This document has been prepared on behalf of **NSW Government Office of Environment and Heritage** by:

Northstar Air Quality Pty Ltd,

Suite 1504, 275 Alfred Street, North Sydney, NSW 2060

www.northstarairquality.com | Tel: +61 (02) 9071 8600

Design of a background air quality monitoring station

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Quality Control

Study	Status	Prepared by	Checked by	Authorised by
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AUSTRALIA	Final	Northstar Air Quality	MD, GCG, OEH	MD
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Final Authority

This report must by regarded as draft until the above study components have been each marked as final, and the document has been signed and dated below.

MDoyle

Martin Doyle **22nd May 2019**

Non-Technical Summary

NSW Government Office of Environment and Heritage has engaged Northstar Air Quality Pty Ltd to perform a review of international best practice or guidance in the design of a background air quality monitoring station. This review will be used, in conjunction with numerous other studies and considerations, by the Office of Environment and Heritage as due diligence for the scope, design, siting and performance of background air quality monitoring stations in NSW.

The review has examined documentation associated with the development of air quality monitoring network in Australia, the European Union, the United States and Canada, concentrating on the relevant components of that documentation in relation to background air quality monitoring.

A review of the definitions, purposes, scales, scope, site selection criteria, and technology used in background air quality monitoring networks across the jurisdictions has been performed.

Several points of consistency can be identified between the definitions of background monitoring including:

- The reference to homogeneous land use and geographies (Australia and United States);
- The distance from large pollutant sources (United State, European Union and Canada); and,
- Scales of 10's to 100's of kilometres (United States and European Union).

Population density is not specifically mentioned in relation to background air quality monitoring apart from in European Union definitions (where lower population density is discussed) and briefly in US EPA regulations (where regional scale measurements of $PM_{2.5}$ should be applicable to "sparsely populated areas"). No specific values of population densities have been identified in any guidance which would relate to background air quality monitoring.

In relation to the purposes of background air quality monitoring (BAQM), stations can be used to assess compliance, although are more often used to inform the potential contribution from long range transport of pollutants (especially fine particulate [often speciated], and O_3), and to support source apportionment analysis and management. It can also be used to determine the influence of natural events from other sources for the assessment of criteria achievement.

In terms of siting, several points of interest have been identified.

- All jurisdictions require that the stations are located so as to provide information representative of the broader location in which they are situated. This requires placement away from local sources of pollutants being monitored.

- Regional scale measurements of $PM_{2.5}$ (speciated) and O_3 are most commonly discussed in reference to that spatial scale, and in the case of potential precursor transportation ($PM_{2.5}$ and O_3), Canada also requires measurements of NO, all oxidized nitrogen compounds (NO_Y), NH_3, SO_2 and VOC (including speciation).

- When siting an O_3 monitor for regional scale background measurements, the US EPA requires that meteorological analysis of trajectories and emission patterns be performed to assist that determination.

- When siting a BAQM, a hierarchical approach is likely to be the most successful, with the determination of the purpose of the background monitoring being the key consideration. Site selection criteria, including the macro and micro scale criteria presented within this review, should be considered according to the purpose, with station and plot design being an important but lower order consideration when compared to the overall purpose of monitoring.

- Spacing from trees is specified as being required as:
  - 10 m from the drip line (US EPA)
  - 20 km from the tree canopy (Canada)
  - Clear sky angles (various) (Australia, EU)

This is a significant difference in the required spacing from trees in the different jurisdictions reviewed.

- Micro scale siting criteria are generally similar between jurisdictions and do not have any varying requirements depending on station type (i.e. BAQMS or other).

- No discussion of any variation in monitoring techniques from urban through to background scales is provided within any of the documentation reviewed. A more detailed review of the technical specifications of monitoring techniques which are currently approved for use within NSW, and selection of those with a broader range, or lower minimum threshold could be investigated.

- No specific requirements for the measurement of meteorological parameters at BAQMS is provided within any of the literature reviewed. As outlined within the case studies, some sites do not measure these parameters at all, some do, and some rely on modelled data. The implementation of meteorological monitoring should be aligned with the purpose of the BAQM.

- It is clear from this review that a particular monitoring station does not have to meet the requirements of 'background' for all pollutants. Often, a station will be representative of background or regional conditions for one pollutant, but be representative of a completely different scale for another. A good example of this is the Colusa-Sunrise Blvd site in the Colusa District of California, USA. The site is classified as a general background type for O_3, for PM_{10} is a highest concentration and population exposure type site and for $PM_{2.5}$ is a population exposure type site. O_3 measurements at that site are reflective of the regional scale, whereas measurements of PM_{10} and $PM_{2.5}$ are reflective of the neighbourhood scale.

Further to the above, from review of the reference material for all jurisdictions, a background monitoring station can be pollutant-specific, or monitor multiple pollutants, so long as the siting criteria are achieved. Adopting a common rationale may conclude that an existing station in the NSW Office of Environment and Heritage network may be suitable for background monitoring purposes, although analysis (especially of sources of emissions and meteorology) should be performed prior to that designation.

As may be expected, no pre-determination is provided in the reviewed guidance prescribing a concentration of air pollutants that may be considered to represent a 'background' condition. This is expected as the background will be determined by the geography, source strength and location and a variety of other factors including topography, distance between agglomerations etcetera.

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1. INTRODUCTION

NSW Government Office of Environment and Heritage (OEH) has engaged Northstar Air Quality Pty Ltd (Northstar) to perform a review of international best practice or guidance in the design of a background air quality monitoring station (BAQMS) (ref: OEH-CAS01-2019). This review will be used, in conjunction with numerous other studies and considerations, by OEH as due diligence for the scope, design, siting and performance of BAQMS in NSW.

1.1 Purpose of the Report

As advised by OEH:

> *"In July 2017, the NSW Environment Minister announced that NSW Government will establish background air quality monitoring as part of the NSW Government's Clean Air Summit commitments. OEH are commencing the design and site selection for a background station. To provide assurance that our design criteria are like or exceed international best practice, the OEH requires a best practice review of background air quality monitoring station design.*

An OEH project group is tasked to oversee this tender, which seeks to review international best practice or guidance in background air quality monitoring network (AQMN) design and covering monitoring scope (pollutants, purpose, extent of monitoring, etc.)."

1.2 Study Outline

The scope of the study is required to consider:

> *"(1) what is done elsewhere…; (2) pollutants monitored in addition to NEPM criteria pollutants, and meteorological parameters measured; (3) monitoring purposes other than compliance and trend reporting; (4) criteria for site selection; and, (5) monitoring systems and technologies available for background monitoring purposes, if any."*

The review is to be performed in consideration of, but not limited to, the following:

- European Commission legislation;
- US EPA Monitoring Regulation;
- National Environment Protection (Ambient Air Quality) Measure (2015);
- Peer Review Committee of the National Environment Protection (Ambient Air Quality) Measure Technical Papers; and
- OEH Scientific Rigour Position Statement.

The review is to include guidelines from:

- United States Environmental Protection Agency (US EPA);
- European Union (EU); and
- One other Organisation for Economic Co-operation and Development (OECD) country.

1.3 Selection of International Case Studies

The scope of work requires the assessment to review the monitoring networks implemented by the United States Environmental Protection Authority (US EPA), the European Union (EU) and a third (unspecified) monitoring network operated by an Organisation for Economic Co-operation and Development (OECD) member country.

As the objective of this study is to review best practice and guidance for BAQMS, and understand how it can be implemented to air quality monitoring network review and design in Australia (and specifically NSW), the selection of the third study area needs to be relevant to the situation as exists in NSW in terms of scope, size, application and serving a population with similar characteristics to NSW.

A number of options were identified including the monitoring networks in Canada, Japan, South Africa and Singapore.

Table 1 presents a summary of the broad characteristics of the various air quality monitoring networks identified, noting that these networks may be designed for purposes other than determination of background air quality.

Table 1 Summary of potential study air quality monitoring networks

Country (Regulator)	Network	Scale	Scope	Est. Date
Canada (Environment Canada)	Global Atmospheric Passive Sampling (GAPS)	Global	POPs	2004
	Canadian Aerosol Measurement (CABM)	Regional	Aerosol	2005
	Integrated Atmospheric Deposition Network (IADN)	Regional	OCP, PAH, PCB, trace elements	1990
	Canadian Air and Precipitation Monitoring Network (CAPMoN)	National	Acid rain, smog, PM, Hg	1983
	National Air Pollution Surveillance (NAPS)	National	SO_2, NO_2, O_3, PM, CO, VOC	1969
Japan (National Institute for Environmental Studies)	Various monitoring networks	Local	SO_2, CO, NO_X, O_X, SPM, NMHC	1999
		Local	SO_2, NO_2	1999
		National	SO_2, NO_2	nd
South Africa (Department of Environmental Affairs)	Ambient Air Quality Monitoring Module within SAAQIS	Regional networks	PM, SO_2, O_3, NO_X, CO, VOC, BC	nd

Country (Regulator)	Network	Scale	Scope	Est. Date
Singapore (National Environment Agency)	Various monitoring networks		SO_2, NO_X, CO, O_3, HC, PM_{10}	nd
			VOCs	nd

Notes: See **Table 3**

Table 2 presents a summary evaluation of the jurisdictions which may be subject to study with regard to scope, scale, ease of information availability and access.

Table 2 Selection of the study network jurisdiction

Country	Established Networks	Scope / scale [(a)]	Ease of Information Access [(b)]	Overall Evaluation [(c)]
Canada	Yes	Appropriate	Good access	High
Japan	Yes	Appropriate	Difficult access	Low
South Africa	Yes	Appropriate	Some access	Medium
Singapore	Yes	Appropriate	Difficult access	Low

Notes: (a) The scope and scale of the identified networks includes a subjective evaluation of the range of pollutants measured by the network(s), the geographical extents of the network and the number of monitoring locations within the network(s).

(b) The ease of information is not intended to represent an evaluation of the function of public dissemination of data to the relevant populations but is a subjective evaluation on the relative ease of accessing data for use in this assessment, inclusive of considerations of access, time and language/interpretation.

(c) The assessment of overall applicability relates to the previous criteria and is a subjective evaluation of the applicability of that network to be used in this assessment, inclusive of technical coverage, ease of data access, language limitations and time.

In light of the above factors, Canada has been identified as a suitable study network.

For each jurisdiction, the relevant site selection criteria for BAQMS are outlined as macro-scale siting criteria, offering guidance on broad regional siting constraints, and as micro-scale siting criteria which, if available, provide specification for siting in proximity to sources or structures or features that might influence airflow.

1.4 General Definitions

Table 3 provides a list of acronyms which are used extensively throughout this report.

Table 3 List of acronyms used throughout report

Acronym	
AS/NZS	Australian Standard / New Zealand Standard
BC	black carbon
CAA	Clean Air Act (US)
CAFE	Cleaner Air for Europe
CEN	European Committee for Standardisation
CO	carbon monoxide
C_6H_6	benzene
DQO	data quality objective
EU	European Union
FEM	federal equivalence method
FRM	federal reference method
GRUB	generally representative upper bound (Australia)
HC	hydrocarbons
Hg	mercury
NEPC	National Environment Protection Council (Australia)
NEPM	National Environment Protection Measure (Australia)
NMHC	non-methane hydrocarbons
NO_X	oxides of nitrogen
NO	nitric oxide
NO_2	nitrogen dioxide
NO_Y	total reactive nitrogen (NO, NO_2, nitric acid [HNO_3], and organic nitrates)
OCP	organochlorine pesticide
OEH	Office of Environment and Heritage
O_3	ozone
PAH	polyaromatic hydrocarbon
Pb	lead
PCB	polychlorinated biphenyl
POPS	persistent organic pollutants

Acronym	
PM	particulate matter
$PM_{2.5}$	particulate matter with an aerodynamic diameter of less than 2.5 microns
PM_{10}	particulate matter with an aerodynamic diameter of less than 10 microns
$PM_{10-2.5}$	coarse particulate matter
SPM	suspended particulate matter
TSP	total suspended particulate
VOC	volatile organic compound

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2. AUSTRALIA

In Australia, the *National Environment Protection (Ambient Air Quality) Measure* (AAQ NEPM) requires air quality monitoring within regions with a population of greater than (>) 25 000 persons, although it does not restrict monitoring in regions with lower populations. Stations are categorised as Performance Monitoring Stations (PMS) to measure pollutants which may be experienced by the large majority of the population. A subset of PMS can be classified as:

a) Generally Representative Upper Bound (GRUB) stations to measure pollutants at the upper bounds of the concentrations which may be likely to be experienced within a region.

b) Population average sites to measure air quality experienced by large portions of the populated area and of the total population within a region.

c) Trend stations sufficient to monitor and assess long term changes in ambient air quality in different parts of the jurisdiction. Trend stations must be operated for one or more decades.

