitoring should follow the Australian / New Zealand standard (AS/NZS 3580.1.1:2007) as far as possible. This is particularly important for regional and neighbourhood sites. A detailed list of site selection considerations for these sites can be found in the AS/NZS standard. Peak sites can deviate from the standards where necessary, but any non-conformity to standard requirements should be clearly detailed in the site metadata.

## 6.4 Representativeness of monitoring sites

### 6.4.1 Spatial representativeness

It is particularly important to select a site that is representative of the location being investigated. This can only be done if the objectives of the monitoring have been clearly identified. The site should not be unduly influenced by sources that are *not* being investigated. For example, it would be preferable *not* to locate a site intended to monitor PM<sub>10</sub> from domestic heating near a busy road (another source of PM<sub>10</sub>).

The NES for air quality stipulate that monitoring must be undertaken where people may be exposed and where the standard is breached by the greatest margin or most frequently.

As an example, a site located in the centre of a residential area primarily for the purpose of monitoring 'worst case' PM<sub>10</sub> emissions from domestic heating may be considered representative of exposure of the entire residential area. Alternatively, a busy roadside site for the purpose of monitoring carbon monoxide may be considered representative of public exposure in that area. Table 3 (see section 6.2) identifies spatial scales adapted from USEPA 40 CFR 58, Appendix D.

Existing air quality monitoring data, emissions inventories and atmospheric dispersion modelling are useful tools and should be used wherever possible when determining worst locations. Regional exposure (eg, how many people may be exposed) should also be taken into consideration when determining the 'worst' location.

In the absence of dispersion modelling information, additional guidance can be found in AS/NZS 3580.1.1:2007, *Methods for sampling and analysis of ambient air – Guide to siting air monitoring equipment*, and the US CFR 58, Appendix D.

### 6.4.2 Temporal representativeness

Ambient air monitoring should also take into account temporal variations in contaminant concentrations. The NES for air quality and AAQG specify time averages for particular contaminants (see section 3.1.1). Meteorological conditions during monitoring should also be considered, as these conditions change with time.

As an example, monitoring benzene continuously for four months (January to April) would not give a temporally representative result if the objective of monitoring is to determine seasonal variations. Monitoring continuously for one month in each of the four seasons would provide better seasonal data.

### **Recommendation 13: Representativeness of monitoring**

The use of existing air quality monitoring data, emissions inventories and atmospheric dispersion modelling is recommended when determining 'worst' locations.

Regional exposure should also be taken into consideration when determining the 'worst' location.

Ambient air monitoring should take into account temporal variations in contaminant concentrations.

## **6.5 Further monitoring considerations**

### **6.5.1 Distances from sources**

It is recommended that monitoring at peak traffic sites should be no less than 5 metres away from the source. In the case of roadside monitoring, the distance between kerbside and building façade is often less than 5 metres. For this reason monitoring at the building façade is practical, since the monitoring station is less likely to create an obstruction to pedestrians and will represent air quality where people are likely to be exposed for longer periods of time.

Monitoring should not be conducted at road intersections (unless the intersection is a specific objective of the monitoring), but instead mid-way along a block. Air quality at intersections is generally unrepresentative, and may be better or worse than the rest of the road, depending on congestion and air flows.

In contrast, monitoring at neighbourhood and background sites needs to ensure that the effects of roadside emissions are not monitored (otherwise they will become peak sites). AS/NZS3580.1.1:2007 includes a table that recommends minimum distances from roads, specific for each contaminant, and takes account of different road flows.

To determine locations for peak industrial sites it is often necessary to use dispersion modelling. Such modelling would require local meteorological data.

### **6.5.2 Monitoring for multiple contaminants**

Emissions from a source usually include a number of contaminants, and so it is often desirable to house a number of analysers together. The housing should be large enough to carry out routine calibration and basic repairs to the equipment.

The temperature inside instrument enclosures should remain constant (ideally around 25 degrees Celsius or at a temperature specified by the instrument manufacturer) and will require an air-conditioning unit with heat and cool cycles. A constant temperature is important as most analysers are temperature sensitive, with moderate variations in temperature affecting data. Smaller housings suffer temperature drops during winter calibrations, when their doors have to remain open for long periods. Walk-in housings do not suffer these problems but can be harder to locate and represent a higher level of expenditure.

Monitoring for multiple contaminants can help in assessing the validity of peak pollution levels. An unusually high level of PM<sub>10</sub> at a roadside site, in association with high levels of NO<sub>x</sub> and possibly CO, would indicate a genuine event rather than an isolated set of anomalous PM<sub>10</sub> values.

#### **Recommendation 14: Instrument enclosure temperatures**

The temperature inside instrument enclosures should remain constant (ideally around 25°C or at any other temperature stated in the instrument's user manual).

Installation of an air-conditioning unit with heat and cool cycles inside instrument enclosures is recommended to prevent variations in temperature.

### **6.5.3 Sample inlet considerations**

Inlet heights should be sited at the breathing zone in order to represent human exposure. This is often not possible, because inlet heights have to be compromised to avoid the risk of vandalism or to accommodate the specific requirements of particular instruments. AS/NZS 3580.1.1:2007 provides guidance on acceptable inlet heights for different contaminants at different types of sites. Table 2 of this standard should be used to assess the acceptable range of parameters where it is not possible to monitor at, or near, the breathing zone.

Some considerations include:

- keeping the inlet at least 20 metres away from tree drip-lines
- ensuring an unrestricted airflow of 270 degrees around the sample inlet (or 180 degrees if at the side of a building)
- ensuring a clear sky angle of 120 degrees.

### **6.5.4 Relevant averaging periods**

It is important to use the specified averaging periods when reporting for the NES for air quality (such as an eight-hour running mean for CO, one-hour mean for NO<sub>2</sub>, and 24-hour mean for PM<sub>10</sub>). The averaging period for the contaminant should be considered when choosing a site. For example, the eight-hour average for CO is based on the known health effects of exposure above the threshold concentration for periods of eight hours or more, so it is appropriate to site the monitoring in locations where people are likely to be exposed to elevated CO over this averaging period.

Schedule 1 of the NES for air quality provides a concise definition of the averaging periods (see Appendix A). It should be noted that the 24-hour mean for PM<sub>10</sub> runs from midnight to midnight.



## 6.6 Long-term viability of sites

Relocating monitoring sites is not desirable if the monitoring objective is to obtain long-term monitoring data for trend analysis. If this cannot be avoided, then it is important to choose an alternative site that will be available in the long term. Areas not subject to future development or change in ownership are potential long-term monitoring sites.

Where equipment must be moved to a new site, efforts should be made to:

- select a site with similar sources and meteorology
- have overlapping data between the old and new sites.

At least one year of simultaneous data recording from both sites is recommended. This data will be needed when trends in air quality are assessed over the period of site relocation.

### **Recommendation 15: Site selection**

Regional, neighbourhood and compliance sites should follow the Australian / New Zealand standard (AS/NZS 3580.1.1.2007).

Peak sites can deviate from the standards when necessary.

Whenever site locations do not meet the standard requirement, this should be clearly detailed in the site metadata.

A minimum co-location period of one year is recommended when relocating monitoring sites.

# 7 Equipment Calibration and Maintenance

## 7.1 Overview

Instrument calibration and maintenance are an integral part of operating an air quality monitoring site and are vital for data quality assurance. Accurate and reliable monitoring results are crucial for data analysis, particularly when the monitoring results are to be compared with the relevant standards or guidelines for compliance purposes, or for population exposure and health risk assessments. Where such analyses lead to air quality policy formulation and air pollution mitigation strategies, the quality of the original data is especially important.

This chapter outlines the basic requirements for the calibration and maintenance of air quality monitoring instruments based primarily on standard monitoring methods. Precedence is given to Australian / New Zealand Standards for ambient air quality monitoring, where relevant, as these are the methods recommended by the AAQG and the methods required by the NES for air quality.

Monitoring agencies should develop their own detailed calibration and maintenance programmes appropriate to their data quality assurance goals. Guidance is provided on various associated technical topics, including calibration frequency and a framework for compiling operating procedures manuals. Specific guidance on data quality assurance is given in chapter 8, which should be read in conjunction with this chapter.

### **Recommendation 16: Monitoring records**

Agencies operating monitoring instruments need to keep detailed records of visits and maintenance, preferably in electronic form.

## 7.2 Equipment calibration

The calibration of an analyser establishes the relationship between instrument response (such as output voltage) and known contaminant concentrations. This response/contaminant concentration relationship is then used to convert analyser response to corresponding ambient pollution concentrations. To meet data quality objectives, most air quality monitoring equipment has to be calibrated at regular intervals to:

- compensate for baseline and span drift
- check the linearity of instrument response.

Note that meteorological instruments also require calibration. Calibration requirements vary depending on instrument type and manufacturer. Detailed operation and service manuals should be requested and supplied with any instrument purchase.

As a general rule, instrument calibration and maintenance should follow the recommendations and requirements of the appropriate standard method and the manufacturer's instructions. The use of Australian / New Zealand standards (AS/NZS) is recommended. In the absence of an AS/NZS, other appropriate standards may be used, such as the USEPA or British Standards. For the purposes of compliance monitoring, the use of specified standard monitoring methods is a statutory obligation.

### **7.2.1 Use of standard monitoring methods**

A range of standard methods for the sampling and analysis of ambient air are available from various agencies such as Standards Australia, Standards New Zealand, USEPA, British Standards and the International Organisation for Standardisation (ISO). Standard monitoring methods set out the basic principles of operation, instrument performance requirements, apparatus and set-up, calibration procedures, and the calculation and expression of results. It is essential that the equipment is then operated according to that standard at all times.

Monitoring instruments that are designated as reference methods or equivalent by organisations such as the USEPA are usually accompanied by detailed calibration and service manuals produced by the instrument manufacturer, which describe how a particular instrument is to be operated to meet the requirements of that designation. Checking whether a particular instrument complies with a standard monitoring method should be made at the time of purchase.

### **7.2.2 Calibration of gas analysers**

The calibration of monitoring instruments for gaseous contaminants requires a calibration gas, a 'zero' air supply and some means of delivering a known calibration gas concentration to the instrument being calibrated, as well as calibration of flow, temperature and pressure sensors. Calibration gas mixtures should be traceable back to standard reference materials.

A gas analyser is only calibrated when the instrument response settings are actually physically changed to agree with a known concentration of supplied analyte gas. During the calibration process, zero air is produced by scrubbing any traces of the contaminant gas (as well as interfering species and moisture) from a stream of atmospheric gas. An analyser is 'zeroed' by adjusting the instrument's response (contaminant concentration output) to read zero while this scrubbed zero air is fed through the system. The instrument is 'spanned' by supplying a known concentration of gas (at the 'span' concentration of around 75 to 80 per cent of the full scale range) and altering the instrument response to read the correct concentration. This procedure establishes the instrument's response/concentration relationship and in most cases will be a straight-line equation.

It is crucial that the zero air supply is as free of analyte (and interfering species) as possible and that the supply of span gas is known accurately and delivered with precision. During the calibration process, zero air and span gases must be treated in exactly the same manner as the ambient sample air flow, and this is usually achieved by passing calibration gases through the sample inlet.

All other types of calibration, such as multi-point calibrations and auto-calibrations, can be regarded as checks to see if the instrument response is performing within defined parameters. The instrument may or may not need adjusting following these checks depending on the specifications contained in the relevant standard or manufacturer's instructions.

## Calibration frequency

Calibration frequency is a key consideration for a calibration and maintenance programme. There are three types of standard method calibration requirements for gaseous contaminants.

1. *Initial calibration:* where zero air and calibration gas atmospheres are supplied and any necessary adjustments are made to the analyser. Once this is done, calibration gas concentrations are required at approximately 20, 40, 60 and 80 per cent of the full measurement range of the instrument, and the instrument response is required to agree within 2 per cent of the calculated reference value. Alternatively, when actual concentration is plotted against expected concentration, the slope of the best-fit line should be within  $1.00 \pm 0.01$ , with a correlation coefficient of at least 0.999. This is also referred to as a linearity or multi-point check.
2. *Operational precision checks:* where the zero and span responses of the instrument are checked for drift on a regular basis. The recommended frequency is daily, but in any case it is recommended that precision checks be undertaken at least weekly to adjust or correct for zero and span drift. The drift tolerances given by the standards vary with each contaminant. In some standards this is also called an operational recalibration.
3. *Operational recalibration:* where zero and span gases are supplied, as for an initial calibration. It should be done when the analyser drift exceeds the instrument performance requirements, or after six months since the last calibration. Multi-point checks should be carried out every six months.

It is recommended that gas analysers be calibrated (or recalibrated):

- upon initial installation
- following relocation
- after any repairs or service that might affect its calibration
- following an interruption in operation of more than a few days
- upon any indication of analyser malfunction or change in calibration
- at some routine interval (see below).

The routine periodic calibrations should be balanced against a number of other considerations, including the:

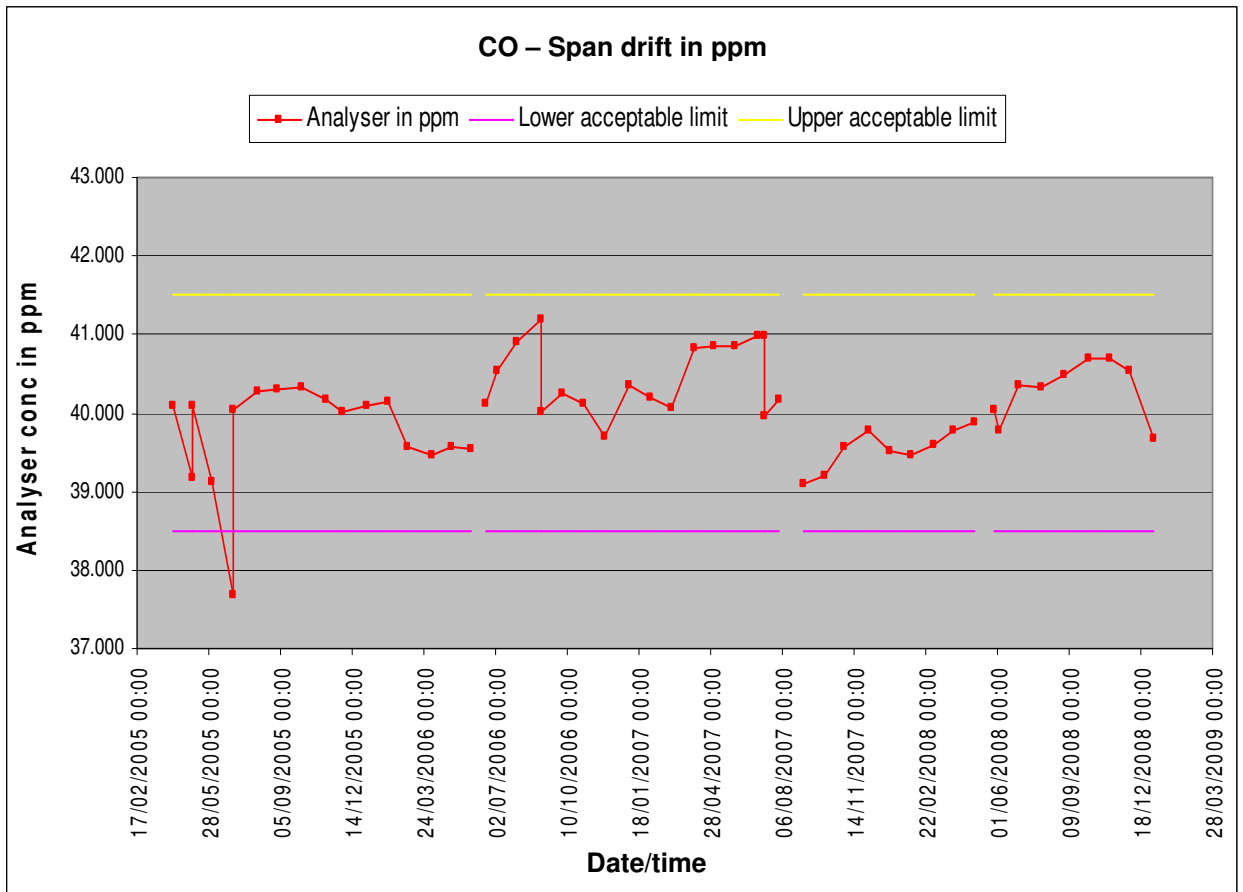
- inherent stability of the analyser under prevailing conditions of humidity, temperature, pressure, mains voltage stability and the like
- costs and time involved in carrying out calibrations
- amount of ambient data lost during calibrations
- data quality goals
- risk of collecting invalid data due to a problem with the analyser not discovered until the calibration is performed.