Given the above categorisations, and the requirement of air quality monitoring for the purposes of the AAQ NEPM to be representative of populated areas, no monitoring of 'background' or 'regional' air quality concentrations are required.

For the purposes of some studies (such as the Port Hedland Air Quality Health Risk Assessment (Government of Western Australia Department of Health, 2016)), monitoring stations representing 'regional background' have been commissioned. The background nature of such stations is often justified by the distance to industrial activities and populations although no criteria are provided for the siting and commissioning of such stations.

Australian/New Zealand Standard (AS/NZS) 3580.1.1:2016 - *Methods for sampling and analysis of ambient air – Part 1.1: Guide to siting air monitoring equipment* outlines the methodology for siting ambient air monitoring equipment. Some of the material in the Standard is derived from 40 CFR Part 58 (see **Section 3**).

Within AS/NZS 3580.1.1:2016, monitoring site are noted as being classifiable as one of the following definitions:

1. *Peak site*

   Peak sites are located where the highest concentrations and exposure are expected to occur, e.g. near roads, in the CBD or near industrial sources. These sites are especially useful for air quality compliance monitoring and source monitoring.

2. *Neighbourhood site*

   Neighbourhood sites are located in areas which typify a broad area of uniform land use, e.g. residential, industrial and commercial. These sites are especially useful for determining urban air quality trends, compliance with air quality standards and effects of major, non-localised sources of pollutants.

3. *Background site*

Background sites are located in urban or rural areas to provide information on background levels. Background sites are usually in areas of homogeneous land use and geography. These sites can be especially useful for assessing transportation of pollutants into a region.

These site classifications are described based on functional requirements rather than any requirements in the Australian National Environment Protection Council (NEPC), US EPA and New Zealand Ministry for the Environment classifications.

In NSW, no formal categorisation of air quality monitoring stations is performed or required at the present time. Therefore, no discussion can be provided on the purposes, scales and scope of that monitoring.

2.1 Site Selection Criteria

Australian/New Zealand Standard (AS/NZS) 3580.1.1:2016 - *Methods for sampling and analysis of ambient air – Part 1.1: Guide to siting air monitoring equipment* outlines the methodology for siting ambient air monitoring equipment. Some of the material in the Australian Standard is derived from 40 CFR Part 58 (see **Section 3**).

All of the requirements presented below are applicable to BAQMS. AS/NZS 3580.1.1:2016 does not generally differentiate between types of monitoring stations, apart from the slight variations in macro scale criteria outlined in **Section 2.1.1**.

2.1.1 Macro Scale

Discussion of macro scale siting criteria outlined in AS/NZS 3580.1.1:2016 is limited to broad statements such as:

> *"it is essential that the sampling unit be situated so as to yield data which are representative of the location. It should not be unduly influenced by immediate surroundings unless those influences are specifically being monitored."*

and:

> *"Background sites are located in urban or rural areas to provide information on background levels. Background sites are usually in areas of homogeneous land use and geography. These sites can be especially useful for assessing transportation of pollutants into a region. "*

2.1.2 Micro Scale

AS/NZS 3580.1.1:2016 provides the following requirements for siting of air quality monitoring equipment:

1. *Avoid sites that have restricted airflows in the vicinity of the sampling inlet, such as sites adjacent to buildings, trees, walls etc. As a general rule, a sampling inlet should be located away from any nearby structure to the extent that the sampling inlet has a minimum clear sky angle of 120º. This rule is not always applicable, e.g. peak station measuring carbon monoxide in a street canyon.*
2. *Avoid sites which are adjacent to objects which may alter pollutant concentrations by adsorption or absorption, such as those near some building surfaces or near leafy vegetation.*

3. *Avoid sites where chemical interference with the pollutant being measured may occur, e.g. emissions from motor vehicles may interfere with ozone measurements, ammonia from a refrigeration plant may interfere with acid gases measurements.*
4. *Avoid sites where physical interference may produce atypical results, e.g. measuring particulate matter near domestic or commercial incinerators, electrical interference to sampling equipment from nearby high voltage power lines.*
5. *Ground level sampling sites (sample inlet less than 5 m above ground level) are generally preferable in low or sparsely built up areas. Elevated sampling sites may be acceptable for a number of purposes in moderate to high density areas (in terms of structures).*
6. *Sampling sites should not be affected by extraneous local emissions.*
7. *Local activities around a sampling site may change its suitability as a site, either temporarily or permanently, e.g. demolition or construction activities, re-routing of motor vehicle traffic.*

Other considerations are as follows:

i. *Seek sites that are secure and have low potential for vandalism.*
ii. *Seek sites that have adequate access for transporting equipment, e.g. instruments, cylinders of calibration gas.*
iii. *Seek sites that have adequate and reliable electricity supply.*
iv. *Seek sites that are not prone to natural disasters, e.g. flooding.*
v. *Seek sites that have adequate and reliable communication services.*
vi. *Seek sites where noise levels generated by pumps or air conditioners or maintenance and calibration activities do not impose on the local residents/population.*
vii. *Seek sites where access times are aligned with the intended capture rates.*
viii. *Seek site where personnel will be able to perform their activities in a safe and secure environment in accordance with OHS regulatory requirements.*

With specific regard to the siting of sampling inlets at background air quality monitoring sites, **Table 4** summarises the requirements as outlined in AS/NZS 3580.1.1:2016.

Table 4 Recommended sampling inlet positioning criteria (AS/NZS 3580.1.1:2016)

Pollutant	Type of monitoring station	Height above ground to probe (m)	Other locating criteria (minimum)
PM_{10}, $PM_{2.5}$	Neighbourhood and background	1.5 to 15	• Clear sky angle of 120° • Unrestricted airflow of 270° around sample inlet • 10 m from any object with a height exceeding 2 m below the height of the sample inlet • No extraneous sources nearby • 50 m from road • Co-located high volume samplers 2 to 4 m apart

Pollutant	Type of monitoring station	Height above ground to probe (m)	Other locating criteria (minimum)
TSP	Peak, neighbourhood and background	1.5 to 15	• Unrestricted airflow of 180° around sample inlet with no obstruction between the major source and the sample inlet • No extraneous sources nearby • Co-located high-volume air samplers 2 to 4 m apart
CO	Neighbourhood and background	2.0 to 15	• Clear sky angle of 120° • Unrestricted airflow of 270° around sample inlet or 180° if inlet is on side of building • 10 m from any object with a height exceeding 2 m below the height of the sample inlet • No extraneous sources nearby • 10 m from road
NO_X	Neighbourhood and background	2.0 to 15	• Clear sky angle of 120° • Unrestricted airflow of 270° around sample inlet or 180° if inlet is on side of building • 10 m from any object with a height exceeding 2 m below the height of the sample inlet • 10 m from road
VOC	Peak, neighbourhood and background	2.0 to 15	• Clear sky angle of 120° • Unrestricted airflow of 270° around sample inlet or 180° if inlet is on side of building • 10 m from any object with a height exceeding 2 m below the height of the sample inlet • 10 m from road
O_3	Peak, neighbourhood and background	2.0 to 15	• Clear sky angle of 120° • Unrestricted airflow of 360° around sample inlet • 10 m from nearest object or tree dripline of trees • 50 m from road
SO_2	Peak, neighbourhood and background	2.0 to 15	• Clear sky angle of 120° • Unrestricted airflow of 270° around sample inlet or 180° if inlet is on side of building • 10 m from any object with a height exceeding 2 m below the height of the sample inlet • No extraneous sources nearby

Pollutant	Type of monitoring station	Height above ground to probe (m)	Other locating criteria (minimum)
Metals	Neighbourhood and background	1.5 to 15	• Clear sky angle of 120° • Unrestricted airflow of 270° around sample inlet • 10 m from any object with a height exceeding 2 m below the height of the sample inlet • No extraneous sources nearby • 50 m from road • Co-located high volume samplers 2 to 4 m apart

Source AS/NZS 3580.1.1:2016 Table 2

With specific relation to roads, table 1 of AS/NZS 3580.1.1:2016 provides recommended distances between neighbourhood and background stations and roads, which are presented in **Table 5**.

Table 5 Recommended minimum distances between neighbourhood and background stations and roads (AS/NZS 3580.1.1:2016)

Roadway traffic Estimated average number of vehicles per day	Minimum distance between monitoring site and road (m)		
	CO	NO_X, VOCs and O_3	PM, PAH and Pb
≤ 10 000	10	10	50
15 000	25	20	*
20 000	45	30	75
30 000	80	*	*
40 000	115	50	100
50 000	135	*	*
60 000	150	*	*
70 000	*	100	*
≥ 110 000	*	250	*

Source AS/NZS 3580.1.1:2016 Table 1
Note: * Distances should be interpolated for intermediate traffic flows

The values presented in **Table 5** are taken from 40 CFR Part 58 (Appendix E) (refer **Section 3**).

2.2 Technology and Systems

Methods for air quality monitoring in Australia are provided within the AAQ NEPM and presented in **Table 6**. No derogations from those methods are noted for any monitoring over differing spatial scales.

Table 6 Approved methods for air quality monitoring under the AAQ NEPM

Pollutant	Method title	Method number
PM_{10}	Determination of Suspended Particulate Matter-PM_{10} High Volume Sampler with Size Selective Inlet-Gravimetric Method	AS/NZS 3580.9.6:2003
	Determination of Suspended Particulate Matter- Dichotomous sampler (PM_{10}, coarse PM and $PM_{2.5}$) – Gravimetric method	AS/NZS 3580.9.7:2009
	Determination of Suspended Particulate Matter-PM_{10} continuous direct mass method using tapered element oscillating microbalance analyser.	AS/NZS 3580.9.8-2008
	Determination of Suspended Particulate Matter-PM_{10} Low Volume Sampler-Gravimetric Method	AS/NZS 3580.9.9:2006
	Determination of Suspended Particulate Matter-PM_{10} beta attenuation monitors	AS/NZS 3580.9.11:2008 /Amdt 1 :2009
$PM_{2.5}$	Determination of Suspended Particulate Matter-$PM_{2.5}$ low volume sampler-Gravimetric Method	AS/NZS 3580.9.10:2008
	Determination of Suspended Particulate Matter-$PM_{2.5}$ beta attenuation monitors	AS/NZS 3580.9.12:2013
	Determination of Suspended Particulate Matter-$PM_{2.5}$ continuous direct mass method using a tapered element oscillating microbalance monitor	AS/NZS 3580.9.13:2013
	Determination of Suspended Particulate Matter-$PM_{2.5}$ high volume sampler with size selective inlet – Gravimetric Method	AS/NZS 3580.9.14:2013
SO_2	Determination of Sulfur Dioxide-Direct Reading Instrumental Method	AS/NZS 3580.4.1-2008
O_3	Determination of Ozone-Direct Reading Instrumental Method	AS/NZS 3580.6.1-2011
CO	Determination of Carbon Monoxide-Direct Reading Instrumental Method	AS/NZS 3580.7.1-2011 /Amdt 1-2012
NO_2	Determination of Oxides of Nitrogen-Chemiluminescence Method	AS/NZS 3580.5.1-2011
Pb	Determination of Suspended Particulate Matter – Particulate metals high or low volume sampler gravimetric collection – Inductively coupled plasma (ICP) spectrometric method	AS/NZS 3580.9.15:2014
	Determination of Suspended Particulate Matter – Total suspended particulate matter (TSP) - High volume sampler gravimetric method	AS/NZS 3580.9.3:2015

Source: AAQ NEPM 2016

3. UNITED STATES

The key legislation in the United States of America regarding the design of ambient air quality monitoring networks is the *Clean Air Act* (CAA) (2004).