The periodicity of regular calibrations can be set operationally by noting the adjustments (if any) required after each calibration and by monitoring span and zero drift performance for each analyser. The requirement for routine instrument servicing and maintenance plus any unforeseen outages generally makes multi-point calibrations a reasonably regular necessity.

Note that routine maintenance and calibrations should be scheduled in such a way that any associated data loss is evenly distributed throughout the year, avoiding critical monitoring times.

Tracking the results of the calibrations on a spreadsheet can help determine the frequency of calibrations and also draws attention to the trend in the drift. Figure 7.1 shows an example. It should be noted that some analysers will take a couple of months to settle down when they are first installed.

**Figure 7.1: Example of calibration results tracking for a CO analyser**



### Multi-point calibrations

Multi-point calibrations are the key criteria by which the instrument's accuracy and linearity of response to a range of known concentrations of a contaminant are assessed (USEPA, 1998). The multi-point calibration results are also used for preparing calibration curves for the data quality assurance process (data adjustments – see section 8.4). While a multi-point calibration is referred to as being only part of an initial calibration by some of the standards (more recent Australian standards include it with operational recalibration), it is interpreted to include the following situations:

- instrument commissioning
- following any maintenance and servicing where the instrument is turned off or settings changed
- at regular operational intervals of not less than six months.

## Zero and span checks

Zero and span checks are performed by introducing zero air and a span gas concentration through the system but not making any actual adjustments. Recording the instrument response at zero and span concentrations provides a way to determine instrument reliability and drift over time, and to assist with the data quality assurance process. The checks can also be used to help set calibration frequency. In some standards, this type of check is called an 'operational precision check'.

Note that 'as is' zero and span checks should be performed immediately before any maintenance, instrument servicing or other shut-down for later quality assurance of the data.

## Automated checks and calibrations

Some air monitoring analysers are capable of periodically carrying out automatic zero and span calibrations and making their own zero and span self-adjustments to predetermined readings. However, this requires permanent connection to a span gas supply, usually through a different inlet from the sample inlet and, in the strictest sense, does not meet the requirement that the calibration gas be treated in the same manner as the sample gas stream. It also requires that instrument parameters before and after calibration are recorded and that the span and zero are discernible from data-logger records for subsequent quality assurance assessment. For these reasons, it is recommended that the auto-calibration function only be used as a zero and span check, as described in the previous section.

Automatic zero and span checks can be useful for remote sites or large networks as they reduce the need for weekly inspections by staff. Automated systems generally allow for any user-defined frequency. While daily checks are possible, consideration must be given to the usefulness of this in terms of data quality assurance, the time of day it is performed (eg, not during peak pollution periods), and the amount of data loss, as most systems require some time to stabilise between concentration ranges and after a calibration process. It is likely that at least one hour's worth (or 4 per cent of a 24-hour period) of data can be lost through this process.

Equipment configuration for automated systems requires a dedicated supply of span gas, such as a certified concentration in a cylinder or permeation tubes, dedicated zero air supply (some instruments include their own scrubber systems), plus the means to switch between different inputs (usually solenoid valves). This usually adds extra cost to the system set-up for each site.

## Concentrations to use for calibration points

The concentrations selected for calibrations and checks should be determined from the requirements of the analyser (zero and 80 per cent span) and also from the data. For example, if it is necessary to have a CO analyser range set at 50 ppm to cover an occasional spike but the usual data maximum is only 15 ppm, then consider doing an additional point at the 15 ppm level.

A secondary reason for selecting additional points is that the calibration equation is normally a straight line (as only the zero and span values are used), but some analysers may not be truly linear. This is why multi-point or linearity checks may be needed.

### 7.2.3 Calibration of PM<sub>10</sub> monitoring instruments

Manual gravimetric methods for PM<sub>10</sub> require air flow calibration, while methods such as beta attenuation, nephelometry or TEOM technology require calibration of flows (and flow sensors), as well as other components specific to the method.

The calibration frequency for PM<sub>10</sub> monitoring equipment varies depending on instrument type and the manufacturer's recommendations. As indicated previously, calibration of air flows (and sensors) is important due to the requirement of maintaining a critical sample flow to achieve the design cut-point of the size-selective inlet.

Instruments that are more sophisticated require calibration of temperature and pressure sensors, along with specific items associated with a method (eg, beta particle attenuation checks use calibrated foils for BAMs and the mass verification is needed for TEOMs). Further discussion of standard PM<sub>10</sub> monitoring methods is provided in chapter 5.

### 7.2.4 Calibration of meteorological instruments

Meteorological instruments such as cup anemometers, wind vanes, and temperature and relative humidity sensors generally require more specialised calibration and servicing, such as wind-tunnel testing, laboratory test atmospheres or calibration against primary standards. This should not prevent checks against calibrated instruments being done on a regular basis.

Sonic anemometers that measure both wind speed and direction involve a solid state technology, and they are calibrated and set at the time of manufacture for the lifetime of the instrument. While they do not require further calibration, they still need regular checks.

### 7.2.5 Use of traceable standards and equipment in calibration

Calibration is the primary means by which to verify that a gas analyser or particle sampler is performing as required, so it is important that the equipment or gases used to perform the calibrations are also certified to be accurate. This includes instruments to measure the following parameters:

- temperature
- pressure
- flow rates
- barometric pressure
- gravimetric balances
- standard gas mixtures (and their delivery regulators).

Calibration equipment should be purchased on the basis that it is accompanied by a certificate indicating calibration against a primary standard, or against other standards traceable to a primary standard. The most common is through the United States National Institutes of Standards and Technology traceable standards. The calibration equipment is also likely to require recalibration from time to time, and an expiry date is usually given on the accompanying calibration certificate.

Gas cylinders should be checked on purchase to ensure the correct concentration has been supplied and again if contamination is suspected during their use. This can be done by running gas from comparable cylinders against each other through a calibrated analyser and comparing the results. Any variation should be within the acceptable tolerances for the supplied gas and equipment. It may be possible to get gas cylinders recertified once they have reached the end of their expiry dates to prevent having to waste unused gas.

## 7.2.6 Calibration of data acquisition systems

Data acquisition systems such as external dataloggers may need calibration periodically if analogue outputs and inputs are used, because the voltages can vary over time. This can usually be avoided if digital interfaces are used.

### **Recommendation 17: Calibration**

Calibrations should be carried out in accordance with the manufacturer's specifications and the requirements of the standard method.

Span and zero checks are recommended on a daily basis.

Multi-point calibrations should be performed not less than six months apart.

## 7.3 Equipment maintenance

Maintenance refers to the regular inspection and servicing of monitoring instruments and ancillary equipment, through to general site maintenance. The efficient and smooth operation of an air quality monitoring station (along with the reliability and quality of data obtained) is entirely dependent on the manner in which it is maintained, and a critical element of this is preventive maintenance.

The following examples highlight some of the types of preventive maintenance and systems checks to ensure good data quality, but they by no-means constitute an exhaustive list:

- conduct regular site inspections, including a check of air-conditioning systems and security
- check instrument diagnostics for normal operation of pneumatics and electronics
- check sample inlets and filters (service or change as required)
- check vacuum pumps and pump filters (service as required)
- ensure datalogger and instrument times are correct (they should be maintained within  $\pm$  1 minute of New Zealand Standard Time).



Maintenance is an ongoing process so it is usually incorporated into daily routines, and there are also monthly, quarterly, six-monthly and annually scheduled activities that must be performed. The physico-chemical properties measured by air quality monitoring instruments to infer ambient concentrations are different for each contaminant, so the specific maintenance requirements for each will also be different. Monitoring agencies should follow the routine maintenance and service requirements outlined and recommended by the instrument manufacturer and incorporate these procedures into their own detailed schedules, with sufficient time allocated accordingly. Note that time allocated for preventive maintenance is separate to the time that may be required for instrument breakdowns and repairs, but sufficient attention paid to the former is likely to reduce the time spent on the latter and, most importantly, avoid instrument down-time and loss of data.

A good preventive maintenance programme should be well documented and include:

- a short description of each procedure
- a frequency and schedule for performing each procedure
- a supply of vital spare parts and consumables in stock
- documentation showing that the maintenance has been carried out.

Much of this information can be summarised in tabulated form with a check-sheet format. This can be done for most activities such as site inspections, instrument diagnostics checklists and (preventive) maintenance schedules.

#### **Recommendation 18: Equipment maintenance**

The routine maintenance and service requirement outlined and recommended by the instrument manufacturer should be followed.

## **7.4 Procedures and documentation**

The measurement of atmospheric gaseous and aerosol contaminants using instrumental methods is an analytical process that requires careful attention to accuracy and precision. This is generally assured by following standardised calibration and maintenance procedures specific to each type of instrument. Monitoring agencies should establish their own detailed procedures manuals and schedules for instrument maintenance and calibration as a fundamental part of their air quality monitoring activities. The importance of this for data quality assurance cannot be overemphasised, particularly where data may be used for assessing compliance with the NES for air quality, examining trends in air pollution over time, or determining strategies for emissions reduction.

Following standardised and documented procedures allows for a transparent process that can be easily audited and provides a level of confidence for end users of the data. Several different aspects of documentation need to be considered for an operational air quality monitoring site:

- routine site inspections – schedules and checklists for appropriate parameters
- instrument calibrations – schedules and procedures for carrying out routine calibrations
- routine maintenance – schedules and procedures for carrying out routine (preventive) maintenance on monitoring instruments and ancillary equipment

- detailed instrument calibration and servicing records – these must be kept as they will invariably be referred to during the data quality assurance process
- site logs – it is important to record all visits and activities undertaken at a site, with reference (where necessary) to the appropriate calibration and servicing records for more detailed information
- documentation of instrument types, date of installation and serial numbers for all equipment at a monitoring site – this allows for easy tracking of instrument replacements and translocations, as well as for asset management purposes
- site metadata – consisting of a compilation of information relating to a particular site (refer to section 8.8 for a list of recommended parameters).

It is recommended as good practice that two copies of all paper records be kept, particularly for instrument maintenance and site logs (one copy on site and one appropriately filed at the main office). Electronic records should be filed in an appropriate database that is regularly backed up.

Examples of instrument check-sheets and maintenance record templates are provided in Appendices E and F.

While it may seem that excessive documentation is required, once the systems are established, maintaining them is a relatively straightforward matter of regular audits and refinements as necessary. Systems should be as simple and transparent as possible. Installing and operating an air quality monitoring station or network is an expensive and labour-intensive process, so it is essential to have a quality data output. Note that much of the documentation work may already be done by adopting and incorporating the procedures and recommendations contained in the standard methods and the detailed operation and maintenance manuals that accompany standard method-compliant instruments.

Organisations may wish to structure their air quality monitoring documentation and procedures by incorporating them into a quality management system such as the ISO 9000 series, which would formalise the tracking and auditing framework. A quality management system is primarily concerned with what an organisation does to achieve:

- data end-users' (such as scientists and policy analysts within an organisation, central government, research providers and consultants) quality requirements
- applicable regulatory requirements (NES for air quality and applicable standard methods), while aiming to enhance customer satisfaction (confidence in monitoring results)
- continual improvement of its performance (high data quality, low data loss, efficient operating systems) in pursuit of these objectives.

Regional councils (or their contractors) have to conform to regulatory requirements (NES for air quality and applicable standard methods), and so appropriate procedures and documentation to achieve high-quality monitoring data and data capture targets are recommended. The adoption of a quality management system is a logical step.

### **Recommendation 19: Calibration and maintenance documentation**

As a vital part of data quality assurance it is recommended that detailed procedure manuals and schedules for instrument maintenance and calibration be established.

## 7.5 Training

Training of technicians carrying out calibration and maintenance work on air quality monitoring instruments is vital, as most instruments are a sophisticated combination of pneumatics, electronics, mechanical components and software. Training should be an integral part of establishing and operating an air quality monitoring site.

Several types of training should be provided (considered as core competencies) to technical staff, including:

- an introduction to fundamental air pollution processes and air pollution monitoring techniques (eg, Clean Air Society of Australia and New Zealand courses)
- specific training on instrumentation operation and maintenance (usually through systems providers)
- electronics and electrical systems
- quality systems management and quality assurance in analytical techniques.

Appropriately trained staff could apply for International Accreditation New Zealand (IANZ) or National Association of Testing Authorities (NATA) accreditation for a monitoring method that meshes well with a quality management system. IANZ or NATA accreditation recognises and facilitates competency in specific types of testing, measurement, inspection or calibration.

Another effective method of training and systems improvement is to participate in reciprocal auditing activities between monitoring agencies. The level of formality of the arrangement is up to the agencies involved, but is likely to work well at any level. The general approach is for technicians from one monitoring agency to visit and audit the procedures and methods (such as calibration and maintenance activities) used at another agency, in relation to both the auditee's own systems and documented procedures as well as against accepted industry practices and standard methods. Both auditee and auditor learn through this exercise, with the ultimate aim of continual improvement in monitoring systems and data quality.

### **Recommendation 20: Training**

Air quality monitoring technical staff should be provided with basic training on core air quality monitoring competencies.

Another effective method of training and systems improvement is to participate in reciprocal auditing activities between monitoring agencies.

## 7.6 Recommended equipment calibration methods for NES for air quality contaminant monitoring

The following sections provide an overview and guidance on the calibration and maintenance of instruments for specific contaminants covered by the NES for air quality (standard methods only). It is not intended to be an exhaustive list or a 'how to' manual, but has been compiled to inform organisations intending to set up monitoring systems of some of the operational requirements and equipment necessary so that they may be included in the budgeting process. The frequency of inspection and maintenance often depends on the environmental conditions at a monitoring site location. For example, sample inlets and lines are likely to require more frequent cleaning or replacement for sites next to busy roads due to higher road-dust and exhaust emission concentrations. Further detail and guidance are provided in the standards and instrument manufacturers' operation and service manuals.

### 7.6.1 Chemiluminescent NO<sub>x</sub> analyser AS 3580.5.1-1993

#### Calibration

- The analyser is checked or calibrated against the known NO (in N<sub>2</sub>) concentration diluted with zero air (see AS3580.2.2) using a mass flow calibrator at least six-monthly or after an extended power outage, maintenance and servicing.
- The recommended standard NO calibration gas concentration is 20–100 ppm (for a 0–500 ppb ambient range).

Refer to the manufacturer's instructions and relevant standard for specific guidance.

Note that there can be considerable lead-time (four to five months) between ordering NO calibration gas and subsequent delivery.

#### Maintenance

- Check the molybdenum converter efficiency three-monthly by gas-phase titration of NO with O<sub>3</sub> (or more often in high NO<sub>2</sub> atmospheres) and change as necessary.
- Clean the reaction cell regularly (refer to the manufacturer's instructions, as this can be checked before carrying out maintenance). More frequent maintenance will be required at locations with higher NO<sub>x</sub> concentrations (eg, roadside monitoring).
- Check seals, pneumatic lines etc and replace as necessary (refer to the manufacturer's instructions) due to the presence of corrosive O<sub>3</sub> in the system.
- Replace exhaust scrubber (for O<sub>3</sub>) regularly to protect the vacuum pump.
- Change the inlet sample line and filter regularly, depending on ambient conditions.
- Check the system for leaks regularly.
- Check flows and pressures regularly.

Refer to the manufacturer's instructions and relevant standard for specific guidance.

## 7.6.2 Direct reading CO infrared analyser *AS 3580.7.1-1992*

### Calibration

- Check the analyser or calibrate it against a known CO (in N<sub>2</sub>) concentration diluted with zero air (see AS3580.2.2) using a mass flow calibrator at least six-monthly, or after an extended power outage, maintenance and servicing.
- The recommended standard CO calibration gas concentration is 0.2 per cent (for a 0–50 ppm ambient range).
- CO standard gas bottle concentrations (eg, 10 ppm, 40 ppm) are readily available for span and intermediate checks instead of using a mass flow calibrator.

Refer to the manufacturer's instructions and relevant standard for specific guidance.

### Maintenance

- Clean the sample cell mirrors regularly (refer to the manufacturer's instructions).
- Check the inlet sample lines and filter and change regularly, depending on local conditions.
- Check the system for leaks regularly.
- Check flows and pressures regularly.

Refer to the manufacturer's instructions and relevant standard for specific guidance.

## 7.6.3 SO<sub>2</sub> direct reading instrumental methods *AS 3580.4.1-1990*

### Calibration

- Check or calibrate the analyser against a known SO<sub>2</sub> (in N<sub>2</sub>) concentration diluted with zero air (see AS3580.2.2) using a mass flow calibrator at least six-monthly or after power outage, maintenance and servicing.
- The recommended standard SO<sub>2</sub> calibration gas concentration is 20–50 ppm (for a 0–500 ppb ambient range).

Refer to the manufacturer's instructions and relevant standard for specific guidance.

Note that there can be considerable lead-time (four to five months) between ordering SO<sub>2</sub> calibration gas and subsequent delivery.

### Maintenance

- Clean the sample cell window regularly (refer to the manufacturer's instructions).
- Check the inlet sample lines and filter and change regularly, depending on ambient conditions.

- Check the system for leaks regularly.
- Check flows and pressures regularly.

Refer to the manufacturer's instructions and relevant standard for specific guidance.

#### 7.6.4 O<sub>3</sub> direct reading instrumental method AS 3580.6.1-1990

##### Calibration

- Due to its reactivity, O<sub>3</sub> has to be generated *in situ* for calibration purposes. Most commercially available mass flow calibrators include the option of an O<sub>3</sub> generator (also used for gas-phase titration of NO<sub>x</sub> instruments). Note that this is known as a secondary (transfer) reference standard and that it will require periodic calibration against a primary reference standard, as described in the O<sub>3</sub> standard method.
- Check or calibrate the analyser against known O<sub>3</sub> concentrations generated with zero air using a mass flow calibrator at least six-monthly or after power outage, maintenance and servicing.

Refer to the manufacturer's instructions and relevant standard for specific guidance.

##### Maintenance

- Check the inlets, sample lines and filter for cleanliness and replace as necessary (refer to the manufacturer's instructions), as O<sub>3</sub> is reactive and will be removed from the sample stream before detection.
- Clean the absorption tube/cell regularly.
- Check the system for leaks regularly.
- Check flows and pressures regularly.

Refer to the manufacturer's instructions and relevant standard for specific guidance.

#### 7.6.5 PM<sub>10</sub> monitoring instruments

The following subsections provide guidance on calibration and maintenance for standard PM<sub>10</sub> monitoring methods.

##### PM<sub>10</sub> by gravimetry

With respect to standard methods, the following instrumentation calibration and maintenance frequencies should be met:

- flow rate after any servicing, maintenance or moving of samplers
- flow rate every two months for high-volume samplers
- flow rate every six months for medium-volume samplers
- size-selective inlets, seals and impactor plates inspected, cleaned and re-coated as necessary

- laboratory analytical balance three-yearly (along with more frequent repeatability checks)
- programmable time clock calibrated annually (or more often as necessary)
- elapsed time meter (run-hours) calibrated annually (or more often as necessary)
- temperature and pressure compensation sensors (if fitted) calibrated annually.

Refer to the manufacturer's instructions and relevant standard for specific guidance.

### **PM<sub>10</sub> by beta particle attenuation**

With respect to standard methods, the following instrumentation calibration and maintenance frequencies should be met:

- annual calibration by measuring the absorption of a blank filter tape and a calibration control membrane (calibration foil) with a known absorption coefficient
- flow rate after any servicing, maintenance or moving of samplers
- flow rate checked (and calibrated if necessary) every three months
- beta attenuation calibrated annually
- size-selective inlets and seals regularly inspected (monthly), and cleaned as necessary
- temperature and pressure compensation sensors calibrated annually.

Refer to the manufacturer's instructions and relevant standard for specific guidance.

### **PM<sub>10</sub> by tapered element oscillating microbalance (TEOM)**

With respect to standard methods, the following instrumentation calibration and maintenance frequencies should be met:

- flow rates and mass transducer verification calibration after any servicing, maintenance or moving of samplers
- flow rates checked (and calibrated if necessary) every six months
- mass transducer verification calibration annually
- size-selective inlets and seals regularly inspected (monthly), and cleaned as necessary
- temperature and pressure compensation sensors calibrated annually.

Refer to the manufacturer's instructions and relevant standard for specific guidance.

# 8 Data Management Protocols

## 8.1 Data quality assurance

Quality assurance of monitoring data is intimately linked to the entire air quality monitoring process, from the choice of site, choice of instrumentation, proficiency of staff, calibration and maintenance processes, data storage, and retrieval and analysis systems. The final product (ambient air quality monitoring data) will only ever be as good and reliable as the systems that produce it.

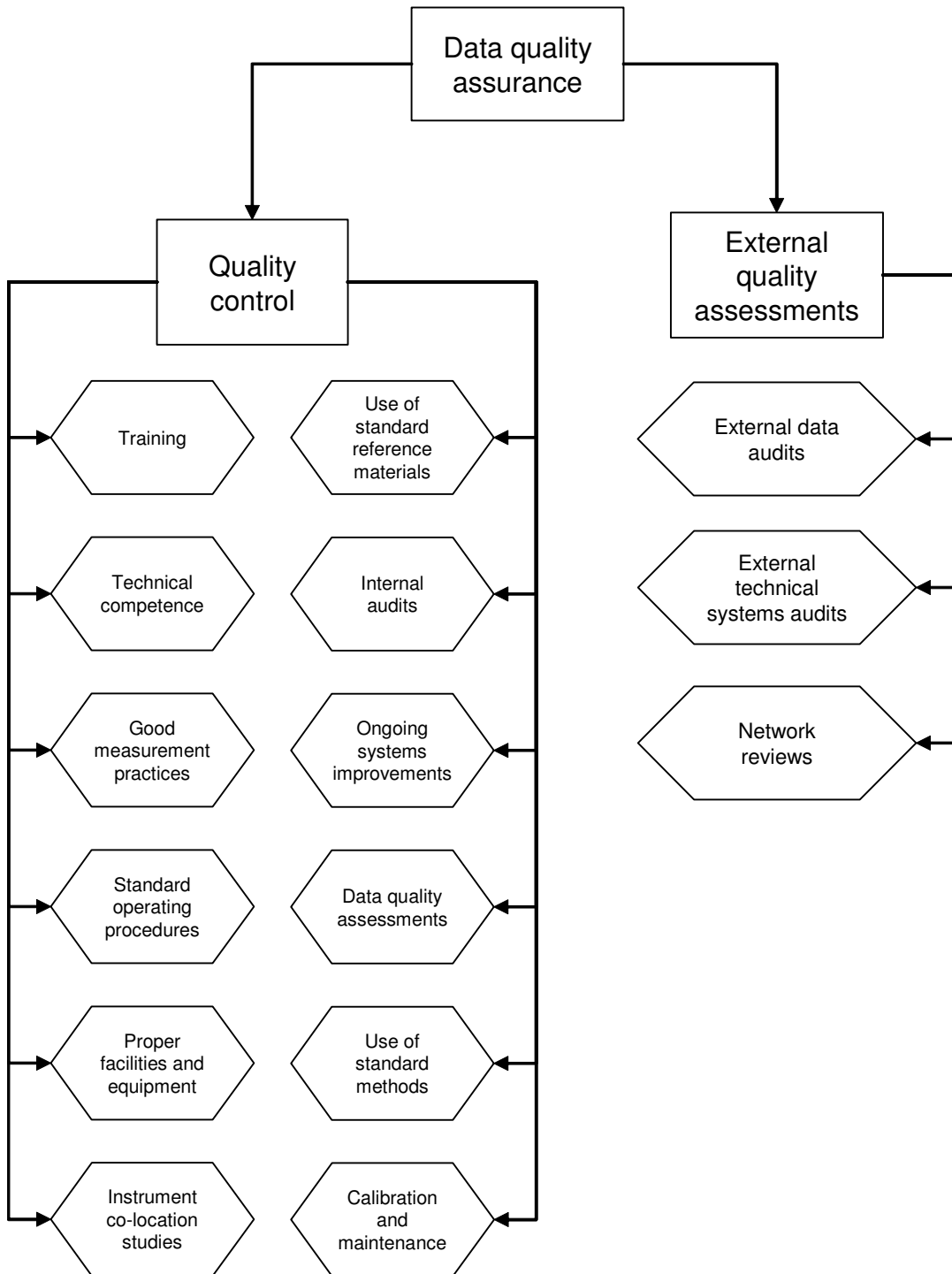
Figure 8.1 presents a flow chart of the essential elements of the quality assurance process that ultimately aims to provide quality assured data as the end product. It shows that the quality assurance process comprises an organisation's own quality control procedures and factors that lead to a quality output, such as staff training, standard operating procedures, and the use of standard methods for monitoring. Internal quality control is complemented by an external assessment or audit of systems, procedures and processes to provide an appropriate level of confidence in the data being produced.

Quality control is the overall system of technical activities that measures the attributes and performance of a process, item, or service against defined standards to verify that they meet the stated requirements of the output. For air quality monitoring, quality control is used to ensure measurement uncertainty is maintained within acceptable limits, such as those defined by standard monitoring methods and a monitoring agency's own data quality objectives. The fundamental objectives of a quality assurance/control programme should be as follows.

- The data obtained from air quality measurement systems is representative of the spatial scale being investigated.
- A minimum data capture rate of 95 per cent is achieved (refer to Recommendation 24).
- A minimum of 75 per cent valid data is collected when calculating averages.
- Measurements are accurate, precise and traceable.
- Data is comparable and reproducible. Results from a monitoring network are internally consistent and comparable with national, international and other accepted standards.



**Figure 8.1: Process elements that provide data quality assurance**



This chapter outlines the basic process of data quality assurance to achieve an end product of quality-assured data that is ready for further analysis and reporting.

## 8.2 Documentation and procedures

There is a basic need to document quality assurance procedures, and this should be developed as part of establishing an air quality monitoring site. A quality assurance procedures manual should incorporate the calibration and maintenance documentation discussed in section 7.4 as well as methods for:

- data quality acceptance criteria
- data storage procedures, including file creation and archiving systems
- data handling and adjustment procedures to correct for calibrations, checks and baseline or span drift
- documentation of any data adjustments and excluded or missing records.

A monitoring agency should define overarching data quality objectives that match the intended use of the data and the purpose of monitoring, such as compliance, air quality research, or screening monitoring studies.

## 8.3 Principal elements of data quality assurance

This section provides an overview of and guidance on data handling and adjustment to produce a quality assured data set that is then ready to be used for air pollution studies and compliance assessments.

**Figure 8.2:** Flow diagram of the acceptance process for routine air quality measurements

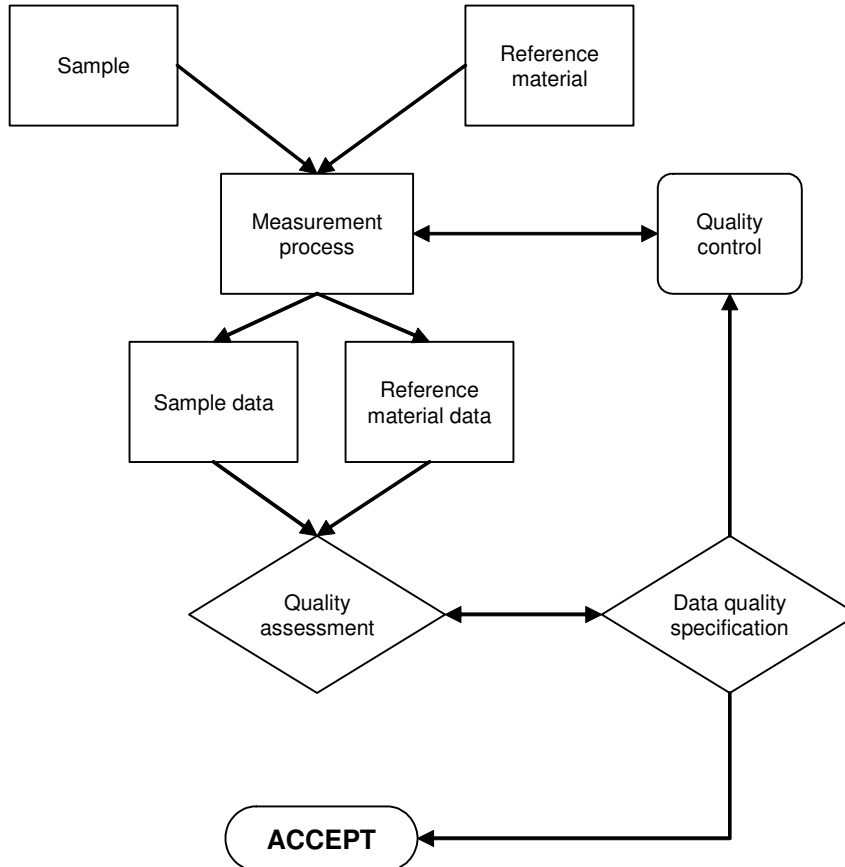


Figure 8.2 presents a flow diagram of the basic process for accepting routine data. It shows that the measurement of a sample to provide a response by an instrument needs to be verified (calibrated) against the response of that instrument to a known concentration (reference material). This calibration data is then used to assess the quality of the sample data (are the measured concentrations real?) before the data is accepted (validated). If data is out of specification then this must inform the quality control process so that system improvements can be made and invalid data excluded from the final data set. The following sections describe some of the essential elements of the data acquisition, quality assurance and validation process.

### 8.3.1 Data acquisition

Most modern continuous air quality monitoring instruments contain their own data acquisition system (DAS) or datalogger, as well as provision for analogue or digital output of data to an external datalogger. As a result, it is possible to utilise an instrument's DAS followed by transfer to a laptop to collect and store monitoring data. However, data management becomes unwieldy if there are a number of instruments and/or a number of monitoring sites. It is recommended that an external datalogger (purpose-built or PC-based) be used for all instruments, including meteorological instruments. It is preferable to use digital signals because analogue voltages can vary over time. Use of an external datalogger ensures that all parameters have exactly the same date/time stamp (New Zealand Standard Time) for subsequent inter-comparisons and analyses.

Continuous monitors should still be configured so that their own DAS is recording data in parallel to an external datalogger in case of any data loss through a data-logger fault. An instrument's internal clock should be synchronised as closely as possible with the external datalogger to prevent any time disparities. If need be, the two sets of data can also be used to check that the external datalogger's programming and averaging algorithms are correct.

It is necessary to have high-resolution raw data files, and the external datalogger should provide and store, at a minimum, 10-minute averages calculated from finer-resolution instantaneous measurements (eg, 10 seconds). Monitoring site dataloggers will require downloading periodically to a central data archive, and the most efficient method for achieving this for permanent monitoring sites is via a telemetry system, usually several times a day. Newer general packet radio service systems allow an almost continuous transfer of data over cellular networks if the sites are within good communication areas. Many monitoring agencies will already operate a telemetry system for other environmental monitoring data such as hydrology networks.

Manual downloads of data are an acceptable alternative but involve regular visits to the monitoring site that take into account the datalogger's data storage capacity. Manual downloads still run the risk of missing instrument faults occurring between site visits.

### 8.3.2 Data storage, archiving and retrieval

All data should be stored in a central database that is regularly backed up. Each monitoring site and parameter should be assigned a unique identifier that enables easy retrieval. It is preferable to store data in such a way that incoming data is appended to the archive file so it can be viewed as a continuous data set. Two parallel data sets should be maintained: one that preserves raw data in its original form and the other that has been quality assured and is available for further analysis. Keeping a raw data set archived means that the data can be revisited and re-analysed if any problems arise with the original quality assurance process (USEPA, 1994).

A variety of software packages are available that can efficiently store air quality data as time-dependent variables and provide for data manipulation, including graphical analysis, the calculation of fixed and moving averages, and exceedence percentiles. Some software also allows for the incorporation of electronic 'comment' files that can be viewed alongside data that has been through the quality assurance process, providing an audit trail that would otherwise have to be recorded separately.

### 8.3.3 Daily data checks

It is essential to screen air quality data by visual examination for spurious and unusual measurements. The main advantage of regular data transfer by telemetry is that the data can be checked at least once a day so that instrument faults, systems failures, data spikes, human error, power failures, interference or other disturbances can be readily identified and promptly remedied to minimise instrument down time and data loss. It is recommended that daily data checks be done (and recorded) for each site that is telemetered (or whenever data is downloaded from untelemetered sites) and notes of events that may affect results (eg, bushfires, dust storms, roadworks, fireworks) recorded.

### 8.3.4 Instrument checks, calibrations and maintenance

Regular instrument checks, calibrations and maintenance are vital to data quality assurance, along with good site logs and technician notes stating exact times and adjustments made, as these will have to be read alongside archived data when validating or removing suspect data.