State air pollution control agencies, owners or operators of sources are required to operate air quality monitoring networks as per the requirements of Title 40, Chapter I, Subchapter C, Part 58 (40 CFR Part 58) '*Ambient Air Quality Surveillance*'. 40 CFR Part 58 contains requirements for measuring and reporting ambient air quality and related information, including:

- Appendix C of 40 CFR Part 58 specifies the criteria pollutant monitoring methods which must be used in the 'SLAMS' AQMN and 'NCore' AQMN stations (see **Section 3.2**). NCore is noted as a subset of the SLAMS network.
- Appendix D of 40 CFR Part 58 provides a useful summary of the design criteria for the various monitoring components of the AQMNs. These criteria are discussed in detail in **Section 3.2**.
- Appendix E of 40 CFR Part 58 provides specific location criteria applicable to SLAMS, NCore and PAMS air quality monitoring stations. These criteria are discussed in detail in **Section 3.5**.

3.1 Definitions and Classifications

The various monitoring networks under the CAA (refer to **Section 3.2**) must be designed to deliver the objectives for the monitoring which may include providing information to communities, reporting compliance with ambient air quality standards, emission control programs and providing data for research on human health and environmental management. To that end, the requirements of the collected data may directly influence the AQMN to include:

1. *Sites located to determine the highest concentrations expected to occur in the area covered by the network;*
2. *Sites located to measure typical concentrations in areas of high population density;*
3. *Sites located to determine the impact of significant sources or source categories on air quality;*
4. *Sites located to determine general background concentration levels;*
5. *Sites located to determine the extent of regional pollutant transport among populated areas; and in support of secondary standards; and,*
6. *Sites located to measure air pollution impacts on visibility, vegetation damage, or other welfare-based impacts."*

It is noted that US EPA also utlise the terminology of Policy Relevant Background (PRB), which they define as (in the case of O_3):

> *"the distribution of O3 concentrations that would be observed in the U.S. in the absence of anthropogenic (man-made) emissions of precursor emissions (e.g., VOC, NOX, and CO) in the U.S., Canada, and Mexico."*

The purpose of this review is not to provide information to allow the location of operation of a 'baseline' monitoring station (e.g. Cape Grimm) and therefore the definitions of 'background' are taken from the CAA and associated documentation.

3.2 Purposes

Air quality monitoring is required under 40 CFR Part 58 to assess compliance against the National Ambient Air Quality Standards (NAAQS), emergency control, real time reporting, trends analysis, and research. Several monitoring networks provide data to assess compliance and these include:

- **SLAMS**: A network of State or Local Air Monitoring Stations (SLAMS). The SLAMS make up the ambient air quality monitoring sites that are primarily needed for NAAQS comparisons, but may serve other / further purposes. SLAMS exclude special purpose monitor (SPM) stations and include NCore, PAMS, and all other State or locally operated stations that have not been designated as SPM stations.
- **NCore**: National Core multipollutant monitoring stations (NCore). This network measures particles ($PM_{2.5}$, speciated $PM_{2.5}$, $PM_{10-2.5}$), O_3, SO_2, CO, ($NO/NO_2/NO_Y$), Pb, and basic meteorology. NCore measures multiple pollutants in order to provide support to integrated air quality management data needs. NCore sites include both 'neighbourhood' and 'urban' scale measurements (see **Table 7**) in general, in a selection of metropolitan areas and a limited number of more rural locations. Continuous monitoring methods are to be used at the NCore sites when available for a pollutant to be measured, as it is important to have data collected over common time periods for integrated analyses. NCore multipollutant sites are intended to be long-term sites useful for a variety of applications including air quality trends analyses, model evaluation, and tracking metropolitan area statistics. As such, the NCore sites are required to be placed away from direct emission sources that could substantially impact the ability to detect area-wide concentrations.
- **PAMS**: Photochemical Assessment Monitoring Stations. These are required in serious, severe and extreme O_3 nonattainment areas.
- **$PM_{2.5}$ Chemical Speciation Network (CSN)** consists of the **Speciation Trends Network (STN)** sites and supplemental speciation sites which, in part, aid in the interpretation of health studies by linking effects to $PM_{2.5}$ constituents.
- **National Air Toxic Trend Stations (NATTS)**: These stations monitor hazardous air pollutants or air toxics.
- **Special Purpose Monitors**: (SPM) stations are designated as a special purpose monitor station in the US EPAs monitoring network plan and in the Air Quality System, and which the US EPA does not count when showing compliance with the minimum requirements of this subpart for the number and siting of monitors of various types.

Under 40 CFR Part 51.308, States are required to address the 'regional haze program requirements' through the submission of a monitoring strategy for measuring, characterising, and reporting of regional haze visibility impairment ('the Regional Haze Rule').

3.3 Scales

Given the focus of this review is the experience of other jurisdictions in implementing 'background' air quality monitoring, those sites which are located to determine highest concentrations, typical concentrations in areas of high population density, and significant source impacts are not considered further. The review focusses on those sites located to measure background air pollutant concentrations, and the extent of regional transport.

40 CFR Part 58 (Appendix D) provides a description of the 'scales of representativeness' for the monitoring sites described in **Section 3.1**:

1. *Microscale—Defines the concentrations in air volumes associated with area dimensions ranging from several meters up to about 100 meters (m).*
2. *Middle scale—Defines the concentration typical of areas up to several city blocks in size with dimensions ranging from about 100 m to 0.5 kilometers (km).*
3. *Neighbourhood scale—Defines concentrations within some extended area of the city that has relatively uniform land use with dimensions in the 0.5 km to 4.0 km range. The neighbourhood and urban scales listed below have the potential to overlap in applications that concern secondarily formed or homogeneously distributed air pollutants.*
4. *Urban scale—Defines concentrations within an area of city-like dimensions, on the order of 4 km to 50 km. Within a city, the geographic placement of sources may result in there being no single site that can be said to represent air quality on an urban scale.*
5. *Regional scale—Defines usually a rural area of reasonably homogeneous geography without large sources, and extends from tens to hundreds of kilometres.*
6. *National and global scales—These measurement scales represent concentrations characterizing the nation and the globe as a whole.*

The relationship between the 'scales of representativeness' and types of monitoring is summarised in **Table 7**.

Table 7 Relationship between site types and scales of representativeness

<table>
<tr><th rowspan="3">Site Type</th><th colspan="6">Siting Scales (Including Typical Representative Scales)</th></tr>
<tr><th>Micro</th><th>Middle</th><th>Neighbour-hood</th><th>Urban / Rural</th><th>Regional</th><th>National</th></tr>
<tr><th><100m</th><th>100m-0.5km</th><th>0.5km-4km</th><th>4km-50km</th><th>10/100s km</th><th>National</th></tr>
<tr><td>Highest concentration</td><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td>Highest concentration (secondary pollutants)</td><td></td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Population oriented</td><td></td><td></td><td colspan="2"></td><td></td><td></td></tr>
<tr><td>Source impact</td><td colspan="3"></td><td></td><td></td><td></td></tr>
<tr><td>General/background & regional transport</td><td></td><td></td><td></td><td colspan="2"></td><td></td></tr>
<tr><td>Welfare-related impacts</td><td></td><td></td><td></td><td colspan="2"></td><td></td></tr>
</table>

3.4 Scope

A summary of how each monitoring network provides measurements of air quality over each spatial scale is presented in **Table 8**.

Table 8 Summary of spatial scales for SLAMS, NCore, PAMS and Open Path (OP) sites

Site Type	SLAMS sites							$PM_{10-2.5}$	NCore	STN[A]	NATTs[B]	PAMS	OP
	SO_2	CO	O_3	NO_2	Pb	PM_{10}	$PM_{2.5}$						
Micro	*	*			*	*	*	*					
Middle	*	*		*	*	*	*	*					*
Neighbourhood	*		*	*	*	*	*	*	*	*	*	*	*
Urban			*	*	*		*		*	*	*	*	*
Regional			*		*		*		*		*		*

Note: (A): Speciation Trends Network requires speciation of $PM_{2.5}$

(B): NATTS = National Air Toxics Trends Stations

Source: (USEPA, 2017)

Note: Open path refers to remote sensing of pollutants using Fourier transform infrared (FT-IR) spectrometers. The use of this method is allowed within 40 CFR Part 58 at SLAMS and PAMS stations. They have been presented as a separate network in **Table 8** as the scales over which this monitoring method can be used vary slightly to the general trend at PAMS and SLAMS networks (i.e. open path analysers can be used at the middle scale, where the PAMS and SLAMS networks generally operate at the neighbourhood and greater scales).

NCore and PAMS stations are required to monitor meteorological variables, at a minimum wind speed and direction, temperature, relative humidity, precipitation and solar radiation.

The IMPROVE (Interagency Monitoring of Protected Visual Environments) program covers a visibility monitoring network designed to monitor progress against the Regional Haze Rule. The network of monitors measures 24-hour samples of PM_{10} and $PM_{2.5}$ on a 1-in-3 day basis. $PM_{2.5}$ filters are analysed for mass, elemental composition and light absorption, sulphate, nitrate, nitrite and chloride using ion chromatography and organic and elemental carbon by thermal optical reflectance techniques. The speciation of $PM_{2.5}$ across the IMPROVE network is similar to that performed at the STN sites.

3.5 Site Selection Criteria

3.5.1 Macro Scale

Rural NCore stations are required to be located to the maximum extent practicable at a regional or larger scale away from any large local emissions source, so that they represent ambient concentrations over an extensive area.

The following outlines macro scale pollutant specific siting criteria contained within 40 CFR Part 58. Siting criteria associated with regional measurement f particulate through the IMPROVE program are also indicated where relevant.

Fine particulate matter ($PM_{2.5}$)

In Appendix D of 40 CFR Part 58, the maximum scale of which $PM_{2.5}$ monitoring is discussed is at the regional scale (10's to 100's of kilometres). Using representative conditions for an area implies a level of homogeneity in that area and for that reason, regional scale measurements are applicable to generally sparsely populated areas. Data collected on this scale would provide information on larger scale processes of particulate emissions, losses and transport.

Appendix D of 40 CFR Part 58 states that the development of effective pollution control strategies requires an understanding at regional geographic scales of the emission sources and atmospheric processes that are responsible for elevated $PM_{2.5}$ levels and may also be associated with elevated O_3 and regional haze.

Data is required at this scale to provide information regarding trends and compliance with standards given that they represent areas where people commonly live and work for extended periods.

Regional $PM_{2.5}$ measurements are made at IMPROVE sites across the US (refer **Section 3.4**). The standard operating procedure (UCDavis, 2017a) for IMPROVE sites outlines the site requirements associated with macro scale siting criteria as:

> *"The site must:*
>
> *..*
>
> - *be located at a site where aerosols are representative of regional, not local, visibility conditions.*
>
> *.."*

Ozone

Regional scale measurements of O_3 are used to typify concentrations over large portions of a metropolitan areas and even larger areas with dimensions of as much as 100's of kilometres (i.e. regional scale). Such measurements are useful in determining the O_3 which is transported into and out of a metropolitan area, as well as background concentrations. Regional scale sites can also be maximum concentration locations when considering very large metropolitan areas.