#### **Recommendation 21: Data acquisition, storage and data checks**

The use of an external datalogger is recommended for all instruments to eliminate one source of variation using analogue connections.

All data should be stored in a central database that is regularly backed up.

It is recommended that daily data checks be done for each telemetered site (or whenever data is downloaded from untelemetered sites), and events noted that may affect results.

## 8.4 Data adjustment

Timely quality assurance of data is important to keep on top of the incoming data stream. It is recommended that quality assurance be done at least monthly given that the NES for air quality require public reporting of a breach within 30 days of its occurrence.

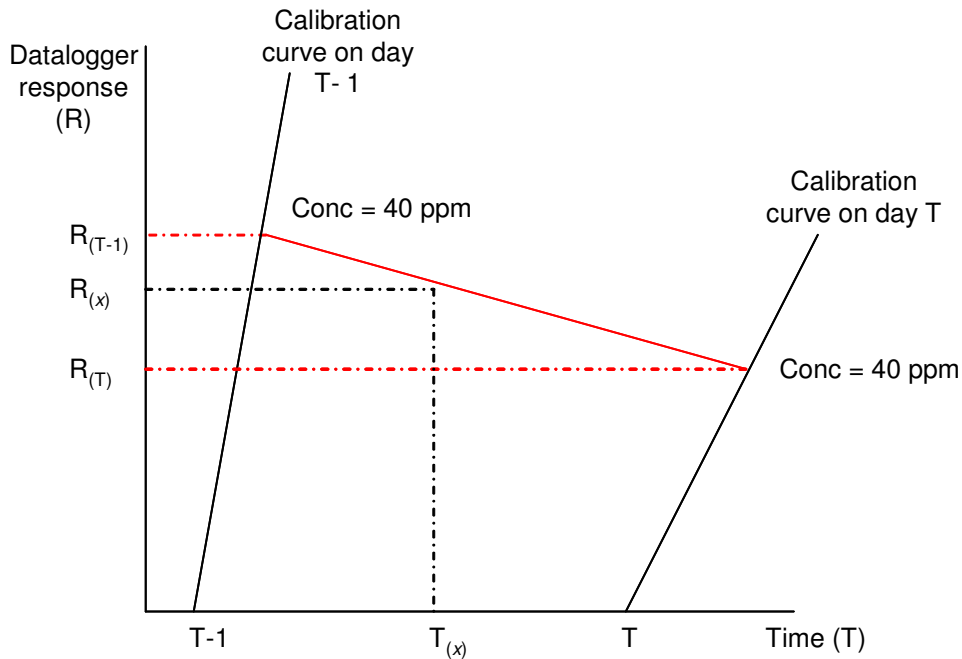
### 8.4.1 Applying manual check or calibration results

The use of the term ‘datalogger response curve’ in this section means the values recorded on an external datalogger or the instrument’s internal datalogger, whichever is used for the data processing.

A datalogger’s response curve relates the response of the datalogger to known concentration units of gas. It can be either linear or non-linear. The response of most analysers and dataloggers tends to drift with the passing of time. These two conditions must be addressed in the mechanism that is used to process the raw analyser readings into final concentration measurements. The theory behind this is discussed below.

The response curve is used to convert the datalogger readings to concentration values and is defined by an equation (if a linear equation is used, the slope and intercept are the important components). This curve is updated at each manual check or calibration. Both the unadjusted and adjusted response readings are required for each point on the curve. Each ambient concentration is calculated from individual slope and intercept values. This is determined by linear interpolation between the response curves of the most recent and first subsequent check, as shown in Figure 8.3.

**Figure 8.3: Response curves used to calculate actual concentrations from recorded instrument response  $R(x)$  at time  $T(x)$**



For a known concentration of 40 ppm, the datalogger will give a response of  $R(T-1)$  on the curve at time  $T-1$  and a response of  $R(T)$  from the curve at time  $T$ . Therefore, at time  $T(x)$  a concentration of 40 ppm will give a response of  $R(x)$  where:

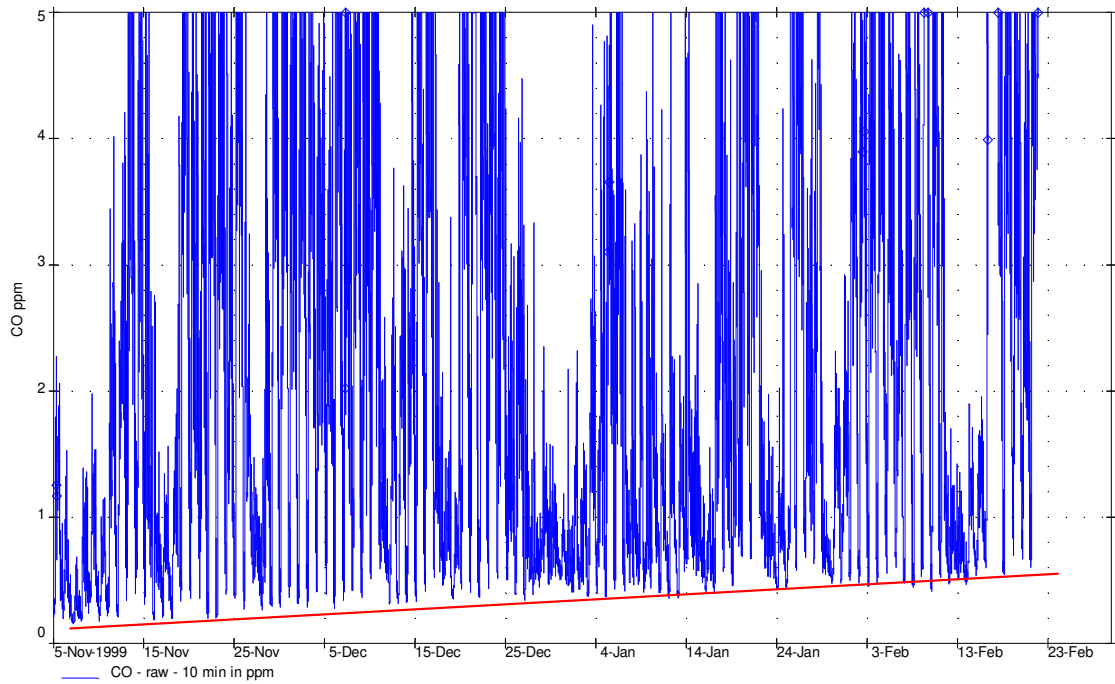
$$R(x) = \text{slope} \times \text{time}(x) + \text{intercept}.$$

A linear equation is required for all ambient concentrations. Many computer programmes will automatically calculate out the concentrations from the input of two response curves and take into account the time between the curves.

## 8.4.2 Changes in zero or span values

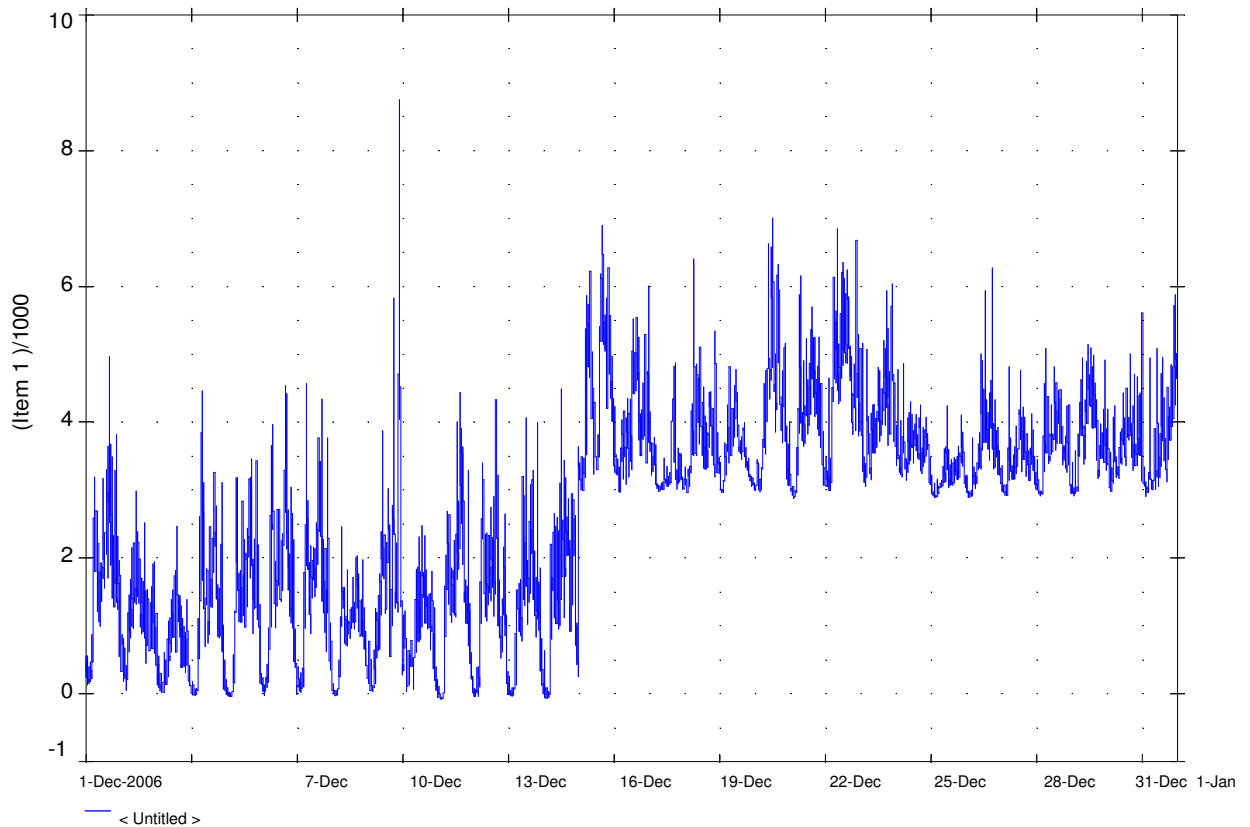
Changes to baselines and other concentrations which happen gradually, as in the example shown in Figure 8.4, can be resolved by applying the response curve to the raw data, as described in the previous section. This is usually known as a 'ramp correction'.

**Figure 8.4:** Example of baseline drift in CO data



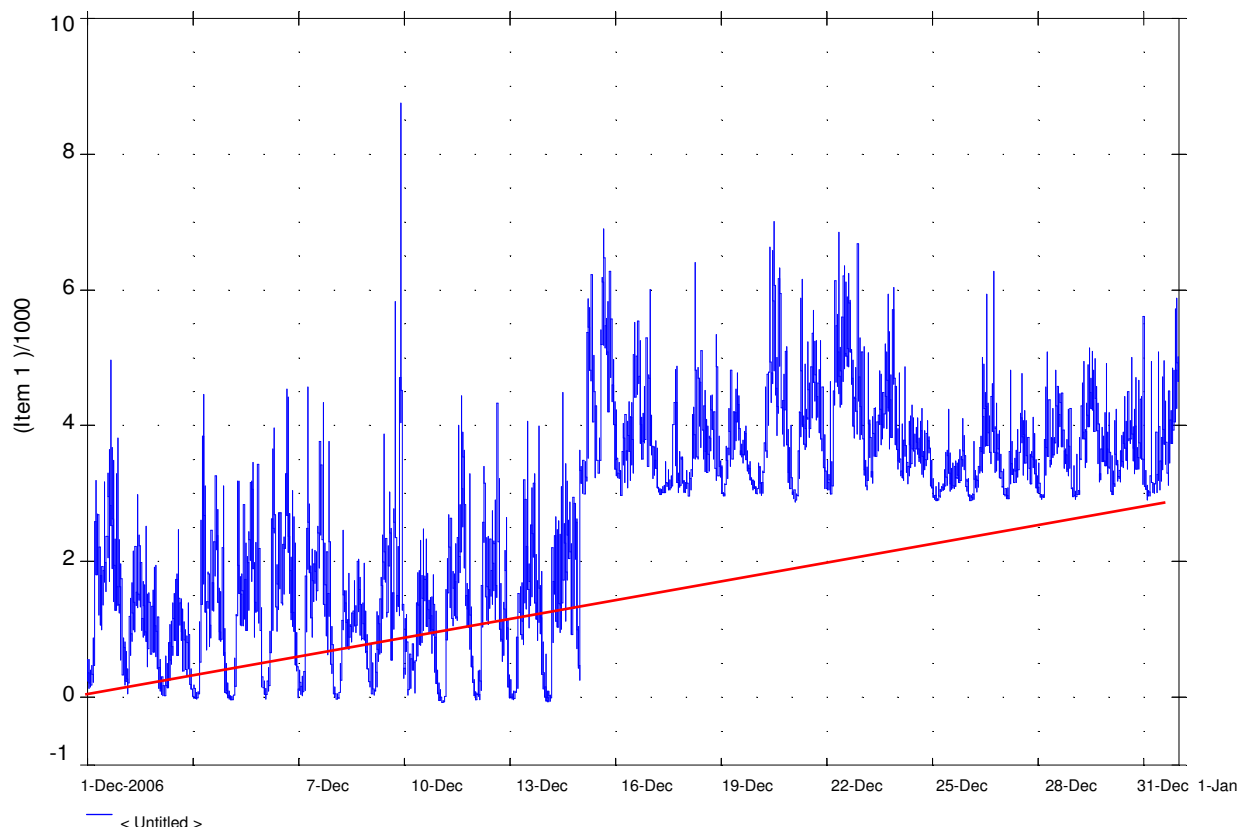
Another issue arises when there is a sudden baseline change, as shown in Figure 8.5.

**Figure 8.5:** Example of a sudden change in data baseline



In this instance, applying the ramping method discussed above would not be truly representative of the data. If we just looked at the zero values and assumed the manual check was done at the start and end of the graph (with zero being 0.2 on 1 December and 2.8 on 1 January), then a straight line between the two, as shown in Figure 8.6, would not be representative, as it is obvious something happened on the 15th to cause a change.

**Figure 8.6: Incorrectly applying a ramp correction**

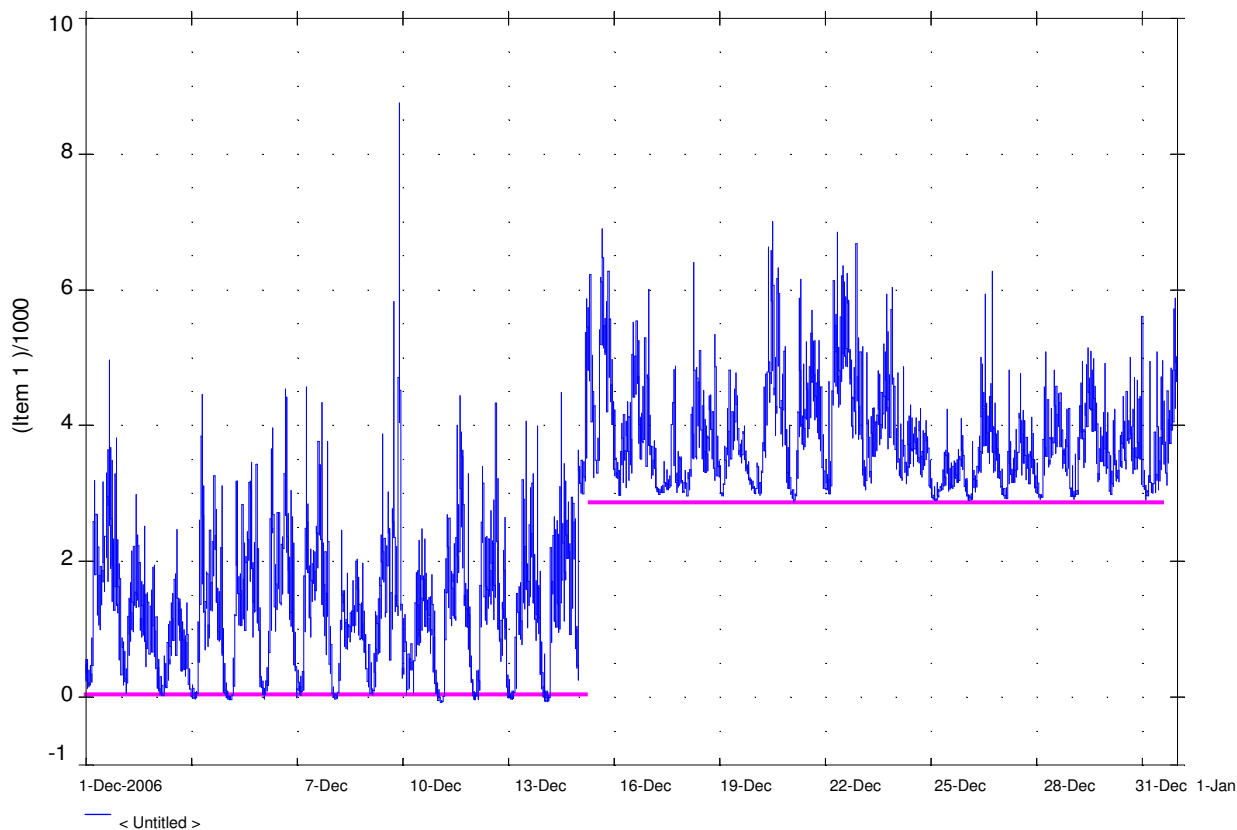


This example demonstrates the benefits of daily zero/span checks or similar, such as daily data checks. These checks would show that something had changed and prompt the technicians to physically visit the site to determine what this was. Some options to resolve this situation if regular checks are done include:

- removing all the data back to the last good zero/span check
- if the period is short enough, then extrapolation of the response curves may be possible, as shown in Figure 8.7
- lowering all the data to match the previous batch if zero and span check results indicate that this would be legitimate.