The determination of a location for a regional scale background O_3 monitoring location should be performed through meteorological analysis and analysis of trajectories and emission patterns.

Regional scale sites may be located to provide data on O_3 transport between cities, as background sites, or for other data collection purposes.

Measurements are required to be made year-round.

Carbon monoxide

In Appendix D of 40 CFR Part 58, the maximum scale of which CO monitoring is discussed is at the neighbourhood scale (0.5 km to 4 km). Data is required at this scale to support health and scientific research and for use in modelling.

Lead

In Appendix D of 40 CFR Part 58, the maximum scale of which Pb monitoring is discussed is at the neighbourhood scale (0.5 km to 4 km). Where a site is located away from immediate Pb sources, the site may be useful in representing typical air quality values for a larger residential area, and therefore suitable for population exposure and trends analyses.

Nitrogen dioxide

In Appendix D of 40 CFR Part 58, the maximum scale of which NO_2 monitoring is discussed is at the urban scale (4 km to 50 km). Data is required at this scale to assess trends in area-wide air quality and the effectiveness of large-scale air pollution control strategies.

Sulphur dioxide

In Appendix D of 40 CFR Part 58, the maximum scale of which SO_2 monitoring is discussed is at the urban scale (4 km to 50 km). Data is required at this scale to estimate concentrations over large portions of an urban area, to assess trends in area-wide air quality and the effectiveness of large-scale air pollution control strategies.

Urban scale sites may also support other monitoring objectives such as identifying background concentrations when monitors are located upwind of local sources.

Particulate matter (PM_{10})

In Appendix D of 40 CFR Part 58, the maximum scale of which PM_{10} monitoring is discussed is at the neighbourhood scale (0.5 km to 4 km). Data is required at this scale to provide information regarding trends and compliance with standards given that they represent areas where people commonly live and work for extended periods.

Coarse particulate matter ($PM_{10-2.5}$)

In Appendix D of 40 CFR Part 58, the maximum scale of which coarse particulate monitoring is discussed is at the neighbourhood scale (0.5 km to 4 km) which would represent conditions throughout some reasonably homogeneous urban sub-region. Homogeneity refers to particulate matter concentrations as well as the land use and surface characteristics.

3.5.2 Micro Scale

40 CFR Part 58 (Appendix E) contains siting criteria for probe and monitoring paths. The pollutant-specific probe and monitoring path siting criteria generally apply to all spatial scales except where noted otherwise.

Horizontal and vertical placement

The probe or at least 80 % of the monitoring path must be located between 2 m and 15 m above ground level for all O_3 and SO_2 monitoring sites, and for neighbourhood or larger spatial scale Pb, PM_{10}, $PM_{2.5}$, NO_2, and CO sites.

Spacing from minor sources

The plume from the local minor sources should not be allowed to inappropriately impact the air quality data collected at a site. Particulate matter sites should not be located in an unpaved area unless there is vegetative ground cover year-round, so that the impact of windblown dusts will be kept to a minimum.

Similarly, local sources of nitric oxide (NO) and ozone-reactive hydrocarbons can have a scavenging effect causing unrepresentatively low concentrations of O_3 in the vicinity of probes and monitoring paths for O_3. To minimise these potential interferences, the probe or at least 90 % of the monitoring path must be away from furnace or incineration flues or other minor sources of SO_2 or NO. The separation distance should take into account the heights of the flues, type of waste or fuel burned, and the sulphur content of the fuel.

Spacing from obstructions

Buildings and other obstacles may possibly scavenge SO_2, O_3, or NO_2, and can act to restrict airflow for any pollutant. To avoid this interference, the probe, inlet, or at least 90 % of the monitoring path must have unrestricted airflow and be located away from obstacles. The distance from the obstacle to the probe, inlet, or monitoring path must be at least twice the height that the obstacle protrudes above the probe, inlet, or monitoring path.

Special consideration must be given to the use of open path analysers due to their inherent potential sensitivity to certain types of interferences, or optical obstructions. A monitoring path must be clear of all trees, brush, buildings, plumes, dust, or other optical obstructions, including potential obstructions that may move due to wind, human activity, growth of vegetation, etc.

Temporary optical obstructions, such as rain, particles, fog, or snow, should be considered when siting an open path analyser. Any of these temporary obstructions that are of sufficient density to obscure the light beam will affect the ability of the open path analyser to continuously measure pollutant concentrations.

Transient, but significant obscuration of especially longer measurement paths could occur as a result of certain meteorological conditions (e.g., heavy fog, rain, snow) and/or aerosol levels that are of a sufficient density to prevent the open path analyser's light transmission. If certain compensating measures are not otherwise implemented at the onset of monitoring (e.g., shorter path lengths, higher light source intensity), data recovery during periods of greatest primary pollutant potential could be compromised. For instance, if heavy fog or high particulate levels are coincident with periods of projected NAAQS-threatening pollutant potential, the representativeness of the resulting data record in reflecting maximum pollutant concentrations may be substantially impaired despite the fact that the site may otherwise exhibit an acceptable, even exceedingly high overall valid data capture rate.

Spacing from trees

Trees can provide surfaces for SO_2, O_3, or NO_2 adsorption or reactions, and surfaces for particle deposition. Trees can also act as obstructions in cases where they are located between the air pollutant sources or source areas and the monitoring site, and where the trees are of a sufficient height and leaf canopy density to interfere with the normal airflow around the probe, inlet, or monitoring path.

To reduce this possible interference/obstruction, the probe, inlet, or at least 90 % of the monitoring path must be at least 10 m or further from the drip line of trees.

The scavenging effect of trees is greater for O_3 than for other criteria pollutants. Monitoring agencies are required to take steps to consider the impact of trees on ozone monitoring sites and take steps to avoid this problem.

Spacing from roadways

In siting an O_3 analyser, it is important to minimise destructive interferences form sources of NO, since NO readily reacts with O_3. A sampling site having a point analyser probe located closer to a roadway **Table 5** (replicated from US EPA requirements) should be classified as microscale or middle scale, rather than neighbourhood or urban scale, since the measurements from such a site would more closely represent the middle scale.

In siting NO_2 monitors for neighbourhood and larger scale monitoring, it is important to minimise near-road influences. A sampling site having a point analyser probe located closer to a roadway than allowed by the requirements in **Table 5** (replicated from US EPA requirements) should be classified as microscale or middle scale rather than neighbourhood or urban scale.

In siting PM monitors, since emissions associated with the operation of motor vehicles contribute to urban area particulate matter ambient levels, spacing from roadway criteria are necessary for ensuring national consistency in PM sampler siting. If the sample is 20 m from the same road, it will be classified as middle scale; if 40 m, neighbourhood scale; and if 110 m, an urban scale.

Cost benefits, historical trends, and other factors may be used to add support to the site selection criteria, however, they in themselves, will not be acceptable reasons for granting a waiver.

In specific relation to particulate matter, section 2.2.4 of (USEPA, 1997) provides guidance for the siting of PM_{10} and $PM_{2.5}$ monitoring equipment for the purposes of background monitoring.

> *"Background and Regional Transport Monitoring Background and regional transport (or boundary) monitors are located outside of local air quality jurisdictions to determine how much of the PM at community-oriented sites derives from external sources. Background sites are intended to quantify regionally representative $PM_{2.5}$ for sites located away from populated areas and other significant emission sources. Transport sites are intended to measure fine particle contributions from upwind source areas, or mixtures of source areas, that move into a planning area.*
>
> *Most planning areas contain at least one substantial metropolitan area. Several of these also include industrial sources, either concentrated in one or a few districts or dispersed throughout the planning area. Air quality planning areas also contain less developed areas that may be distant from the densely populated centers and industrial emitters. These may include agricultural areas, dormant lands, large parks, wildlife and nature preserves, large military bases, etc.*
>
> *Transport sites should be located upwind of planning area boundaries, outside of the urban-scale zone of influence. For the most part, transport sites are between planning areas, or between districts containing large emitters (e.g., industrial complexes, isolated point sources) and a planning area. Measurements from transport sites represent transport into the planning area only during periods when the wind is from the direction of the external source area toward the planning area. During other periods, the transport site may also serve the purposes of a background site, or as a transport site for another planning area. For this reason, transport site locations are selected to achieve multiple purposes.*
>
> *Meteorological data needed to evaluate which purposes are being served should be available along with the $PM_{2.5}$ measurements. Background monitors are intended to measure $PM_{2.5}$ concentrations that are not dependent on upwind sources, although the particles they quantify will be a mixture of natural and manmade source material. These stations should be distant from identified emitters, and may be at higher elevations than the urban-scale community exposure monitors.*
>
> *Current IMPROVE (Interagency Monitoring of Protected Visual Environments) $PM_{2.5}$ monitoring in National Parks and Wilderness Areas (Eldred et al., 1990) provides the best examples of background monitoring sites, but there is a dearth of these sites in the non-western states.*
>
> *Properly sited background stations should measure $PM_{2.5}$ typical of the lowest ambient concentrations in a state or region. These sites should not be along transport pathways, though in densely populated or industrialised regions (such as the northeast corridor) a given sample may or may not be along such a pathway depending on which way the wind is blowing. Several background sites may be needed in large and geographically diverse states, such as California and others in the west, where terrain produces major barriers to atmospheric flow. Regions lacking IMPROVE monitors should determine the proximity of National Parks, Wilderness Areas, and State Preserves as candidates for background sites. Background monitors also contribute to regional visibility goals that are part of other air quality regulations."*

Regional $PM_{2.5}$ measurements are made at IMPROVE sites across the US (refer **Section 3.4**). The standard operating procedure (UCDavis, 2017a) for IMPROVE sites outlines the site requirements associated with micro scale siting criteria as:

"The site must:

- *be removed from local sources, such as diesel, wood smoke, automobile emissions, road dust, or construction*
- *adhere to siting requirements conducive to regional aerosol sampling, including inlet height, an absence of interference in air flow from trees or buildings in a 30° cone above the sampler, and a minimum of 270° of free air flow around the sampler*
- *be secure from potential vandalism*
- *have an operator available to service the site*
- *be accessible during all months of the year"*

The standard operating procedure (UCDavis, 2017a) for IMPROVE sites also provides general advice in the location of prospective sites which is relevant to the selection of BAQMS:

"Site selection begins with the process of locating potential sites in the monitoring area of interest. Specific siting criteria should be obtained from the project manager, and this information may include regional or site-specific program objectives and meteorological conditions of the monitoring area, as well as other considerations. Potential sites may be located from maps and through consultation with a local contact familiar with the monitoring area of interest.

The site should not be located in areas subject to unusual aerosol transport conditions. There should be no local pollution sources or unusual meteorology. The aerosol at the site should be representative of the regional air mass.

The site criteria fall into three categories:

(1) the site must represent nearby Class I areas [Regional Haze Rule applies to Class I areas such as national parks, wilderness areas etc];

(2) the site should be regionally representative, avoiding local pollution sources or areas with unusual meteorology; and

(3) the site must avoid nearby obstacles that could affect sample collection. In most cases, the criteria are based on EPA guidelines. The criteria are not absolutes. A site that falls slightly outside a criterion may be the best choice. Significant variances from any criterion should be well documented and will be reviewed by the IMPROVE steering committee before the site is installed.

The following criteria should be used as guidelines in selecting the specific location of a sampling site.

(1) If a site is intended to represent Class I areas, it must meet the following criteria:

a. The distance between the site and the closest portion of all Class I areas should not be greater than 100 km. A smaller distance would be desirable. Note that the closest site may not be the best site.

b. The elevation of the site should lie between the highest and lowest elevations of all Class I areas to be represented. Exceedances of 100 feet or 10% are considered to be meeting this criterion. Larger exceedances are permitted if agreed to by the states and FLMs.