**Figure 8.7: Extrapolating a calibration**



In any of these situations, having a valid reason for data editing is essential before making any changes. The reasons for any changes made should be recorded with the data.

### 8.4.3 Data correction

Data correction is not always necessary. If it cannot be avoided, it is recommended that the following be considered before correcting data:

- the primary objective of the monitoring programme
- the reason(s) for making any correction
- the duration of the co-location data set and the strength of that relationship (minimum 12 months co-location)
- the complexity of the airshed (eg, emission sources)
- seasonality
- the co-location method (eg, hi-vol, TEOM, Partisol).

In any event, a copy of the raw data should be archived. Corrected data should also be clearly marked as such to inform data users.<sup>3</sup>

<sup>3</sup> Minutes from the Beta Attenuation Monitor Workshop, Hawke's Bay Regional Council, Napier, 17 March 2008.

### **Recommendation 22: Data adjustment**

Data quality assurance should be subsequent to multi-point calibrations for gases and done at least monthly given that the NES for air quality require public reporting of a breach within 30 days of its occurrence.

Applying the response curve to raw data can correct gradual changes to baselines but is not recommended when there is a sudden baseline change.

A minimum co-location period of one year is recommended before correcting data. A copy of raw data should be archived, and all corrected data should be marked to inform data users.

## **8.5 Data validation**

Data validation must be carried out at regular intervals (eg, three- or six-monthly) to ensure it is reliable and consistent. The data validation process involves a critical review of all information relating to a particular data set in order to verify, amend or reject the data, and forms the crux of the quality assurance process. A wide range of inputs need to be considered in the ratification process. When the data has been validated, it represents the final data set to be used in the review and assessment process. It is therefore important that the validation process be undertaken very carefully. Steps in the validation process include:

- examination of check and calibration records to ensure the correct application of check and calibration factors
- examination of data for other contaminants, meteorological data and other monitoring sites to highlight any anomalies
- deletion of data known to be spurious (eg, spikes generated by the analyser)
- removal of data collected during calibration and maintenance, including sufficient time for instrument stabilisation
- correction of any analyser / datalogger drift, as indicated by examination of zero and span check records.

Factors that need to be considered during data validation include:

- instrument history and characteristics – has the equipment malfunctioned in this way before?
- calibration factors and drift – rapid or excessive response drift can make data questionable
- negative or out-of-range data – is the data correctly scaled?
- rapid excursions or ‘spikes’ – are such sudden changes in pollution concentrations likely?
- the characteristics of the monitoring site – is the station near a local pollution sink or source that could give rise to these results?
- the effects of meteorology – are such measurements likely under these weather conditions?
- time of day and year – are such readings likely at this time of day/week/year?

- the relationship between different contaminants – some contaminant concentrations may rise and fall together (eg, from the ‘same source’)
- results from other sites in a network – these may indicate whether observations made at a particular site are exceptional or questionable
- occurrence of anomalous events such as bushfires, volcanic eruptions and fireworks displays during Chinese New Year and Guy Fawkes' night.

A robust understanding of air contaminant chemistry, air pollution meteorology, local emission sources and instrument calibration processes is required to provide good data validation.

## 8.6 Negative data

Every instrument has an uncertainty associated with each measurement. This is normally described as  $\pm$  a specific value (eg, the FH62 BAM is reported as being  $\pm 9 \text{ ug/m}^3$  at a 10-minute average concentration). This means that at very low ambient concentrations, it is conceivable that the FH62 BAM could report a result of  $-9 \text{ ug/m}^3$  as a 10-minute average. Likewise, most calibration and datalogging systems will also have an uncertainty measurement. It is necessary to calculate the total of all the uncertainties for the entire operation to determine what the overall uncertainty for the data is.

Because there is no such thing as negative  $\text{PM}_{10}$  (or a negative gas concentration for that matter), it can be very tempting to simply delete any result below zero. Unfortunately, removing all negative data from the data set (or replacing the negative data with zero) will artificially increase the ambient concentration, although the increase when averaged over 24 hours will normally be very minor. Instead of deleting negative data, it is recommended to leave negative data in the data set where such data is within the expected system uncertainty.

Occasionally, large negative spikes may occur due to instrumental error. These negative (and positive) spikes should be reviewed during the data analysis process to evaluate whether they are real or spurious. Unless there is good evidence to remove a value, it should be left in and a comment made in the metadata.

Inadequate or faulty heating of the inlet air on some particulate monitors (most commonly seen on BAMs) can allow moisture to affect the sample, giving rise to large positive spikes, normally followed by large negative spikes. In such cases, care should be taken not to remove the large negative spike and leave the corresponding positive spike, as this will artificially increase the resulting concentration. Instead, it is recommended that both spikes be removed as invalid data, the temperature sensors checked for faults, and the inlet temperature set to 40 degrees.

### Recommendation 23: Negative data

Negative and positive spikes should be reviewed during the data analysis process to evaluate whether they are real or spurious. Unless there is good evidence to remove a value, it should be left in and a comment made in the metadata.

Where negative values are within the expected error of the instrument, they should be retained within the data set to avoid creating a positive bias in the final result.

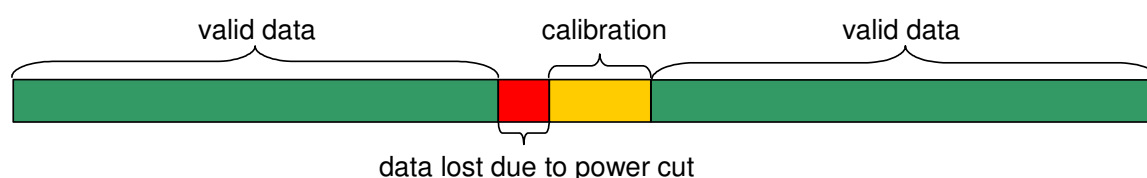
Where large negative spikes are observed in the data record from some particulate monitors, check to see whether a large positive spike is also present. If both a large positive and a large negative spike are present, then remove both spikes as invalid data and check the inlet temperature sensors for faults.

## 8.7 Missing data

No monitoring record is ever complete. There will inevitably be periods of missing data – some deliberate and necessary, such as calibration periods – but most unforeseen, such as equipment failures, power outages, bias and drifts. Even in the most diligently operated monitoring networks it is difficult to reach anything close to 100 per cent valid data for long-term monitoring.

Note that calculation of data capture normally excludes down time for routine calibrations and maintenance while the per cent valid data calculation includes this down time. Slight bias, drifts or calibration shifts can often be dealt with, but complete outages need special consideration.

The diagram below shows an example of a data capture rate and per cent valid data calculation.



24-hour average = 24 1-hour averages

If



power cut = 1 hour (1 1-hour average)

calibration = 2 hours (2 1-hour averages)

valid data points = 21 hours (21 1-hour averages)

then

per cent valid data for averaging =  $21/24 = 88\%$

data capture rate =  $21/24-2 = 95\%$

data loss =  $1/24 = 4\%$

Interpolation or extrapolation to fill in missing data should not be used in the process of producing a basic quality-assured data set, and the missing data should be left as a gap. If a gapless data set is required for a specific purpose (eg, dispersion modelling), then it should be constructed for that purpose alone using whatever interpolation or extrapolation is considered valid.

#### **Recommendation 24: Per cent valid data and data capture rate**

Sites used for compliance monitoring should achieve at least:

- 75% valid data for averaging
- 95% data capture.

Per cent valid data for averaging =  $\frac{\text{number of valid data points obtained}}{\text{total number of data points in the averaging period}}$

Data capture rate =  $\frac{\text{number of valid data points obtained}}{\text{total number of data points for the period} - \text{calibration/maintenance data points}}$

## **8.8 Monitoring site metadata**

Documented site metadata is necessary to interpret air quality monitoring results. This is because the interpretation of data from any air quality monitoring site needs to take into account the site situation and its implications. It is also useful to have a general description of the site characteristics and any local sources of air contamination.

Recommendation 25 lists the type of information that should be recorded about the site that can influence air quality and monitoring. These lists provide the minimum amount of information that should be recorded about a monitoring site. Information should be recorded either in hard copy or in a database.

**Recommendation 25: Site metadata**

Documented site metadata should be used when interpreting air quality monitoring results. Metadata should be recorded either in hard copy or in a database.

<b>Parameter</b>	<b>Explanation</b>
<b><i>Monitoring site metadata</i></b>	
Indicators/contaminants monitored	List all the contaminants that have been or are being monitored at the site
Site code	Site code specified by monitoring agency
Site title	Common name of site; eg, Taihape
Location	Street address of site
Region	For example, Southland region
Co-ordinates	New Zealand Mapping Series/Grid reference preferable (latitude and longitude optional)
Equipment owner's name/s	Name of party/ies who own the equipment at the site
Land owner's details	Name/s and contact information of land owner/s
Equipment housing	For example, shed, lab, air conditioning
Housing environment	For example, air conditioning at 25°C
Monitoring objectives	For example, to determine population exposure in high-density areas where air quality is suspected to be poor
Site topography	For example, there are hills 1 km to the southwest; to the north are high-rise commercial buildings
Location and description of major emission sources	This should include information on the nature, location and distance to predominant sources (eg, roads, factories, domestic fires)
Site category	See section 6.2
Scale of representation	See section 6.2
Site height above sea level	
Electrician and air conditioner service person contact details	
Photographs of the site	
<b><i>Meteorological site metadata</i></b>	
Meteorological variables measured	For example, wind speed, wind direction, temperature at height at which they are measured
Meteorological data operator	Person who operates the met station
Location of meteorological site	For example, on site up mast 6 m high, at the neighbouring airport
Meteorological data information	Where met data can be obtained (eg, met service, regional council)
Regional and local meteorological characteristics	A brief description of met conditions likely to affect air quality at the site (eg, inversions, prevailing wind direction)

<b>Contaminant metadata</b>	
Contaminant	For example, PM <sub>10</sub> , NO <sub>2</sub>
Data owner	Name of organisation that actually owns the data recorded by the equipment
Instrument/s	Name and any other details of the instrument/s (make, brand, serial number and model). If using more than one instrument, include both in this section
Period of operation	Dates when equipment was operated (eg, 12.3.2001 to 8.5.2003 or 11.3.2008 ongoing)
Method	Details of the standard method followed to operate the equipment (eg, USEPA or AS/NZS standard). Also, include details of any deviation from the standard method (eg, conditioning and weighing of filters)
Data logging	For example, remote via modem, or not used
Data storage	Describe how the data is stored by the data owner
Sampling period	How often the concentration is sampled and measured
Sampling probe height	Height of probe above ground
Calibration frequency	Summarised details of equipment calibration
Per cent valid data	Amount of data that has passed quality assurance checks (see Recommendation 24), recorded on a yearly basis (eg, 2005 – 95%; 2006 – 98%; 2007 – 96%)

Records (description, time and date) should also be kept of any unusual events that may affect air quality, such as scrub fires, power shortages (resulting in an increase in the use of domestic fires), weather extremes, volcanic eruptions, factory fires, roadworks, firework displays.

## 8.9 Monitoring units

It is often necessary to convert measurements between various units, and methods for carrying this out are discussed in the next section. However, such conversions depend on the temperature and pressure used. In some applications, the correct specification of an appropriate temperature and pressure is vital, particularly where compliance with guidelines or standards is being assessed. Ambient air quality guidelines and standards are specified at a wide range of temperatures for various historical reasons, and there is little consistency. Some of these are:

- NES for air quality – not specified
- AAQG – use 0°C
- Australian Environmental Protection Measures – use 0°C
- USEPA – uses 25°C
- conventional engineering practice (eg, American Society of Heating, Refrigerating and Air-Conditioning Engineers) – uses 0°C
- stack testing – often referenced at 0°C

- WHO – uses 0°C
- Organisation for Economic Co-operation and Development Indicators guidelines – specify 0°C (Ministry for the Environment, 2000).

For the purposes of monitoring and recording air quality data, it is recommended that the following units be used:

1. Gases may be recorded and archived as ppm or ppb, with conversion to  $\text{mg/m}^3$  or  $\mu\text{g/m}^3$  at 0°C for reporting purposes against standards or guidelines as necessary (see section 8.10 for a discussion of conversion factors).
2.  $\text{PM}_{10}$  should be recorded and archived as  $\mu\text{g/m}^3$  at 0°C.

Care should be taken to understand an instrument's data reporting software protocols and alter these as necessary. For example, monitoring instruments manufactured in the US are likely to have a default correction setting of 25°C if mass concentration units are used. Instrument output in ambient mass concentration units ( $\text{mg/m}^3$  or  $\mu\text{g/m}^3$ ) is usually calculated using internal pressure and temperature sensors. This can be avoided by the use of volume units (ppm and ppb) for gaseous contaminants where the volume ratio (volume contaminant/volume of air) is constant at all temperatures and pressures.

#### **Recommendation 26: Monitoring units**

The recommended units for recording and archiving the monitoring results of gases are parts per million (ppm) or parts per billion (ppb), with conversion to  $\text{mg/m}^3$  or  $\mu\text{g/m}^3$  at 0°C for reporting purposes.

$\text{PM}_{10}$  results should be recorded and archived as  $\mu\text{g/m}^3$  at 0°C.

## **8.10 Conversion factors**

Concentrations of air contaminants may be measured by volume or mass. Most analysers measure by volume. Volume measurements, such as parts per billion (ppb) or parts per million (ppm), are independent of temperature and pressure and are the recommended unit for recording and archiving gaseous air contaminant data. Concentrations by mass, such as  $\text{mg/m}^3$  or  $\mu\text{g/m}^3$ , refer to the weight of a gas or particulate contaminant in a cubic metre of dry air, and recorded values are dependent on ambient temperature and pressure at the time.



## 8.10.1 How mass occupies volume

The Ideal Gas equation is written as:

$$PV = nRT$$

where:

P = pressure (kPa)

V = volume (m<sup>3</sup>)

n = number of moles of gas

R = universal gas constant (8.3144 J/Kmol)

T = temperature Kelvin (K)

and:

$$n = m/Mr$$

where:

m = mass of gas (mg or µg – see later)

Mr = relative molecular mass (g/mol).

This gives:

$$PV = mRT/Mr$$

which can be rearranged to:

$$m/V \text{ (mg/m}^3 \text{ or } \mu\text{g/m}^3\text{)} = PMr/RT \text{ (ppm or ppb respectively).}$$

This allows you to take account of temperature, molecular mass and pressure. Pressure is usually taken as 101.325 kPa, as it does not markedly change the factor but may need to be considered at some elevated locations.

## 8.10.2 Conversion calculations

Mass per unit volume (mg/m<sup>3</sup> or µg/m<sup>3</sup>) is the unit required by the NES for air quality in reporting contaminant concentrations, and by the ambient air quality guidelines for recommended ambient concentrations.