(2) The site must avoid small valleys with non-representative meteorology. Valleys with towns or other emission sources are definitely to be avoided. Valleys without emission sources, but with significant inversions, should also be avoided. The site should not be located on barren ground that is not typical of the region.

(3) The site must avoid all local sources of pollution.

a. automotive sources

b. combustion sources

Avoid any areas influenced by diesel generator emissions, wood smoke, or incinerators.

c. dust sources

At least 400m from a large potential source of dust, such as a landfill, agricultural operations, or an unpaved road with more than 400 cars per day.

(4) The site must not have large obstructions such as trees or buildings that would hinder the sampling of regional representative aerosols. If necessary, the sampler could be placed on a platform to clear obstructions or to stay above any snow pack.

a. There should be unrestricted airflow for an arc of at least 270°. The predominant wind direction must be in the unrestricted 270°. In practice, having unrestricted flow in all directions is preferable.

b. Within 10m of the sampler, any solid barriers or trees should be at least 1m below the inlet, as shown on the left side of [sic]

c. Figure 5. In general, a pole or meteorological tower will not be a solid barrier. We will set as a guideline that a solid barrier is any object that subtends more than 10°. (Example: Hold a ruler at arm's length [24 inches]; if the object subtends more than four inches, it is a solid barrier.) [sic]

d. Beyond 10m of the sampler, the solid barriers or trees should not be higher than 30° above the horizontal with respect to the inlet, as shown on the right side of Figure 5. (Example: Hold a ruler at arm's length [24 inches]; 30° is a height of 14 inches.)

(5) If possible, all other samplers located at the site should use brushless pump motors (i. e., high-volume samplers often use motors with brushes that can result in high copper emissions). If brush pumps exist, the Project Manager should be notified and provided with the sampler specifications and the sampling schedule. The Project Manager will devise a site-specific approach for minimizing the effects of pump emissions.

(6) The site must have electrical power (2 circuits; 120 volt, 60 hertz, 20 Amperes). If new power must be installed it is anticipated that the local FLM will be able to obtain the necessary financial resources. The Steering Committee will consider exceptions.

(7) The site must be accessible for a weekly sample change in all but the most severe weather conditions

(8) The site should be located near existing particulate monitoring stations to provide continuity to the data set whenever possible.

(9) The sampler inlets must be located between 3 and 4 meters above the ground, and at least 1 meter above the shelter roof or above any other obstruction within 10 meters of the inlets. The spacing between inlet stacks must be at least 24 inches

(10) There must be an available and reliable site operator.

(11) The site should be secure from potential vandalism.

(12) If possible, the sampler should be located in an open-air shelter.

(13) There should be local land manager or landowner cooperation.

3.6 Technology and Systems

Data collected from Federal Reference Methods (FRM), Federal Equivalent Methods (FEM) and Approved Regional Methods (ARM) are used by the US EPA to compare measured values against the NAAQS. The SLAMS and NCore stations are used to validate regional air quality management assumptions / modelling.

Section 2.2.6 of (USEPA, 2017) provides guidance on the measurement methods in $PM_{2.5}$ monitoring networks:

> *"Measurement methods applied in PM networks are ground-based and are divided into three categories: Federal Reference Method (FRM) samplers, Federal Equivalent Method (FEM) samplers, and other samplers. The non-FRM samplers are distinguished by their level of similarity in design to Federal Reference Methods (FRM). The further from the FRMs in design, the more stringent are the requirements for designation of an instrument as an equivalent method. ·*
>
> *Federal Reference Methods: Federal Reference Methods for $PM_{2.5}$ are methods that have been designated as such under CFR 40 Chapter 1 Part 53, having met design and performance characteristics described in Part 50, Appendix L; Part 53, Subpart E; and Part 58, Appendix A. Reference method instruments acquire deposits over 24-hour periods on Teflon-membrane filters from air drawn at a controlled flow rate through a tested $PM_{2.5}$ inlet. The inlet and size separation components are specified by design, with drawings and manufacturing tolerances published in the Code of Federal Regulations. Most of the other measurement components and procedures are specified by performance characteristics, with specific test methods to assess that performance. ·*
>
> *Class I Equivalent Methods: Class I equivalent method instruments maintain the same measurement principles as reference method instruments, but with minor design changes. Class I instruments are intended to provide for sequential sampling without operator intervention at measurement sites that sample every day. Testing of design and performance characteristics for Class I instruments is given in Part 53, Subpart E. ·*
>
> *Class II Equivalent Methods: Class II equivalent method instruments include all other instruments based on a 24-hour integrated filter sample with subsequent moisture equilibration and gravimetric mass analysis, but differ substantially in design from the reference method instruments. More extensive performance testing is required for a Class II equivalent instrument than for reference or Class I equivalent instruments. Testing of design and performance characteristics for Class II methods is given in Part 53, Subpart F. ·*
>
> *Class III Equivalent Methods: Class III equivalent method instruments include any candidate instruments that cannot qualify as Class I or Class II instruments. These may either be filter-based integrated samplers not meeting Class I or Class II criteria, or filter or non-filter based continuous or semi-continuous samplers. Test procedures and performance requirements for Class III candidate method instruments will be determined on a case-by-case basis. The testing for these instruments will be the most stringent, because equivalency to reference methods must be demonstrated over a wide range of particle size distributions and aerosol compositions. Other methods include all non-FRM or non-equivalent measurement methods capable of characterizing fine particles that may not be or have not yet been classified as an equivalent method. Existing manual and continuous analyzers are in this category and potentially include the dichotomous sampler, IMPROVE samplers, nephelometers, beta attenuation monitors, and Tapered Element Oscillating Microbalances (TEOMs). Such instruments are not precluded from becoming equivalent on a site-specific, regional or national basis."*

A description of the FRM and FEM systems used to monitor the six criteria air pollutants for assessment of compliance with the NAAQS is presented in (USEPA, 2018) and (Gilliam & Hall, 2016). A summary of those methods is presented in **Table 9**. Note that no derogations from those FRM and FEM systems are noted for any monitoring over differing spatial scales. The criteria relating to the range, precision, accuracy and sampling period associated with each FRM method are presented in **Table 10**.

Table 9 Approved methods for air quality monitoring under the US CAA

Pollutant	FRM/FEM	Method
PM_{10}	FRM	Particulate Filtration (CFR 40, Part 50, App J)
	FEM	Beta-Attenuation Monitoring
		Tapered Element Oscillating Microbalance (TEOM®)
		Dichotomous Air Sampler
		Optical light scattering
$PM_{2.5}$	FRM	Particulate Filtration (CFR 40, Part 50, App J)
	FEM	Beta-Attenuation Monitoring
		Vert Sharp Cut Cyclone (VSCC)
		Tapered Element Oscillating Microbalance (TEOM®)
		Dichotomous Air Sampler
		Laser Aerosol Spectrometry
		Optical light scattering
$PM_{10-2.5}$	FRM	Particulate Filtration (CFR 40, Part 50, App J)
	FEM	Beta-Attenuation Monitoring
		Tapered Element Oscillating Microbalance (TEOM®)
		Dichotomous Air Sampler
		Optical light scattering
SO_2	FRM	Pararosaniline Method (CFR 40, Part 50, App. A)
	FEM	U.V. Fluorescence
		Differential Optical Absorption Spectroscopy (DOAS)
O_3	FRM	Ethylene Chemiluminescence (CFR 40, Part 50, App. D)
	FEM	U.V. Photometry
		Differential Optical Absorption Spectroscopy (DOAS)
CO	FRM	Non-Dispersive Infrared Photometry (CFR 40, Part 50, App. C)
	FEM	U.V. Photometry
NO_2 / NO_X	FRM	Gas Phase Chemiluminescence (CFR 40, Part. 50, App. F)
	FEM	Sodium Arsenite (SA) Method for NO_2
		TGS-ANSA
		Differential Optical Absorption Spectroscopy (DOAS)
		U.V. Photolytic Conversion
		Cavity Attenuated Phase Shift Spectroscopy (CAPS)

Pollutant	FRM/FEM	Method
Pb	FRM	Reference Method for the Determination of Lead (Pb) in Total Suspended Particulate (TSP) Matter {Collected from Ambient Air Using a High-Volume Sampler} (CFR 40, Part 50, Appendix G)
	FEM	Flame/Flameless Atomic Absorption Spectroscopy
		Inductively Coupled Plasma-Optical Emission Spectrometry
		Inductively Coupled Plasma-Mass Spectrometry (ICP-MS)
		X-Ray Fluorescence Spectrometry

Source: (Gilliam & Hall, 2016), (USEPA, 2018)

Table 10 Operational criteria for FRM

Pollutant	Method	Range	Precision	Accuracy	Sampling period
PM_{10}	Particulate Filtration (CFR 40, Part 50, App J)	Upper 24-hr mass concentration of 300 µg·m^{-3} whilst maintaining operating flow rate within limits	5 µg·m^{-3} for concentrations below 80 µg·m^{-3} and 7 % for concentrations above 80 µg·m^{-3}	±10 % of that calculated for an ideal sampler whose sampling effectiveness is explicitly specified. Also, the particle size for 50 % sampling effectiveness is required to be 10 ±0.5 micrometres	24 hrs ± 1 hr
$PM_{2.5}$	Particulate Filtration (CFR 40, Part 50, App J)	Lower range of approx. 2 µg·m^{-3} Upper 24-hr mass concentration of 200 µg·m^{-3} whilst maintaining operating flow rate within limits	-	±10 % of that calculated for an ideal sampler whose sampling effectiveness is explicitly specified.	24 hrs ± 1 hr

Pollutant	Method	Range	Precision	Accuracy	Sampling period
$PM_{10-2.5}$	Particulate Filtration (CFR 40, Part 50, App J)	Lower range of approx. 3 µg·m^{-3} Upper 24-hr mass concentration of 200 µg·m^{-3} whilst maintaining operating flow rate within limits	Upper 95 percent confidence limit for the coefficient of variation (CV) of 15 percent	(As bias) upper 95 percent confidence limit for the absolute bias of 15 percent	24 hrs ± 1 hr
SO_2	Pararosaniline Method (CFR 40, Part 50, App. A)	Lower: 0.01 ppm (25 µg·m^{-3}) in air sample of 30 L and 0.005 ppm (13 µg·m^{-3}) in 288 L Upper: 0.43 ppm (1 130 µg·m^{-3}) in 30 L and 0.23 ppm (590 µg·m^{-3}) in 288 L	4.6% (at the 95 % confidence level)	The replication error varies linearly with concentration from ±2.5 µg·m^{-3} at concentrations of 100 µg·m^{-3} to ±7 µg·m^{-3} at concentrations of 400 µg·m^{-3}.	Short term – 30 mins to 1 hr Longer term – 24-hr
O_3	Ethylene Chemiluminescence (CFR 40, Part 50, App. D)	Dependent on photometer	Dependent on photometer	Dependent on photometer	Continuous
CO	Non-Dispersive Infrared Photometry (CFR 40, Part 50, App. C)	Dependent on analyser	Dependent on analyser	Dependent on analyser	1 hr or longer
NO_2 / NO_X	Gas Phase Chemiluminescence (CFR 40, Part. 50, App. F)	Dependent on analyser	Dependent on analyser	Dependent on analyser	Continuous

Pollutant	Method	Range	Precision	Accuracy	Sampling period
Pb	Reference Method for the Determination of Lead (Pb) in Total Suspended Particulate (TSP) Matter {Collected from Ambient Air Using a High-Volume Sampler} (CFR 40, Part 50, Appendix G)	0.00024 µg·m^{-3} to 0.6 µg·m^{-3}	±1 % RSD	±1 %	24 hrs

The IMPROVE monitoring network uses four sampling modules 1A, 2B, 3C and 4D. The standard operating procedure for the installation of samplers (UCDavis, 2017b) provides a description of the four modules:

"Module 1A collects fine particles (0 – 2.5µm) on a stretched Teflon® filter, and provides data on elemental composition of fine particles.