Volume per unit volume (mass per unit mass) ppb is either ppbv or ppbm. If not stated, usually ppbv is used. Most instruments' output is in ppbv. For gaseous contaminants, the conversion between the ppb and µg/m<sup>3</sup> (or ppm and mg/m<sup>3</sup>) units depends on the molecular weight of the gas and temperature of the gas.

$$\begin{aligned}
1 \text{ ppb (vol) of contaminant} &= 1 \text{ litre of contaminant} / 10^9 \text{ litres of air} \\
&= \frac{1 \text{ litre} \times \text{MW} \times 10^9 \text{ } \mu\text{g/gm} \times 10^{-3}}{22.41 \times 10^9 \text{ litres} \times (T/273) \times 10^{-3} \text{ m}^3/\text{litre}} \\
&= \frac{\text{MW} \times 273}{22.41 \times T} \\
&= 0.0409 \times \text{MW } \mu\text{g/m}^3 \text{ (at } 25^\circ\text{C)} \\
&= 0.0416 \times \text{MW } \mu\text{g/m}^3 \text{ (at } 20^\circ\text{C)} \\
&= 0.0423 \times \text{MW } \mu\text{g/m}^3 \text{ (at } 15^\circ\text{C)} \\
&= 0.0431 \times \text{MW } \mu\text{g/m}^3 \text{ (at } 10^\circ\text{C)} \\
&= 0.0446 \times \text{MW } \mu\text{g/m}^3 \text{ (at } 0^\circ\text{C)}
\end{aligned}$$

Where MW is the molecular weight of the contaminant, 22.41 is the average molecular volume for dry air, and T the temperature of the gas in degrees Kelvin. This relationship falls down if there is significant moisture in the air. Also, only the most common isotopes are assumed.

#### **EXAMPLE – 10 ppb O<sub>3</sub>**

$$\begin{aligned}
\text{MW} &= 3 \times \text{O} = 3 \times 16 = 48 \\
\text{at } 0^\circ\text{C} &\text{ multiply by } 0.0446 \times 48 = 2.14 \\
\text{therefore } 10 \text{ ppb O}_3 &= 21.4 \text{ } \mu\text{g/m}^3.
\end{aligned}$$

#### **EXAMPLE – 20 ppb SO<sub>2</sub>**

$$\begin{aligned}
\text{MW} &= 1 \times \text{S} + 2 \times \text{O} = 32 + 2 \times 16 = 64 \\
\text{at } 0^\circ\text{C} &\text{ multiply by } 0.0446 \times 64 = 2.85 \\
\text{therefore } 20 \text{ ppb SO}_2 &= 57 \text{ } \mu\text{g/m}^3.
\end{aligned}$$

Note that these examples have taken a rounded-off figure for the molecular weights. Typically these are not integers, since the elements are made up of different isotopes with different atomic weights. In practice, this is a very small (typically less than 1 per cent) difference and can be omitted, given that the measurement uncertainties are almost certainly larger than this.

Appendix G shows the conversion factors for various gases and temperatures.

# 9 Reporting Monitoring Results

## 9.1 Time formats

In September (last Sunday of the month) each year, New Zealand switches to New Zealand Daylight Time, moving clocks forward one hour. This reverts to New Zealand Standard Time (NZST) in April (first Sunday of the month), when clocks move one hour back (Department of Internal Affairs, 2009).

For all air quality data, it is recommended that time and date always be reported in NZST. Converting to daylight time would upset the averaging processes. It is also recommended that the midnight hour be labelled as 24.00 instead of 00.00 to avoid time averaging issues.

### Recommendation 27: Time format

Times and dates should always be reported in New Zealand Standard Time.

Labelling of the midnight hour should be 24.00 instead of 00.00.

## 9.2 Reporting data formats

Instruments have different precision levels and those undertaking air quality monitoring use different instruments. This leads to inconsistencies in reporting data at the national level. To address this, it is recommended that a uniform format be used for reporting air quality data.

### Recommendation 28: Reporting data formats

It is recommended that data from all monitoring sites be reported in the following format:

Contaminant	Data format	Nominal precision
Carbon monoxide	X.X mg/m <sup>3</sup>	tenth of a mg/m <sup>3</sup>
Nitrogen dioxide	X.X µg/m <sup>3</sup>	tenth of a µg/m <sup>3</sup>
Ozone	X.X µg/m <sup>3</sup>	tenth of a µg/m <sup>3</sup>
Particulate matter (PM <sub>10</sub> )	XX µg/m <sup>3</sup>	a whole µg/m <sup>3</sup>
Sulphur dioxide	X.X µg/m <sup>3</sup>	tenth of a µg/m <sup>3</sup>
Lead	X.X µg/m <sup>3</sup>	tenth of a µg/m <sup>3</sup>

## 9.3 Significant digits and rounding protocols

Significant digits are specified in the recommended data format in section 9.2. As an example,  $PM_{10}$  should be reported as a whole number, while  $NO_2$  should be reported up to the first decimal place. If instrument precision is higher than the recommended data format, it would be necessary to round off to the significant digit when reporting results.

When the value following the significant digit is equal to or greater than 5, the digit should be rounded up; otherwise, the digit is retained (National Environment Protection Council, 2001).

Examples:

$PM_{10}$

49.9 is rounded-off to  $50 \mu\text{g}/\text{m}^3$

50.3 is rounded-off to  $50 \mu\text{g}/\text{m}^3$

50.5 is rounded-off to  $51 \mu\text{g}/\text{m}^3$

50.7 is rounded-off to  $51 \mu\text{g}/\text{m}^3$

$NO_2$

199.99 is rounded-off to  $200.0 \mu\text{g}/\text{m}^3$

200.04 is rounded-off to  $200.0 \mu\text{g}/\text{m}^3$

200.05 is rounded-off to  $200.1 \mu\text{g}/\text{m}^3$

200.08 is rounded-off to  $200.1 \mu\text{g}/\text{m}^3$

The recommended data format in section 9.2, and the rounding-off protocols above also provide guidance for the reporting of all exceedences. For all monitoring sites, an exceedence occurs when the reported concentration is above the standard, after rounding to the significant digit (see Recommendation 28). For example, a  $PM_{10}$  exceedence is counted once a concentration of  $50.5 \mu\text{g}/\text{m}^3$  is obtained.

### **Recommendation 29: Significant digits and rounding-off protocols**

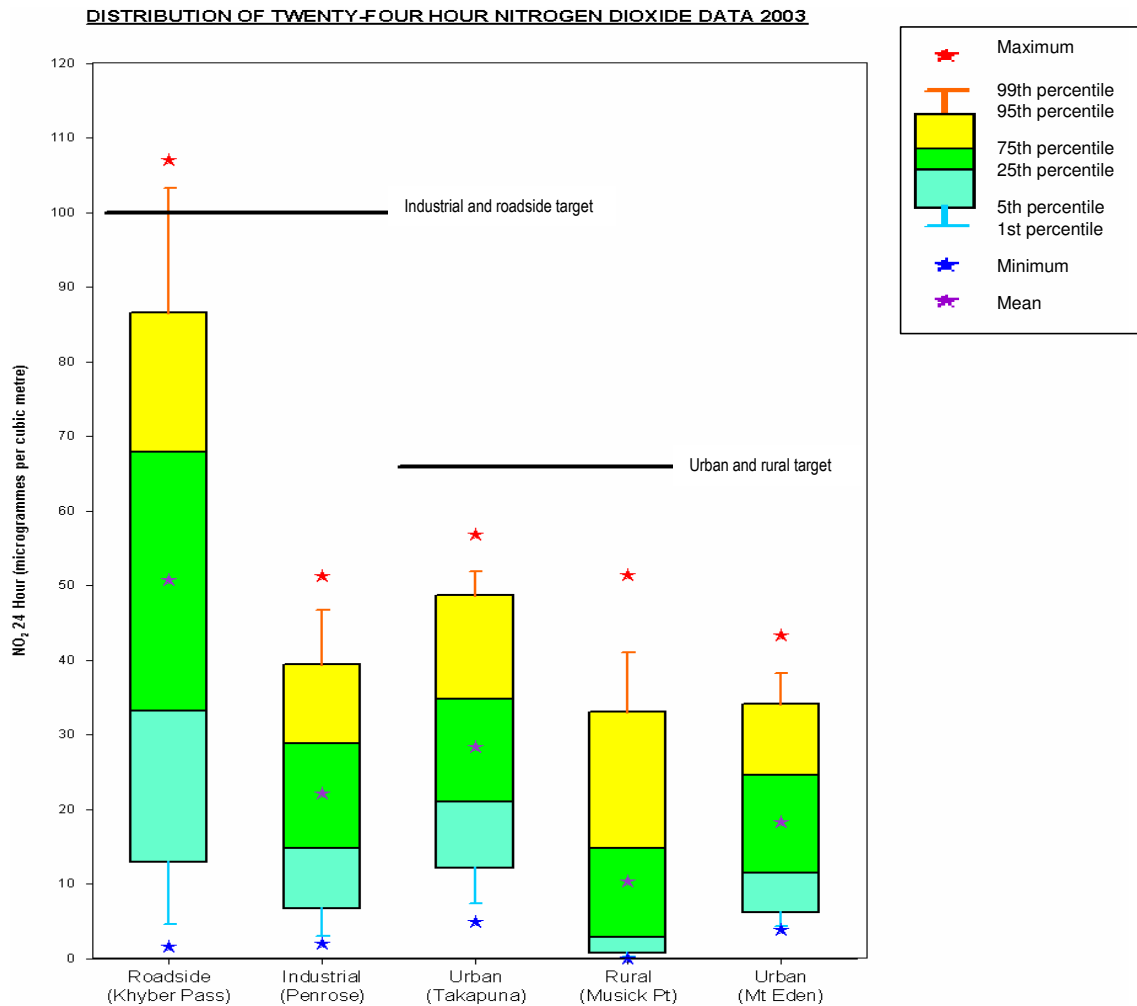
The recommended data format in section 9.2 specifies the significant digits for the reporting of a contaminant.

When the value following the significant digit is equal to or greater than five, the digit should be rounded up; otherwise, the digit is retained.

For all monitoring sites, an exceedence occurs when the reported concentration is above the standard, after rounding to the significant digit.

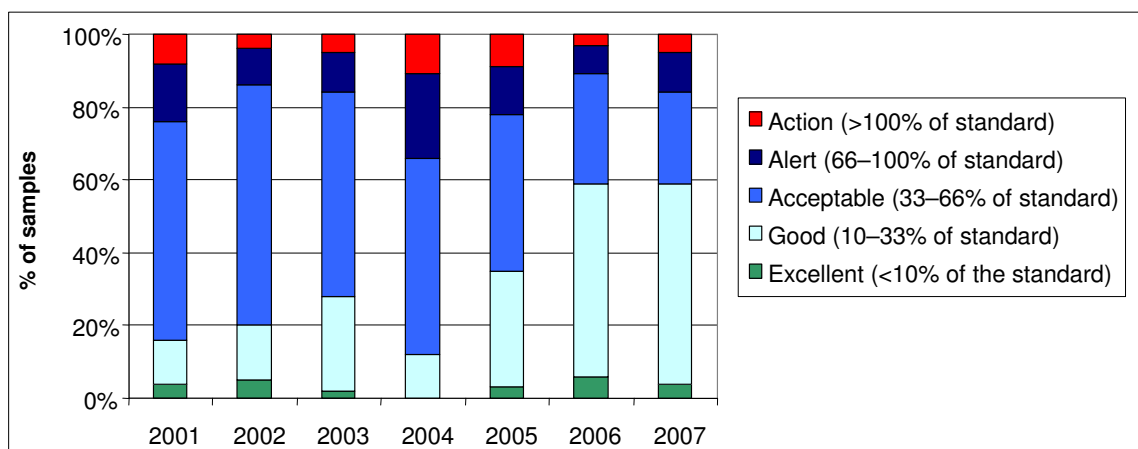


**Figure 9.1: Example of box plot showing contaminant distribution at different monitoring sites**



Source: Auckland Regional Council.

**Figure 9.2: Example of figure showing the proportion of PM<sub>10</sub> samples belonging to different air quality categories**



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# Appendix A: Time Averages (NES for Air Quality, Schedule 1)

## **1-hour mean**

- a) a mean calculated every hour on the hour for the preceding hour; and
- b) in relation to a contaminant at a particular location for a particular hour, means the mean of not more than 10-minute means, collected not less than once every 10 seconds, for the contaminant at that location during that hour

## **24-hour mean**

- a) a mean calculated every 24 hours at midnight for the preceding 24 hours; and
- b) in relation to a contaminant at a particular location for a particular 24-hour period, means
  - i) the mean level at which the contaminant is recorded in the air, by continuous sampling of the air at that location, throughout that 24-hour period; or
  - ii) the mean of the 1-hour means for that contaminant at that location for the preceding 24 hours

## **running 8-hour mean**

- a) a mean calculated every hour on the hour for that hour and the preceding 7 hours to give 1 running 8-hour mean per hour; and
- b) in relation to a contaminant at a particular location for a particular hour, means the mean of the 1-hour means for that contaminant at that location for that hour and the preceding 7 hours.

# Appendix B: Wind Speed Conversions and Presentation of Wind Speed Data

## Wind speed conversions

1 knot	=	1.000 knot	=	0.514 m/s	=	1.853 km/hr	=	1.151 mph
1 m/s	=	1.944 knot	=	1.000 m/s	=	3.600 km/hr	=	2.236 mph
1 km/hr	=	0.540 knot	=	0.278 m/s	=	1.000 km/hr	=	0.621 mph
1 mph	=	0.869 knot	=	0.447 m/s	=	1.610 km/hr	=	1.000 mph

# Appendix C: Sample Filter Characteristics and Applications

Type	Characteristics	Application
Glass-fibre	High flow rates, high efficiencies, low pressure drops, high solids capacity, good wet strength. Can withstand very high temperatures. Fragile: care must be taken in handling for gravimetric work. Levels of background contaminants vary according to grade/type. Relatively inexpensive.	Gravimetric measurements, particularly with high-flow samplers. Binder-free glass-fibre filters used for sampling and analysis of organics (eg, polycyclic aromatic hydrocarbons (PAHs)). Grades with low acid-soluble contaminant levels used if metals analysis required. Quartz type used for sulphate or nitrate analysis.
Mixed cellulose ester, cellulose nitrate or cellulose acetate	Low levels of metal contaminants. Easily oxidised and destroyed during extraction and digestion. Can be cleared for optical microscopy examination. Susceptible to moisture. Relatively inexpensive.	Chemical analysis of metal content of particulates by atomic absorption spectroscopy, auger emission spectroscopy, fluorescence, infrared and X-ray diffraction analysis. Determination of airborne fibre (eg, asbestos) concentrations.
Polyvinyl chloride	Low moisture pick-up. Resistant to concentrated acids and alkalis.	Gravimetric analysis. Sampling of particulates for analysis of silica, quartz, carbon black.
Polytetrafluoroethylene	Naturally hydrophobic but some grades treated to render hydrophilic. Relatively inert and unreactive. Resistant to most chemicals, including high-performance liquid chromatography (HPLC) solvents. Expensive.	Sampling of particulates for ultraviolet or HPLC analysis. Sampling of PAHs.
Nylon	Resistant to many chemicals, including organic solvents. Flexible, durable and tear-resistant.	Sampling of gaseous species (eg, hydrogen chloride).
Silver membrane	High collection efficiency, uniform pore size. Expensive.	Sampling of crystalline substances for analysis by X-ray diffraction. Sampling of gaseous species (eg, halogens).
Cellulose	High flow rates, low pressure drops, collection efficiencies of some grades poor. Low impurity levels. Ashless grades available. Cheap.	Ashing of samples to determine organic content. Washing of samples on filter to determine water-soluble component.
Polycarbonate	Some grades virtually transparent: no clearing necessary for optical microscopy. Non-hygroscopic: equilibrium with water vapour not necessary before weighing. Resistant to many solvents. Low ash content.	Sampling of particulates. Examination by optical microscopy. Ashing of samples to determine organic content.