Module 2B collects fine particles (0 – 2.5µm) on a nylon filter, has a denuder before the nylon filter to remove acidic gases, and is used to quantify particulate anions (nitrate, nitrite, sulfate, and chloride).

Module 3C collects fine particles (0 – 2.5µm) on a quartz filter to measure organic and elemental carbon.

Module 4D collects coarse particles (0 – 10µm) on a stretched Teflon® filter, and provides data on PM10 mass loading.

Some sites have a fifth module for collocated precision measurements (called a 5X module), which can be a duplicate of an 1A, 2B, 3C, or 4D module.

Each module is independent, with a separate inlet, sizing device, flow measurement system, critical orifice flow restrictor, and pump. All modules are wired to a common controller which, for IMPROVE sampling, is programmed to collect a twenty-four hour sample every third day from midnight to midnight. The design is simple and rugged to withstand ambient field conditions, and for ease of operation and maintenance. The purpose of this standard operating procedure is to facilitate installation of IMPROVE aerosol samplers, to assure consistent, quality data, and to minimize data loss by installing aerosol monitoring systems according to design specifications and EPA requirements."

3.7 Case study: Background air quality monitoring in California

The California Air Resources Board (CARB) operates an extensive air quality monitoring network of over 250 sites in the southwest of the United States. Similar to NSW, many regions in California are characterised by complex terrain, variable meteorological conditions and diverse emissions sources. The network is designed to assess compliance against National Air Quality Standards, and also standards applicable in California, set by CARB.

The monitoring objectives and spatial scales associated with air quality monitoring in California align with those set out by the US EPA and which are presented in **Table 7** (micro, middle, neighbourhood, urban and regional scales). The objectives are also aligned between California and the broader US with those being the monitoring of highest concentrations or source impacts, concentrations associated with high population densities, and those associated with background concentrations, regional transport, or impacts on visibility, vegetation and other welfare-based impacts.

Federal regulations require state and local agencies that conduct ambient air quality monitoring for regulatory purposes to submit an Annual Network Plan to the US EPA. The 2018 Annual Monitoring Network Report for California covers 25 of the 35 air districts in California, with the remainder choosing to submit their own plans. Of the 77 stations covered by the network report, 15 are classified as 'general background' sites for one or more pollutants, on spatial scales associated with the 'neighbourhood', 'urban' and 'regional' scales.

It is notable that sites which are classified as general background for one or more pollutants can often be classified in a different manner for other pollutants. For example, the Red Bluff-Walnut site in the Tehama District monitors O_3, PM_{10} and $PM_{2.5}$. For O_3, the site is classified as a population exposure type, for PM_{10} is a highest concentration type site and for $PM_{2.5}$ is a general background type site. All pollutant measurements are reflective of the neighbourhood scale at this site.

Another example may be those sites which monitor certain pollutants reflective of the regional scale. The Colusa-Sunrise Blvd site in the Colusa District also monitors O_3, PM_{10} and $PM_{2.5}$. For O_3, the site is classified as a general background type, for PM_{10} is a highest concentration and population exposure type site and for $PM_{2.5}$ is a population exposure type site. O_3 measurements are reflective of the regional scale, whereas measurements of PM_{10} and $PM_{2.5}$ are reflective of the neighbourhood scale.

These examples are provided to demonstrate that the classification of a site type is in large part a function of its location in relation to sources of air pollutants which can vary pollutant to pollutant.

No meteorological measurements are made at the Red Bluff-Walnut site but are made at the Colusa-Sunrise Blvd sites. Those measurements are temperature, relative humidity, wind direction and wind speed.

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4. EUROPEAN UNION

The "Air Quality Framework Directive" on ambient air quality assessment and management (96/62/EC) was adopted by the European Council on 27 September 1996. Supplementing the Air Quality Framework Directive were a series of 'daughter' directives:

- Directive 1999/30/EC of the European Parliament and of the Council relating to limit values for sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter and lead in ambient air (First Daughter Directive).
- Directive 2000/69/EC of the European Parliament and of the Council relating to limit values for benzene and carbon monoxide in ambient air (Second Daughter Directive).
- Directive 2002/3/EC of the European Parliament and of the Council relating to ozone in ambient air (Third Daughter Directive).
- Directive 2004/107/EC of the European Parliament and of the Council relating to arsenic, cadmium, mercury, nickel and polycyclic aromatic hydrocarbons in ambient air (Fourth Daughter Directive).

Subsequently, the Air Quality Framework Directive and the subsequent daughter directives have been brought together under the Ambient Air Quality and Cleaner Air for Europe (CAFE) Directive (2008/50/EC) (the CAFE Directive).

4.1 Definitions and Classifications

Directive 2008/50/EC, Chapter I, Article 2 provides definitions used in the Directive. Clause 1 provides the following definition of "contributions from natural sources":

> *" 'contributions from natural sources' shall mean emissions of pollutants not caused directly or indirectly by human activities, including natural events such as volcanic eruptions, seismic activities, geothermal activities, wild-land fires, high-wind events, sea sprays or the atmospheric re-suspension or transport of natural particles from dry regions"*

The following definition for "urban background locations":

> *" 'urban background locations' shall mean places in urban areas where levels are representative of the exposure of the general urban population"*

No other *definitions* relating to background air quality on other scales / localities are outlined within the CAFE Directive.

Reference is however made within the CAFE Directive to 'rural background', specifically in relation to measurements of fine particulate matter (Clause 8):

> *"Detailed measurements of fine particulate matter at rural background locations should be made in order to understand better the impacts of this pollutant and to develop appropriate policies. Such measurements should be made in a manner consistent with those of the cooperative programme for monitoring and evaluation of the long range transmission of air pollutants in Europe (EMEP) set up under the 1979 Convention on Long-range Transboundary Air Pollution approved by Council Decision 81/462/EEC of 11 June 1981"*

Further information relating to 'rural background' is provided in **Section 4.4**.

Although no specific definition of other site 'types' are provided in the CAFE Directive, mention is made of 'traffic' (Annex III, B 1 (b)), 'industrial' (Annex I, A) and 'suburban' (Annex VIII, A) sites.

The system of site classification adopted by the UK (an EU member) Department for Environment, Food and Rural Affairs (DEFRA) in the Automatic Urban and Rural Network (AURN) is based on two criteria:

- the nature of the surrounding area (which may be **urban**, **suburban** or **rural**); and,
- the types of pollution sources involved (which may be **traffic**, **industrial** emissions, or "**background**" i.e. not located close to any specific emission source).

As detailed within the Site Operator's Manual for the AURN (Ricardo AEA, 2012) (page 30):

> *"So, a site could be described as (for example) "urban traffic" – in an urban area, and close to a busy road where local concentrations of pollutants are dominated by vehicle emissions, "urban background" – in an urban area but well away from major roads and specific industrial emission sources, or "rural background" if it is in a rural area well away from emission sources. Any combination is possible, although some (such as "rural traffic" or "rural industrial", are likely to be rare)."*

With specific reference to 'background' stations (Ricardo AEA, 2012) states that they should be:

> *"Located such that its pollution level is not influenced significantly by any single source or street, but rather by the integrated contribution from all sources upwind of the station e.g. by all traffic, combustion sources etc. upwind of the station in a city, or by all upwind source areas (cities, industrial areas) in a rural area. These sampling points shall, as a general rule, be representative for several square kilometres. At rural background sites, the sampling point should not be influenced by agglomerations or industrial sites in its vicinity, i.e. sites closer than five kilometres."*

4.2 Purposes

Annex IV (Measurements at background locations irrespective of concentration) provides a summary of the definitions for background monitoring as prescribed under the CAFE Directive. The objectives are defined as:

> *"The main objectives of such measurements are to ensure that adequate information is made available on levels in the background. This information is essential to judge the enhanced levels in more polluted areas (such as urban background, industry related locations, traffic related locations), assess the possible contribution from long-range transport of air pollutants, support source apportionment analysis and for the understanding of specific pollutants such as particulate matter. It is also essential for the increased use of modelling also in urban areas."*

4.3 Scales

The macroscale siting classification of monitoring sites is defined by Annex VIII and is presented in **Table 11**.

Table 11 Macroscale siting classification – CAFE Directive

Type of station	Objectives of measurement	Representativeness[(a)]	Macroscale siting criteria
Urban	Protection of human health: To assess the exposure of the urban population to ozone, i.e. where population density and ozone concentration are relatively high and representative of the exposure of the general population	A few km^2	• Away from the influence of local emissions such as traffic, petrol stations, etc.; • Vented locations where well mixed levels can be measured; • Locations such as residential and commercial areas of cities, parks (away from the trees), big streets or squares with very little or no traffic, open areas characteristic of educational, sports or recreation facilities
Suburban	Protection of human health and vegetation: to assess the exposure of the population and vegetation located in the outskirts of the agglomeration, where the highest ozone levels, to which the population and vegetation are likely to be directly or indirectly exposed occur	Some tens of km^2	• At a certain distance from the area of maximum emissions, downwind following the main wind direction/directions during conditions favourable to ozone formation; • Where population, sensitive crops or natural ecosystems located in the outer fringe of an agglomeration are exposed to high ozone levels; • Where appropriate, some suburban stations also upwind of the area of maximum emissions, in order to determine the regional background levels of ozone
Rural	Protection of human health and vegetation: to assess the exposure of population, crops and natural ecosystems to sub-regional scale ozone concentrations	Sub-regional levels (some hundreds of km^2)	• Stations can be located in small settlements and/or areas with natural ecosystems, forests or crops; • representative for ozone away from the influence of immediate local emissions such as industrial installations and roads; • at open area sites, but not on summits of higher mountains

Type of station	Objectives of measurement	Representativeness(a)	Macroscale siting criteria
Rural background	Protection of vegetation and human health: to assess the exposure of crops and natural ecosystems to regional-scale ozone concentrations as well as exposure of the population	Regional/ national/ continental levels (1,000 to 10,000 km^2)	• Station located in areas with lower population density, e.g. with natural ecosystems, forests, at a distance of at least 20 km from urban and industrial areas and away from local emissions; • Avoid locations which are subject to locally enhanced formation of near-ground inversion conditions, also summits of higher mountains; • Coastal sites with pronounced diurnal wind cycles of local character are not recommended

Note: (a) Sampling points should, where possible, be representative of similar locations not in their immediate vicinity.

4.4 Scope

Chapter II (Assessment of Air Quality), Article 6 (Assessment criteria), Clause 5 states:

> *"In addition to the assessments referred to in paragraphs 2, 3 and 4, measurements shall be made, at rural background locations away from significant sources of air pollution, for the purposes of providing, as a minimum, information on the total mass concentration and the chemical speciation concentrations of fine particulate matter ($PM_{2,5}$) on an annual average basis and shall be conducted using the following criteria:*
>
> *(a) one sampling point shall be installed every 100 000 km^2;*
>
> *(b) each Member State shall set up at least one measuring station or may, by agreement with adjoining Member States, set up one or several common measuring stations, covering the relevant neighbouring zones, to achieve the necessary spatial resolution;*
>
> *(c) where appropriate, monitoring shall be coordinated with the monitoring strategy and measurement programme of the Cooperative Programme for Monitoring and Evaluation of the Long-range Transmission of Air Pollutants in Europe (EMEP)"*

Annex IV (Measurements at rural background locations irrespective of concentration) provides a succinct summary of the definitions for background monitoring as prescribed under the CAFE Directive. The following guidance is provided:

> *"Measurement of $PM_{2,5}$ must include at least the mass concentration and appropriate compounds to characterise its chemical composition. At least the list of chemical species given below shall be included.*
>
> *SO_4^{2-} Na^+ NH_4^+ Ca_2^+ elemental carbon (EC)*
>
> *NO_3^- K^+ Cl^- Mg_2^+ organic carbon (OC)*

Guidance for other pollutants is not addressed in Annex IV.