# Appendix D: Particulate Monitoring Instruments Commonly Used in New Zealand

Instrument	Sampling	Features
Beta attenuation monitor (BAM)	Sampler fitted with PM <sub>10</sub> or PM <sub>2.5</sub> selective inlet. Some instruments fitted with dichotomous sampler to allow simultaneous monitoring of PM <sub>10</sub> and PM <sub>2.5</sub> . Air is passed through the paper tape for a fixed time (a few minutes to 24 hours).	Absorbance of β-radiation by particles on paper tape. Instrument calibrated to give direct reading of the particle mass concentration in µg/m <sup>3</sup> . Automated method. Continuous monitor suitable for unattended operation. Accuracy of measurements depends on geometry of the measuring head, strength of the beta source, and uniformity of thickness of the filter tape.
Tapered element oscillating microbalance (TEOM)	Ambient air (heated to 40–50 °C to prevent condensation) is drawn onto a filter through a standard PM <sub>10</sub> sampling head. The filter is attached to the top of a vibrating, tapered glass tube. If required, the PM <sub>10</sub> sampling head can be replaced with either a PM <sub>2.5</sub> or PM <sub>1</sub> head.	Particles collected on the surface of the filter reduce the frequency of oscillation. Instrumental measurements of frequency are converted to mass. May be supplemented with a filter cartridge collection unit if subsequent chemical analysis required. The measurements are made sequentially, giving continuous data. Measurements are usually made over a sampling average period of 15 minutes. Some semi-volatile particulates could be lost at the operating temperature. Relatively expensive. Main applications in well-funded and long-term air quality monitoring networks.
Partisol	Sequential air sampler that could monitor different particle size fractions. A built-in pump draws ambient air through the sample inlet. The air passes through the filter for a specified period. Filters are automatically changed and stored.	Gravimetric determination: the mass of particles collected is determined by the difference between the weight of the filter before and after exposure. Filter cassettes can hold up to 16 filters. Continuous and unattended monitoring can be done for a period of up to two weeks. Has an RS232 interface for data retrieval and remote operation.
Hi-vol	Hi-vol sampler fitted with size-selective inlet. Multi-stage cascade impactor inlets can also be used to determine the full particle-size distribution.	Gravimetric determination: the mass of particles collected is determined by the difference between the weight of the filter before and after exposure. Membrane or glass fibre filters can be used depending on whether gravimetry alone or further analysis is required. Continuous monitoring is possible but compliance monitoring requirements (changing of filters at midnight) may present operational difficulties. Some samplers can be connected to a datalogger and programmed to start/stop under specific wind directions and/or speeds. Many can be configured for either PM <sub>2.5</sub> or PM <sub>10</sub> fractions by changing the inlet head.
Light scattering method: optical particle counters	Technique requires an appropriate flow rate to avoid erroneously low results. Most instruments operate at about 1 L/min. Examples are Casella APM950 Ambient Particulate Monitor, SKC Ltd Haz-Dust II and Grimm GmbH Series 1.200 Ambient Particle Size Dust Monitor.	Light striking a particle within the measurement cell is scattered. The photomultiplier tube output is proportional to the size of the particle; also affected by shape, colour and the refractive index of the particle. Results obtained relate only to equivalent polystyrene spheres (used for calibration) giving the same magnitude of light pulses and should be referred to as equivalent optical particle sizes rather than true particle sizes. Some operate using infrared light or laser light.

# Appendix E: Examples of Routine Check-sheets for a BAM Instrument and a CO Analyser

FH62 C14 Particulate Monitor Check-sheet				
Instrument serial number:				
Site name:				
Grid reference:				
Date installed:				
<b>Indicate value or short comment as items are completed.</b>				
Date				
Person's initial				
Instrument date				
Instrument time				
Status				
Error				
PM concentr (0–5000 ug/m <sup>3</sup> )				
PM concentr (0–5000 ug/m <sup>3</sup> )				
Mass µg				
<b>Air flow</b>				
Air flow (1000 ± 10 L/hr)				
Vol head (1000 ± 10 L/hr)				
Norm 273K (1000 ± 10 NL/hr)				
<b>Mean values in µg/m<sup>3</sup></b>				
½ hr				
1 hr				
3 hr				
24 hr				
<b>Radon content</b>				
Concentr: Bq/m <sup>3</sup>				
Natural activity Bq				
Status				
	stabilisation		plateau-shift	
Error status	0000 0000	0000 0000	0000 0000	0000 0000
	0000 0000	0000 0000	0000 4000	0000 0000

<b>Error status messages</b>				
	0000 0000	0000 0000	0000 0000	0000 0000
	0000 2000	0000 2000	0000 4000	0000 4000
<b>Temperatures status</b>				
T1 (ambient temperature)				
T2 (dust chamber temperature)				
T3 (filter temperature)				
T4 (sample tube temperature)				
P1 (differential pressure)				
P2 (low pressure suction chamber)				
P3 (ambient pressure)				
Q1 (air flow rate at pm10 hd)				
<b>Air flow status</b>				
REG %				
NOM				
ACT				
<b>General checks</b>				
Pump checked				
Tubings checked				
Filter tape checked				
Calibration				
<b>NOTES</b>				
	Readings after	Readings before	Readings after	Readings before
	foil cal	foil cal checks	foil cal checks	annual service

# API M300 CO ANALYSER CHECK SHEET (E Series)



Analysers S/N: \_\_\_\_\_ Site: \_\_\_\_\_ Project No: \_\_\_\_\_

All boxes MUST be completed (except where no Analyser Warning Messages Occur)

Date	Expected range/units			
Time	NZST			
Technician	Name			
<b>DATALOGGER CHECKS</b>				
Logger Response (responding OK?)				
Logger Time (from computer)	NZST			
Adjusted Time (if applicable)	NZST			
<b>M300 ANALYSER CHECKS</b>				
<b>Analysers Test Menu</b>				
Time	NZST			
Range	ppm			
Stability	ppm			
CO Meas	3200 – 4700 mV			
CO Ref	3200 – 4700 mV			
MR Ratio	1.15 – 1.225			
Pressure	28 – 30 in-Hg-A			
Sample Flow	720 - 880 cc/min			
Sample Temp	46 – 50 °C			
Bench Temp	47 – 49 °C			
Wheel Temp	67 – 69 °C			
Box Temp	~10°C above ambient			
PHT Drive	2400 – 2600 m			
Slpe	0.65 – 1.5			
Offs	0.03 – 0.1			
<b>Analysers Warning Messages</b>				
<b>GENERAL CHECKS</b>				
Data File ID (if manual download)				
Ambient CO	Analysers / logger			
Room Temperature (from temp. probe)	°C			
Calibration Type	Weekly or check or adjust			
Linearity Calibration	y/n			
Sample Filter Replaced	y/n			
Check Sample Tube				
<b>REMARKS</b>				

# Appendix F: Example of a Maintenance and Calibration Record for an FH62 Instrument

FH62 C14 PM <sub>10</sub> ANALYSER MAINTENANCE RECORD					
Site name:			Performed by		
Instrument make / model:		Ref no:	Date		
Instrument serial number:			Time (NZST)		
Date installed:			Person's initial		
Maintenance / Calibration Overview					
<b>Maintenance type</b>	2-monthly	6-monthly	Annually	Repair	Other
<b>Completed?</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
MAINTENANCE AND CALIBRATION					
<b>2-monthly</b>				<b>DUE</b>	<b>DONE</b>
<b>Task</b>	<b>Action</b>	<b>Value / Limit</b>	<b>Performed?</b>	<b>Pass</b>	<b>Fail</b>
PM 10 head cleaning	Cleaning	Dust free			
<b>3-monthly</b>				<b>DUE</b>	<b>DONE</b>
<b>Task</b>	<b>Action</b>	<b>Value / Limit</b>	<b>Performed?</b>	<b>Pass</b>	<b>Fail</b>
Complete 2-monthly	Completed				
Check filter tape	Check	Position/length			
Particle mass check	check	± 5%			
Check air flow rate	Check	1000 + 60 L/hr			
<b>6-monthly</b>				<b>DUE</b>	<b>DONE</b>
<b>Task</b>	<b>Action</b>	<b>Value / Limit</b>	<b>Performed?</b>	<b>Pass</b>	<b>Fail</b>
Complete 3-monthly	Completed				
Pump carbon filter	Cleaning	Dust free			
Check filter tape	Check	Position/length			
Check air flow	Check	1000 + 60 L/hr			
<b>Yearly</b>				<b>DUE</b>	<b>DONE</b>



TEST AND CALIBRATION	Action	Value / Limit	Performed?	Pass	Fail
<b>Complete 6-monthly</b>	Completed				
<b>Mass calibration</b>	Foil set #				
Zero	Offset %				
Span	Count rate				
	Span value				
	Mass value				
Amplification	Old				
	New				
	New value?				
<b>Air flow calibration</b>	Flow meter #	deltaCal #			
Measured flow rate	L / h				
Reference flow rate	L / min				
(l/min x 60 min)	L /h	0			
Air flow calibration	Adjusted				
<b>Temperatures</b>	Temp meter #	deltaCal #			
<b>T1</b> Ambient temperature (T room $\pm$ 1 °C)	Reference reading				
	BAM reading				
	Adjusted ?				
<b>T2</b> Temperature over filter tape (T room $\pm$ 1 °C)	Reference reading				
	BAM reading				
	Adjusted?				
<b>T3</b> Temperature under filter tape (T room $\pm$ 1 °C)	Reference reading				
	BAM reading				
	Adjusted?				
<b>T4</b> Temperature of the tube heater (T room $\pm$ 1 °C)	Reference reading				
	BAM reading				
	Adjusted?				

<b>PRESSURES</b>	Pres meter #				
<b>P1</b> Differential pressure _orifice (± 2 kPa)	Reference reading_Zero				
	BAM reading_Zero				
	Calibrated?				
	Reference reading_Span				
	BAM reading_Span				
	Calibrated?				
<b>P2</b> Pressure under filter (± 2 kPa)	Pres meter #				
	Reference reading_Zero				
	BAM reading_Zero				
	Calibrated?				
	Reference reading_Span				
	BAM reading_Span				
<b>P3</b> Barometric pressure (± 2 kPa)	Pres meter #				
	Reference reading				
	BAM reading				
	Adjusted?				
<b>Zero check</b>	24 ± 2 h with zero	< 2 µg			
(< 2 µg)	Particle filter				
Pump carbon vanes	Replace				
Dust/air passage	Cleaning				
Particulate filter tape	Replace				
Measurement chamber	Cleaning				
Repair	<b>STATUS</b>	<b>ACTION</b>		<b>DONE</b>	
<b>NOTES</b>					

# Appendix G: Quick Reference Conversion Tables

To convert ppb to  $\mu\text{g}/\text{m}^3$ , multiply by:

Contaminant	Symbol	Molecular weight	0°C	10°C	15°C	20°C	25°C
Sulphur dioxide	SO <sub>2</sub>	64	2.85	2.76	2.71	2.66	2.62
Nitric oxide	NO	30	1.34	1.29	1.27	1.25	1.23
Nitrogen dioxide	NO <sub>2</sub>	46	2.05	1.98	1.95	1.91	1.88
NOx (90:10 ratio)	NOx	31.6	1.41	1.36	1.34	1.31	1.29
Ozone	O <sub>3</sub>	48	2.14	2.07	2.03	2.00	1.96
Carbon monoxide	CO	28	1.25	1.21	1.18	1.16	1.15
Carbon dioxide	CO <sub>2</sub>	44	1.96	1.90	1.86	1.83	1.80
Hydrogen sulphide	H <sub>2</sub> S	34	1.52	1.47	1.44	1.41	1.39
Methane	CH <sub>4</sub>	16	0.714	0.690	0.677	0.666	0.654
*NMHC (light)	C <sub>6</sub>	72	3.21	3.10	3.05	3.00	2.94
*NMHC (heavy)	C <sub>12</sub>	144	6.42	6.21	6.09	6.00	5.89

\* Non-methane hydrocarbon

To convert  $\mu\text{g}/\text{m}^3$  to ppb, multiply by:

Contaminant	Symbol	Molecular weight	0°C	10°C	15°C	20°C	25°C
Sulphur dioxide	SO <sub>2</sub>	64	0.350	0.363	0.369	0.376	0.382
Nitric oxide	NO	30	0.747	0.773	0.788	0.801	0.813
Nitrogen dioxide	NO <sub>2</sub>	46	0.487	0.504	0.514	0.523	0.532
NOx (90:10 ratio)	NOx	31.6	0.710	0.734	0.748	0.761	0.775
Ozone	O <sub>3</sub>	48	0.467	0.484	0.493	0.501	0.510
Carbon monoxide	CO	28	0.801	0.829	0.844	0.859	0.870
Carbon dioxide	CO <sub>2</sub>	44	0.510	0.527	0.537	0.546	0.555
Hydrogen sulphide	H <sub>2</sub> S	34	0.659	0.682	0.700	0.707	0.719
Methane	CH <sub>4</sub>	16	1.401	1.950	1.478	1.502	1.529
*NMHC (light)	C <sub>6</sub>	72	0.311	0.322	0.328	0.334	0.340
*NMHC (heavy)	C <sub>12</sub>	144	0.156	0.161	0.164	0.167	0.170

\* Non-methane hydrocarbon

# Appendix H: Summary of Recommendations

Number	Recommendation
1	<p><b>Screening methods</b></p> <p>Screening methods cannot be used to determine compliance with the NES for air quality or to establish whether an airshed meets the ambient air quality guidelines. They may, however, be used to provide indicative data for other monitoring purposes.</p> <p>A screening method's level of accuracy and precision must be suitable for the purpose of monitoring (eg, occupational health and safety equipment is not suitable for ambient air quality monitoring).</p>
2	<p><b>Hydrogen sulphide</b></p> <p>The recommended method for hydrogen sulphide is fluorescence monitoring, in accordance with <b>AS3580.4.1-2008, Methods of sampling and analysis of ambient air – Determination of sulphur dioxide – Direct reading instrumental method.</b></p>
3	<p><b>Lead content of PM<sub>10</sub></b></p> <p>The recommended method for lead content of PM<sub>10</sub> is high-volume gravimetric sampling in accordance with <b>United States Code of Federal Regulations, Title 40 – Protection of Environment, Volume 2, Part 50, Appendix J and Appendix G.</b></p>
4	<p><b>Benzene and 1,3-butadiene</b></p> <p>The recommended methods for benzene and 1,3-butadiene are:</p> <p><b>USEPA method TO-1</b> – Method for the determination of VOCs in ambient air using Tenax<sup>®</sup> adsorption and gas chromatography / mass spectrometry (GC/MS)</p> <p><b>USEPA method TO-14A</b> – Determination of VOCs in air using specially prepared canisters with subsequent analysis by gas chromatography</p> <p><b>USEPA method TO-15</b> – Determination of VOCs in air collected in specially prepared canisters and analysed by gas chromatography / mass spectrometry (GC/MS)</p> <p><b>USEPA method TO-17</b> – Determination of VOCs in air using active sampling onto sorbent tubes</p> <p><b>BS EN 14662-1:2005</b> – Ambient air quality – Standard method for measurement of benzene concentrations – Pumped sampling followed by thermal desorption and gas chromatography</p> <p><b>BS EN 14662-2:2005</b> – Ambient air quality – Standard method for measurement of benzene concentrations – Pumped sampling followed by solvent desorption and gas chromatography</p> <p><b>BS EN 14662-3:2005</b> – Ambient air quality – Standard method for measurement of benzene concentrations – Automated pumped sampling with in situ gas chromatography</p> <p><b>BS EN 14662-4:2005</b> – Ambient air quality – Standard method for measurement of benzene concentrations – Diffusive sampling followed by thermal desorption and gas chromatography</p> <p><b>BS EN 14662-5:2005</b> – Ambient air quality – Standard method for measurement of benzene concentrations – Diffusive sampling followed by solvent desorption and gas chromatography.</p>
5	<p><b>Formaldehyde and acetaldehyde</b></p> <p>The recommended method for formaldehyde and acetaldehyde is <b>USEPA method TO-11A</b> – Determination of formaldehyde in ambient air using adsorbent cartridge followed by high performance liquid chromatography (HPLC).</p>
6	<p><b>Benzo(a)pyrene</b></p> <p>The recommended methods for BaP are:</p> <p><b>USEPA method TO-13A</b> – Determination of polycyclic aromatic hydrocarbons (PAHs) in ambient air using gas chromatography / mass spectrometry (GC/MS)</p> <p><b>BS EN 15549:2008</b> – Air quality – Standard method for the measurement of the concentration of benzo(a)pyrene in ambient air.</p>