Annex V (Criteria for determining minimum numbers of sampling points for fixed measurement of concentrations of sulphur dioxide, nitrogen dioxide and oxides of nitrogen, particulate matter (PM_{10}, $PM_{2,5}$), lead, benzene and carbon monoxide in ambient air) provides the following requirements for BAQMS. The minimum requirement for NO_2, PM, C_6H_6 and CO as at least one (1) urban background monitoring station and that the number of BAQMS cannot vary by a factor of 2 from the number of 'traffic orientated' AQMS.

Corresponding, Annex VIII (criteria for classifying and locating sampling points for assessment of O_3 concentrations) provides the following criteria for the siting of rural BAQMS with regard to O_3 measurements:

- Objective: Protection of vegetation and human health: to assess the exposure of crops and natural ecosystems to regional-scale ozone concentrations as well as exposure of the population
- Representativeness: Regional/national/continental levels (1 000 to 10 000 km^2)
- Macroscale siting criteria: Station located in areas with lower population density, e.g. with natural ecosystems, forests, far removed from urban and industrial areas and away from local emissions; Avoid locations which are subject to locally enhanced formation of near-ground inversion conditions, also summits of higher mountains; Coastal sites with pronounced diurnal wind cycles of local character are not recommended.

As a footnote, Annex VIII states:

> ***"For rural and rural background stations the location shall, where appropriate, be coordinated with the monitoring requirements of Commission Regulation (EC) No 1737/2006 of 7 November 2006 laying down detailed rules for the implementation of Regulation (EC) No 2152/2003 of the European Parliament and of the Council concerning monitoring of forests and environmental interactions in the Community."***

A review of EC 1091/94[1] indicates that the siting criteria should be conversant with the selection of arboreal 'reference' plots which are used to measure flora degradation / loss due to air pollution.

Annex IX (criteria for determining the minimum number of sampling points for fixed measurement of concentrations of ozone) states that one (1) rural BAQMS should be provided per 50 000 km^2, as an average density over all zones, and one (1) per 25 000 km^2 in areas of complex terrain.

Chapter II, Section 1, Article 10, Clause 3 provides specifications for the monitoring of ozone states:

> ***"Nitrogen dioxide shall be measured at a minimum of 50 % of the ozone sampling points required under Section A of Annex IX. That measurement shall be continuous except at rural background stations, as referred to in Section A of Annex VIII, where other measurement methods may be used."***

1 https://publications.europa.eu/en/publication-detail/-/publication/cf2c9abb-3442-42a9-b853-4b59053da3fd/language-en

4.5 Site Selection Criteria

4.5.1 Macro Scale

Macroscale siting requirements for urban background monitoring stations is described in Annex III, B 1(c):

> *3(c) Urban background locations shall be located so that their pollution level is influenced by the integrated contribution from all sources upwind of the station. The pollution level should not be dominated by a single source unless such a situation is typical for a larger urban area. Those sampling points shall, as a general rule, be representative for several square kilometres*

Macroscale siting requirements for rural background monitoring stations is described in Annex III, B 1 (d-e):

> *(d) Where the objective is to assess rural background levels, the sampling point shall not be influenced by agglomerations or industrial sites in its vicinity, i.e. sites closer than five kilometres*
>
> *(e) Where contributions from industrial sources are to be assessed, at least one sampling point shall be installed downwind of the source in the nearest residential area. Where the background concentration is not known, an additional sampling point shall be situated within the main wind direction*

4.5.2 Micro Scale

Microscale Siting is described in Annex III C as:

In so far as is practicable, the following shall apply:

- *the flow around the inlet sampling probe shall be unrestricted (free in an arc of at least 270°) without any obstructions affecting the airflow in the vicinity of the sampler (normally some metres away from buildings, balconies, trees and other obstacles and at least 0,5 m from the nearest building in the case of sampling points representing air quality at the building line),*
- *in general, the inlet sampling point shall be between 1,5 m (the breathing zone) and 4 m above the ground. Higher positions (up to 8 m) may be necessary in some circumstances. Higher siting may also be appropriate if the station is representative of a large area,*
- *the inlet probe shall not be positioned in the immediate vicinity of sources in order to avoid the direct intake of emissions unmixed with ambient air,*
- *the sampler's exhaust outlet shall be positioned so that recirculation of exhaust air to the sampler inlet is avoided,*

The following factors may also be taken into account:

- *interfering sources; security; access; availability of electrical power and telephone communications; visibility of the site in relation to its surroundings; safety of the public and operators; the desirability of co-locating sampling points for different pollutants; planning requirements.*

4.6 Technology and Systems

In terms of specified technology, the CAFE Directive makes reference to 'fixed measurement' at BAQMS (see **Section 4.1**).

Chapter I, Article 2(23) provides the following definition which is relevant:

> *"fixed measurement" shall mean measurements taken at fixed sites, either continuously or by random sampling to determine the levels in accordance with the required data quality objectives*

Further to the above, Annex I provides the following data quality objectives (DQO):

Table 12 CAFÉ Directive - data quality objectives

Fixed measurements(A)	SO_2, NO_2, NO_x, CO	C_6H_6	PM_{10}, $PM_{2.5}$, Pb	O_3 (and related NO and NO_2)
Uncertainty	15 %	25 %	25 %	15 %
Minimum data capture	90 %	90 %	90 %	90 % (summer) 75 % (winter)
Minimum time coverage	--	35 %	--	--
Urban background and trend	--	90 %	--	--

Notes: (A): Member States may apply random measurements instead of continuous measurements for benzene and particulate matter if they can demonstrate to the Commission that the uncertainty, including the uncertainty due to random sampling, meets the quality objective of 25 % and the time coverage is still larger than the minimum time coverage for indicative measurements. Random sampling must be evenly distributed over the year in order to avoid skewing of results. The uncertainty due to random sampling can be determined by the procedure laid down in ISO 11222 (2002) "*Air Quality – Determination of the Uncertainty of the Time Average of Air Quality Measurements*". If random measurements are used to assess the number of exceedances (N[estimate]) of the PM_{10} daily limit value, the following correction should be applied: N[estimate] = N[measurement] x 365 days / number of measured days.

The European Committee for Standardisation (CEN) has produced centralised and standardised monitoring methods for the performance of the CAFE Directive that achieve the DQO set out above. The current prescribed methods are:

- Oxides of nitrogen: EN14211:2012: Ambient air. Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence
- Sulphur dioxide: EN14212:2012: Ambient air. Standard method for the measurement of the concentration of sulphur dioxide by ultraviolet fluorescence
- Ozone: EN14625:2012: Ambient air. Standard method for the measurement of the concentration of ozone by ultraviolet photometry
- Carbon monoxide: EN14626:2012: Ambient air. Standard method for the measurement of the concentration of carbon monoxide by non-dispersive infrared spectroscopy
- Particulate: EN12341:2014: Ambient air. Standard gravimetric measurement method for the determination of the PM_{10} or $PM_{2.5}$ mass concentration of suspended particulate matter
- Benzene: EN14662-1:2005: Ambient air. Standard method for the measurement of benzene concentrations. Automated pumped sampling with in situ gas

chromatography
EN14662-3:2015: Ambient air. Standard method for the measurement of benzene concentrations. Automated pumped sampling with in situ gas chromatograph

- Lead — EN12902:2005: Ambient air quality. Standard method for the measurement of Pb, Cd, AS, and Ni in the PM_{10} fraction of suspended particulate matter

4.7 Case study: Background air quality monitoring in the United Kingdom

Site: Lullington Heath
Environment Type: Rural Background
Environment: Located on a high plateau surrounded by heath land. 1.5 km from nearest road.

The Lullington Heath rural background monitoring station is located on the south coast of the UK, northeast of Brighton and approximately 5 km from the English Channel. The data collected at the monitoring station is used in ecosystem and air quality management. The station is one of 22 stations classified as Rural Background in the Automatic Urban and Rural Network (AURN). There is a total of 170 monitoring stations in the AURN at the time of writing.

The station was commissioned as part of the AURN in 1986, measuring only background O_3 at that time. In 1988, measurements of NO, NO_2, NO_X and SO_2 were added. Particulates are not measured as part of the AURN at Lullington Heath, although speciated particulate and some gaseous pollutants are measured as part of the Acid Gas and Aerosol Network (AGANet), measurements which commenced in 2017. A number of pollutants in precipitation are also monitored at Lullington Heath as part of the United Kingdom Eutrophying & Acidifying Network (UKEAP) Precipitation Network (PrecipNet), and NO_2 diffusion tube network (NO_2-Net) which commenced at Lullington Heath in 2016 and 2017, respectively.

The use of the Lullington Heath site has evolved over time and reviews (e.g. DEFRA, 2013) continue to recognise the importance of data collected at this location to inform large scale ecosystem and air quality management. Although no specific document outlining the rationale for siting individual stations is publicly available, the Site Operator's Manual (Ricardo AEA, 2012) defines the two criteria which make up the classification of 'Rural' + 'Background' as:

> *"Rural area (R)*
>
> ***Sampling points targeted at the protection of vegetation and natural ecosystems shall be sited more than 20 km away from agglomerations and more than 5 km away from other built-up areas, industrial installations or motorways or major roads, so that the air sampled is representative of air quality in a surrounding area of at least 1000 km^2. Stations can be located in small settlements and/or areas with natural ecosystems, forests or crops.***

Background station (B)

Located such that its pollution level is not influenced significantly by any single source or street, but rather by the integrated contribution from all sources upwind of the station e.g. by all traffic, combustion sources etc. upwind of the station in a city, or by all upwind source areas (cities, industrial areas) in a rural area. These sampling points shall, as a general rule, be representative for several square kilometres. At rural background sites, the sampling point should not be influenced by agglomerations or industrial sites in its vicinity, i.e. sites closer than five kilometres."

Site operators within the UK are also encouraged to take into account more practical considerations which are included within the Site Operator's Manual (Ricardo AEA, 2012):

- *It should be practical for power and telephone connections to be made at the site;*
- *The site should be accessible for a lorry to deliver the housing (if necessary)*
- *It should be reasonably easy for gas cylinders to be delivered close to the site and transferred to the housing (or the building in which the site is located).*
- *The LSO should be able to gain access to the site whenever necessary.*
- *The site should be in an area where the risks of vandalism are minimal.*
- *Account should be taken of visual impact of the housing.*

No derogations from the selection of instrumentation used across the AURN is required when operating a BAQMS, or indeed any classification of AQMS.

The measurement methods used across the AURN are as follows (table 7-1 of (Ricardo AEA, 2012)):

- O_3 UV Absorption
- NO/NO_2 Chemiluminescence
- SO_2 UV Fluorescence
- CO IR Absorption
- $PM_{10}/PM_{2.5}$ FDMS, BAM, Gravimetric Sampler

The techniques used are 'state-of-the-art' for automated monitoring networks and conform to the National Measurement System (NMS). As stated in (Ricardo AEA, 2012):

"Essential requirements for conformity with the NMS are as follows:

- *Measurement methods used must be of known performance and defined scope of application;*
- *All calibrations must be traceable through an unbroken chain to international standards (the SI system);*
- *Measurements should be made within a documented quality system;*
- *Where possible, measurements should be harmonised with those made by organisations both within and outside UK."*

Meteorological parameters are not measured at Lullington Heath (apart from rainfall used in the PrecipNet measurements), rather modelled wind direction, wind speed and temperature are adopted.

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5. CANADA

5.1 Definitions and Classifications

In Canada, a number of pollutants are managed by the establishment of Canadian Ambient Air Quality Standards (CAAQS) under the Canadian Council of Ministers of the Environment (CCME) Environmental Standards Sub-Agreement. The agreed CAAQS are implemented agreement of the CCME under the Air Quality Management System (AQMS) and replaces the *Canada-wide Standards (CWS) for Particulate matter and Ozone*.