Number	Recommendation
7	<p><b>Mercury, chromium and arsenic</b></p> <p>The recommended method for mercury, chromium and arsenic is:</p> <p>PM<sub>10</sub> sampling in accordance with <b>40CFR Part 50, Appendix J</b>, followed by analysis using atomic absorption spectroscopy or an equivalent method.</p> <p>For mercury:</p> <p><b>Method IO-5</b> (<i>Sampling and analysis for vapour and particle phase mercury in ambient air utilising cold vapour atomic fluorescence spectrophotometry</i>)</p> <p><b>BS EN 15852</b> – Ambient air quality – <i>Standard method for the determination of total gaseous mercury.</i></p>
8	<p><b>Meteorological monitoring</b></p> <p>The minimum monitoring required is as follows:</p> <ul style="list-style-type: none"> <li>• mast, 6 m minimum, 10 m preferable</li> <li>• wind speed (resolution 0.1 m/s accuracy ± 0.2 m/s, start-up 0.2 m/s)</li> <li>• wind direction (resolution 1°, accuracy ± 2°, referenced to true north)</li> <li>• air temperature (resolution 0.1°C, accuracy 0.2°C)</li> <li>• automated logging system, reliable power, with battery back-up.</li> </ul> <p>The use of the Cartesian coordinate system is recommended, whereby data is converted to its x and y components. This data can then be accumulated in a vector form. This solves averaging and unweighted direction problems. Results may subsequently be converted to polar coordinates, if required.</p> <p>Desirable measurements are:</p> <ul style="list-style-type: none"> <li>• humidity (or dew point) (resolution 1% relative humidity (rh), accuracy ± 5% rh)</li> <li>• solar radiation (for stability estimates) (resolution 1 W/m<sup>2</sup>, accuracy 10 W/m<sup>2</sup>)</li> <li>• rainfall (resolution 1 mm)</li> <li>• temperature profile (T at two heights – 1.5 m and 10 m, needs 0.1°C accuracy) using identical sensors at both heights.</li> </ul> <p>Specific siting requirements:</p> <p>Must be free of influence of trees, buildings, structures – should be at least two times the height away from the obstacle, and for wind sensors it should be at least 10 times the height away from obstacles (refer to Part I, sections 5.9.2 and 6.2 of the <i>Guide to Meteorological Instruments and Methods of Observation</i> (World Meteorological Organization, 1996; Oke TR, 2006).</p> <p>Required time resolution:</p> <ul style="list-style-type: none"> <li>• data should be collected at the same minimum time resolution as air quality data</li> <li>• resolution should be at least hourly.</li> </ul> <p>Period of monitoring:</p> <p>For atmospheric modelling and trend analysis, a minimum of one year's data is recommended.</p>
9	<p><b>Independent accreditation</b></p> <p>Accreditation of agencies/firms undertaking air quality monitoring by an independent and approved accreditation organisation is strongly recommended.</p>
10	<p><b>Operation of a beta attenuation monitor</b></p> <ul style="list-style-type: none"> <li>• Enclosure temperatures should be maintained at 25°C ± 3°C to avoid moisture collecting on filter paper.</li> <li>• Regular maintenance in accordance with the operation manual is critical. Irregular and/or inadequate maintenance can result in up to 20 per cent variation.</li> <li>• The sample heater should be switched off for at least one hour before calibration.</li> <li>• The condition of the radioactive source should be checked twice a year (R2 count). It may be necessary to adjust after two to three years due to decay in the radioactive source.</li> <li>• Inlet temperature should be set to 40°C.</li> <li>• Equipment should be maintained in accordance with operation manual (refer also to AS/NZS 3580.9.11:2008).</li> <li>• Data correction to gravimetric equivalent is <i>not</i> generally recommended.</li> <li>• Where possible, humidity should be logged along with appropriate meteorological data.</li> </ul>
11	<p><b>Operation of a tapered element oscillating microbalance (TEOM)</b></p> <p>It is recommended that TEOMs be fitted with a filter dynamics measurement system (FDMS) when monitoring for national standards.</p> <p>Alternatively, TEOMs can be used without the FDMS by using a correction factor that is determined by co-locating the TEOM with a gravimetric monitor for at least one year.</p>

Number	Recommendation
12	<p><b>The importance of filter conditioning</b></p> <p>Manual methods for particulate monitoring are all based on weighing material collected on a filter. It is therefore important to recognise that the pre- and post-conditioning of the filter and the filter weighing techniques are just as important as the selection and use of the sampling equipment.</p> <p>Most filters will absorb moisture from the atmosphere, so filter weight will vary in accordance with the surrounding humidity. Particulate matter collected on the filters will also behave in the same way. It is therefore essential that the filters be carefully conditioned and weighed under conditions of constant temperature and humidity, both before and after sampling.</p> <p>Detailed procedures for filter handling, conditioning and weighing are given in the relevant standard method specifications. For example, the USEPA recommends that filters be conditioned for at least 24 hours at a humidity between 20 to 45%, <math>\pm 5\%</math>, and a temperature of 15 to 30°C, <math>\pm 3^\circ\text{C}</math> (40 CFR Part 50, Appendix J).</p>
13	<p><b>Representativeness of monitoring</b></p> <p>The use of existing air quality monitoring data, emissions inventories and atmospheric dispersion modelling is recommended when determining 'worst' locations.</p> <p>Regional exposure should also be taken into consideration when determining the 'worst' location.</p> <p>Ambient air monitoring should take into account temporal variations in contaminant concentrations.</p>
14	<p><b>Instrument enclosure temperatures</b></p> <p>The temperature inside instrument enclosures should remain constant (ideally around 25°C or at any other temperature stated in the instrument's user manual).</p> <p>Installation of an air-conditioning unit with heat and cool cycles inside instrument enclosures is recommended to prevent variations in temperature.</p>
15	<p><b>Site selection</b></p> <p>Regional, neighbourhood and compliance sites should follow the Australian / New Zealand standard (<i>AS/NZS 3580.1.1.2007</i>).</p> <p>Peak sites can deviate from the standards when necessary.</p> <p>Whenever site locations do not meet the standard requirement, this should be clearly detailed in the site metadata.</p> <p>A minimum co-location period of one year is recommended when relocating monitoring sites.</p>
16	<p><b>Monitoring records</b></p> <p>Agencies operating monitoring instruments need to keep detailed records of visits and maintenance, preferably in electronic form.</p>
17	<p><b>Calibration</b></p> <p>Calibrations should be carried out in accordance with the manufacturer's specifications and the requirements of the standard method.</p> <p>Span and zero checks are recommended on a daily basis.</p> <p>Multi-point calibrations should be performed not less than six months apart.</p>
18	<p><b>Equipment maintenance</b></p> <p>The routine maintenance and service requirement outlined and recommended by the instrument manufacturer should be followed.</p>
19	<p><b>Calibration and maintenance documentation</b></p> <p>As a vital part of data quality assurance it is recommended that detailed procedure manuals and schedules for instrument maintenance and calibration be established.</p>
20	<p><b>Training</b></p> <p>Air quality monitoring technical staff should be provided with basic training on core air quality monitoring competencies.</p> <p>Another effective method of training and systems improvement is to participate in reciprocal auditing activities between monitoring agencies.</p>
21	<p><b>Data acquisition, storage and data checks</b></p> <p>The use of an external datalogger is recommended for all instruments to eliminate one source of variation using analogue connections.</p> <p>All data should be stored in a central database that is regularly backed up.</p> <p>It is recommended that daily data checks be done for each telemetered site (or whenever data is downloaded from untelemetered sites), and events noted that may affect results.</p>

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22	<p><b>Data adjustment</b></p> <p>Data quality assurance should be subsequent to multi-point calibrations for gases and done at least monthly given that the NES for air quality require public reporting of a breach within 30 days of its occurrence.</p> <p>Applying the response curve to raw data can correct gradual changes to baselines but is not recommended when there is a sudden baseline change.</p> <p>A minimum co-location period of one year is recommended before correcting data. A copy of raw data should be archived, and all corrected data should be marked to inform data users.</p>																																		
23	<p><b>Negative data</b></p> <p>Negative and positive spikes should be reviewed during the data analysis process to evaluate whether they are real or spurious. Unless there is good evidence to remove a value, it should be left in and a comment made in the metadata.</p> <p>Where negative values are within the expected error of the instrument, they should be retained within the data set to avoid creating a positive bias in the final result.</p> <p>Where large negative spikes are observed in the data record from some particulate monitors, check to see whether a large positive spike is also present. If both a large positive and a large negative spike are present, then remove both spikes as invalid data and check the inlet temperature sensors for faults.</p>																																		
24	<p><b>Per cent valid data and data capture rate</b></p> <p>Sites used for compliance monitoring should achieve at least:</p> <ul style="list-style-type: none"> <li>• 75% valid data for averaging</li> <li>• 95% data capture.</li> </ul> <p>Per cent valid data for averaging = <math>\frac{\text{number of valid data points obtained}}{\text{total number of data points in the averaging period}}</math></p> <p>Data capture rate = <math>\frac{\text{number of valid data points obtained}}{\text{total number of data points for the period} - \text{calibration/maintenance data points}}</math></p>																																		
25	<p><b>Site metadata</b></p> <p>Documented site metadata should be used when interpreting air quality monitoring results. Metadata should be recorded either in hard copy or in a database.</p> <table border="1"> <thead> <tr> <th>Parameter</th> <th>Explanation</th> </tr> </thead> <tbody> <tr> <td colspan="2"><b>Monitoring site metadata</b></td> </tr> <tr> <td>Indicators/contaminants monitored</td> <td>List all the contaminants that have been or are being monitored at the site</td> </tr> <tr> <td>Site code</td> <td>Site code specified by monitoring agency</td> </tr> <tr> <td>Site title</td> <td>Common name of site; eg, Taihape</td> </tr> <tr> <td>Location</td> <td>Street address of site</td> </tr> <tr> <td>Region</td> <td>For example, Southland region</td> </tr> <tr> <td>Co-ordinates</td> <td>New Zealand Mapping Series/Grid reference preferable (latitude and longitude optional)</td> </tr> <tr> <td>Equipment owner's name/s</td> <td>Name of party/ies who own the equipment at the site</td> </tr> <tr> <td>Land owner's details</td> <td>Name/s and contact information of land owner/s</td> </tr> <tr> <td>Equipment housing</td> <td>For example, shed, lab, air conditioning</td> </tr> <tr> <td>Housing environment</td> <td>For example, air conditioning at 25°C</td> </tr> <tr> <td>Monitoring objectives</td> <td>For example, to determine population exposure in high-density areas where air quality is suspected to be poor</td> </tr> <tr> <td>Site topography</td> <td>For example, there are hills 1 km to the southwest; to the north are high-rise commercial buildings</td> </tr> <tr> <td>Location and description of major emission sources</td> <td>This should include information on the nature, location and distance to predominant sources (eg, roads, factories, domestic fires)</td> </tr> <tr> <td>Site category</td> <td>See section 6.2</td> </tr> <tr> <td>Scale of representation</td> <td>See section 6.2</td> </tr> </tbody> </table>	Parameter	Explanation	<b>Monitoring site metadata</b>		Indicators/contaminants monitored	List all the contaminants that have been or are being monitored at the site	Site code	Site code specified by monitoring agency	Site title	Common name of site; eg, Taihape	Location	Street address of site	Region	For example, Southland region	Co-ordinates	New Zealand Mapping Series/Grid reference preferable (latitude and longitude optional)	Equipment owner's name/s	Name of party/ies who own the equipment at the site	Land owner's details	Name/s and contact information of land owner/s	Equipment housing	For example, shed, lab, air conditioning	Housing environment	For example, air conditioning at 25°C	Monitoring objectives	For example, to determine population exposure in high-density areas where air quality is suspected to be poor	Site topography	For example, there are hills 1 km to the southwest; to the north are high-rise commercial buildings	Location and description of major emission sources	This should include information on the nature, location and distance to predominant sources (eg, roads, factories, domestic fires)	Site category	See section 6.2	Scale of representation	See section 6.2
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25	Site height above sea level	
	Electrician and air conditioner service person contact details	
	Photographs of the site	
	<b>Meteorological site metadata</b>	
	Meteorological variables measured	For example, wind speed, wind direction, temperature at height at which they are measured
	Meteorological data operator	Person who operates the met station
	Location of meteorological site	For example, on site up mast 6 m high, at the neighbouring airport
	Meteorological data information	Where met data can be obtained (eg, met service, regional council)
	Regional and local meteorological characteristics	A brief description of met conditions likely to affect air quality at the site (eg, inversions, prevailing wind direction)
	<b>Contaminant metadata</b>	
	Contaminant	For example, PM <sub>10</sub> , NO <sub>2</sub>
	Data owner	Name of organisation that actually owns the data recorded by equipment
	Instrument/s	Name and any other details of the instrument/s (make, brand, serial number and model). If using more than one instrument, include both in this section
	Period of operation	Dates when equipment was operated (eg, 12.3.2001 to 8.5.2003 or 11.3.2008 ongoing)
	Method	Details of the standard method followed to operate the equipment (eg, USEPA or AS/NZS standard). Also, include details of any deviation from the standard method (eg, conditioning and weighing of filters).
	Data logging	For example, remote via modem, or not used
	Data storage	Describe how the data is stored by the data owner
	Sampling period	How often the concentration is sampled and measured
Sampling probe height	Height of probe above ground	
Calibration frequency	Summarised details of equipment calibration	
Per cent valid data	Amount of data that has passed quality assurance checks (see Recommendation 24), recorded on a yearly basis (eg, 2005 – 95%; 2006 – 98%; 2007 – 96%)	
26	<b>Monitoring units</b> The recommended units for recording and archiving the monitoring results of gases are parts per million (ppm) or parts per billion (ppb), with conversion to mg/m <sup>3</sup> or µg/m <sup>3</sup> at 0°C for reporting purposes. PM <sub>10</sub> results should be recorded and archived as µg/m <sup>3</sup> at 0°C.	
27	<b>Time format</b> Times and dates should always be reported in New Zealand Standard Time. Labelling of the midnight hour should be 24.00 instead of 00.00.	



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28	<p data-bbox="403 282 639 309"><b>Reporting data formats</b></p> <p data-bbox="403 315 1238 338">It is recommended that data from all monitoring sites be reported in the following format:</p> <table border="1" data-bbox="403 344 1254 602"> <thead> <tr> <th data-bbox="403 344 722 389">Contaminant</th> <th data-bbox="722 344 975 389">Data format</th> <th data-bbox="975 344 1254 389">Nominal precision</th> </tr> </thead> <tbody> <tr> <td data-bbox="403 389 722 423">Carbon monoxide</td> <td data-bbox="722 389 975 423">X.X mg/m<sup>3</sup></td> <td data-bbox="975 389 1254 423">tenth of a mg/m<sup>3</sup></td> </tr> <tr> <td data-bbox="403 423 722 456">Nitrogen dioxide</td> <td data-bbox="722 423 975 456">X.X µg/m<sup>3</sup></td> <td data-bbox="975 423 1254 456">tenth of a µg/m<sup>3</sup></td> </tr> <tr> <td data-bbox="403 456 722 490">Ozone</td> <td data-bbox="722 456 975 490">X.X µg/m<sup>3</sup></td> <td data-bbox="975 456 1254 490">tenth of a µg/m<sup>3</sup></td> </tr> <tr> <td data-bbox="403 490 722 524">Particulate matter (PM<sub>10</sub>)</td> <td data-bbox="722 490 975 524">XX µg/m<sup>3</sup></td> <td data-bbox="975 490 1254 524">a whole µg/m<sup>3</sup></td> </tr> <tr> <td data-bbox="403 524 722 557">Sulphur dioxide</td> <td data-bbox="722 524 975 557">X.X µg/m<sup>3</sup></td> <td data-bbox="975 524 1254 557">tenth of a µg/m<sup>3</sup></td> </tr> <tr> <td data-bbox="403 557 722 602">Lead</td> <td data-bbox="722 557 975 602">X.X µg/m<sup>3</sup></td> <td data-bbox="975 557 1254 602">tenth of a µg/m<sup>3</sup></td> </tr> </tbody> </table>	Contaminant	Data format	Nominal precision	Carbon monoxide	X.X mg/m <sup>3</sup>	tenth of a mg/m <sup>3</sup>	Nitrogen dioxide	X.X µg/m <sup>3</sup>	tenth of a µg/m <sup>3</sup>	Ozone	X.X µg/m <sup>3</sup>	tenth of a µg/m <sup>3</sup>	Particulate matter (PM <sub>10</sub> )	XX µg/m <sup>3</sup>	a whole µg/m <sup>3</sup>	Sulphur dioxide	X.X µg/m <sup>3</sup>	tenth of a µg/m <sup>3</sup>	Lead	X.X µg/m <sup>3</sup>	tenth of a µg/m <sup>3</sup>
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29	<p data-bbox="403 613 858 640"><b>Significant digits and rounding-off protocols</b></p> <p data-bbox="403 647 1310 696">The recommended data format in section 9.2 specifies the significant digits for the reporting of a contaminant.</p> <p data-bbox="403 703 1385 752">When the value following the significant digit is equal to or greater than five, the digit should be rounded up; otherwise, the digit is retained.</p> <p data-bbox="403 759 1374 808">For all monitoring sites, an exceedence occurs when the reported concentration is above the standard, after rounding to the significant digit.</p>																					