As stated in the Guidance Document for the Achievement Determination (GDAD) for the Canadian Ambient Air Quality Standards for Fine Particulate Matter and Ozone:

> *"Under the CWS for PM and Ozone, background concentrations were included as one of the possible pollution origins that could contribute to the non achievement of the CWS. The CWS GDAD provided a definition of background concentrations which is similar to the EPA policy-relevant background concentration definition: "Background concentrations are the ambient levels resulting from anthropogenic and natural emissions outside North America and natural sources within North America". There is also a scientific definition of "background concentrations", where the levels originate from natural sources only.*
>
> *Because of the challenge in defining and quantifying background contributions, the CAAQS GDAD does not explicitly mention background concentrations as a possible cause for the nonachievement of a given standard. However, some of the given examples for EE ('exceptional event') implicitly capture any "background" contribution."*

5.2 Purposes

Canada operates a number of air quality monitoring networks for a variety of purposes, including:

- **National Air Pollution Surveillance (NAPS) Network**[2]: The NAPS network is a collaborative monitoring network operated jointly by federal, provincial, territorial and municipal governments. It provides long-term data on the ambient concentrations of SO_2, NO_2, O_3, PM and CO. The data is used by the provinces to report to the Air Quality Index (AQI) and by Environment Canada to report to the Air Quality Health Index (AQHI).
- **Canadian Air and Precipitation Monitoring Network (CAPMoN)**: CAPMoN is operated by Environment Canada, is designed to study the regional patterns and trends of atmospheric pollutants such as acid rain, smog, particulate matter and mercury, in both air and precipitation. Its initial purpose was to manage acid rain, but has expanded to include NO_X, PM, Hg and O_3. Of relevance to this report, CAPMoN data is used to assess regional background and the long-term transport of pollutants.

[2] https://open.canada.ca/data/en/dataset/1b36a356-defd-4813-acea-47bc3abd859b

The Canadian Council of Ministers for the Environment (2011) *Ambient Air Monitoring Protocol for $PM_{2.5}$ and Ozone* (CCME, 2011) provides a summary of the ambient monitoring networks operated in Canada. As stated in Section 4.1 of CCME 2011 the objectives (excluding exposure related studies) are to:

- measure background concentrations and transport of PM, O_3 and their precursors into areas impacted by background/transboundary sources;
- support the development of appropriate management strategies on a regional basis;
- track and report on air quality trends and the effectiveness of management strategies.

The definitions provide in CCME 2011 include the following:

Table 13 Monitoring strategy for the CWS for PM and ozone (CCME, 2011)

Monitoring Station Type	Main Purpose of Monitoring Station
CWS achievement reporting	Tracking and reporting of progress toward meeting the CWS [CAAQS] for PM and Ozone.
Regional transport / background	Demonstrating transboundary influence and influence from background levels and natural events for achievement determination.
Chemical speciation / precursor	Characterizing air quality and trends, developing and evaluating emission control strategies, estimating health related exposure risks, evaluating source- receptor relationships, providing data for input to run and evaluate models and measuring overall progress of air pollution control programs.
Special studies	To gain a better understanding of the causes of high $PM_{2.5}$ and ozone concentrations in the ambient air for the development of abatement strategies and conduct health studies, but short term, and may be mobile.

In regard to BAQMS, the defined 'regional transport / background' monitoring stations are relevant.

5.3 Scales

As noted above, the Canadian AQMS uses definitions consistent with those published by the US EPA (US EPA, 1998), which are reproduced below:

- **Micro Scale**: Localised areas such as downtown street canyons, traffic corridors or a major stationary source such as a power plant where the general public would be exposed to maximum concentrations.
- **Middle Scale**: Downtown areas that people typically pass through, areas near major roadways, areas such as parking lots, and feeder streets generally with dimensions of a few hundred metres.
- **Neighbourhood Scale**: Reasonably homogeneous urban sub-regions with dimensions of a few kilometres and of generally more regular shape than the middle scale.
- **Urban / Rural Scale**: Entire metropolitan or rural area ranging in size from 4 to 50 kilometres.
- **Regional Scale**: Dimensions of as much as 100s of kilometres with some degree of homogeneity.

As specified in *Guidance Document for the Achievement Determination (GDAD) for the Canadian Ambient Air Quality Standards for Fine Particulate Matter and Ozone*, CAAQS stations are typically located on a "neighbourhood" or "urban scale" to quantify exposure risk but may be located on a "regional" scale in more remote locations providing an equivalent purpose as a background air quality monitoring station.

In terms of CAAQS reporting stations for O_3, they should be located at a location representative of the expected maximum O_3 concentrations, which is typically located outside of the urbanised areas.

Table 7 presents a graphical summary of the interaction between monitoring purpose(s) in the US and spatial considerations. For clarity, Environment Canada have adopted the same descriptors.

As a function of its initial objective to monitor acid rain, CAPMoN is a non-urban network. Table 8 of *Ambient Air Monitoring Protocol for $PM_{2.5}$ and Ozone - Canada-wide Standards for Particulate Matter and Ozone* provides the relevant siting requirements for CAPMoN stations and components of that table are reproduced in **Table 14**.

Table 14 CAPMoN network requirements (precipitation constituents and ozone)

Influence	Consideration
Industrial pollution sources	>50 km for individual point sources (>10,000 tonnes SO_2 / NO_X) or sum collective point and area sources (>10,000 tonnes SO_2 / NO_X).
Population centres	> 5 km (pop <5,000)
	>10 km (pop 5,000 - 10,000)
	>40km (pop >10,000)
Transportation routes	>500 m from transport route
	>3km from small airports
	>10 km from large airports
Local pollution sources	>500 m from small-scale sources
Agriculture	>500 m from intensive agriculture

5.4 Scope

NAPS is essentially an exposure evaluation network, although may be located on a 'regional' scale, and encompass exposure risk evaluation for NO_2, O_3, PM, SO_2 and CO.

A function of the CAPMoN network is to provide data on the regional background conditions across Canada including:

- Precipitation chemistry, 24-hour integrated samples. Cl^-, NO_3^-, $SO_4^=$, NH_4^+, Na^+, K^+, Ca^{++}, Mg^{++}, pH.
- Particles and related trace gases, 24-hour integrated filter samples. particulate Cl^-, NO_3^-, SO_4^-, NH_4^+, Na^+, K^+, Ca^{++}, Mg^{++}, gaseous HNO_3 and SO_2.
- Tropospheric (ground level) O_3 measurements, as hourly averages.
- Nitrogen measurements, gaseous NO, NO_2, and NO_y as hourly averages.

- Size-selective particulate matter, 24-hour integrated samples $PM_{2.5}$, PM_{10} and coarse fraction mass.
- Total gaseous mercury, hourly averages.
- Hg in precipitation, weekly integrated samples.

5.5 Site Selection Criteria

5.5.1 Macro Scale

CCME 2011 provides the following on the siting of regional transport / background stations:

> *"Regional transport/background monitoring is used to determine the upwind concentration of $PM_{2.5}$ and ozone for communities that may be significantly influenced by pollution from transboundary source regions or high background levels. Regional scale stations* (see **Section 5.3**) *are typically appropriate for this objective. The GDAD* (Guidance Document on Achievement Determination) *provides the following recommendations regarding the siting of regional transport and background monitors for demonstrating transboundary influence and high background levels.*
>
> ***Transboundary Influence***
>
> - *Jurisdictions should identify one or more monitoring sites upwind of the non-compliant community in question, located between the community and the major source area that may be affecting it.*
> - *In the case of a community adjacent to… a border with another province/territory, the measurement site may have to be at a near-border location within the community, upwind of the community core. Similarly, for a community on the shores of a border water body, the measurement site should be sited within the community near the shoreline, upwind of the community core.*
> - *Jurisdictions should measure $PM_{2.5}$ (including chemical speciation for major inorganic ions as a minimum), ozone and local winds at this site using standard methods accepted by the National Air Pollution Surveillance (NAPS) Monitoring Network or the Canadian Air and Precipitation Monitoring Network (CAPMoN).*
> - *If it is likely that precursor pollutants are being transported from the upwind jurisdiction and are contributing to $PM_{2.5}$ or ozone levels in the community, then jurisdictions should measure ambient concentrations of NO, all oxidized nitrogen compounds (NO_Y), NH_3, SO_2 and VOC (including speciation).*
>
> ***Influence from Background or Natural Events***
>
> - *Jurisdictions should identify one or more monitoring sites upwind of the non-compliant community in question and in a location that is not downwind of any major anthropogenic source area.*
> - *Depending on the pollutant in question, jurisdictions should measure $PM_{2.5}$ (including chemical speciation for major inorganic ions as a minimum), ozone and local winds at this site using standard methods accepted by NAPS or CAPMoN.*
> - *Jurisdictions should also measure ambient concentrations of VOC, including isoprene and terpenes. Isoprene is a primary precursor of ozone, and terpenes are important precursors of the organic component of $PM_{2.5}$.*

Table 8 of (CCME, 2011) provides the specification for CAPMoN station siting, which is reproduced below:

Table 15 CAPMoN station and probe siting criteria (CCME, 2011)

Pollutant	Sampling Height	Influence	Spacing Distance
Precipitation constituents and ozone (regional scale)	3 m	Industrial Pollution Sources	>50 km for individual point sources (exceeding 10,000 tonnes SO_2 or NO_X emissions) or the sum of collective point and area sources (exceeding 10,000 tonnes SO_2 or NO_X emissions)
		Population Centres	>5 km from small towns or villages (population <5000)
			>10 km from larger towns (population 5,000-10,000)
			>40 km from cities
		Water Bodies	>10 km from Great Lakes shoreline
			>40 km from large water body (ocean, gulf)
		Transportation Routes	>500 m from any roads, canals, railways (except seldom traveled access road)
			>3 km from small airports
			>10 km from large airports
		Local Pollution Sources	>500 m from small-scale pollution sources (as specified)
		Agricultural Activity	>500 m from any intensive agricultural activity
		On-site Obstructions	Distance of the sampler from any air flow obstructions must be >2.5 x height of obstacle above the sampler (e.g., trees, towers, poles, etc.)
		On-site Buildings	Distance of the sampler from any on-site buildings must be 10X height of the building

5.5.2 Micro Scale

In regard to site selection, CCME 2011 provides the following guidance:

> *"Rural monitoring sites should be located upwind of the non-compliant community in question. In addition, for assessing the transboundary influence these sites should be located between the community and the major source area that may be affecting it. For assessing the background influence, rural sites should not be downwind of any major anthropogenic source area. Analytical tools such as back trajectory models, pollution roses and modelling can be used to select the most appropriate areas for locating these monitors."*

Section 4.5.2 'probe siting criteria' provides more specific requirements in terms of micro-scale siting.

Table 16 NAPS network sample probe siting criteria (CCME, 2011)

Pollutant	Scale	Probe			Distance from			Additional
		height	vertical	horiz.	large city	roadside	tree canopy	
PM	regional	2-15	--	>2m	15-100km	100m(A)	20km	avoid low lying areas
O_3	regional	3-15	>1m	>1m	30-100km	250m(A) 20m(B)	20km	avoid NO_X sources avoid low lying areas hilltop desirable

Table 16 above provides specifications for micro-scale siting, including distances from "on-site obstructions" and "on-site buildings".

5.6 Technology and Systems

As stated in the Guidance Document for the Achievement Determination (GDAD) for the Canadian Ambient Air Quality Standards for Fine Particulate Matter and Ozone:

> *"NAPS monitoring agencies reviewed the process used for approving the $PM_{2.5}$ Class III FEM (Federal Equivalence Methods) instruments and concluded that the testing requirements were sufficiently comprehensive as to include most ambient conditions found at Canadian monitoring locations. As such, the CCME Ambient Air Monitoring Protocol for $PM_{2.5}$ and Ozone for the CWS9 (the Monitoring Protocol), developed by NAPS agencies, recommends that all new purchases of continuous $PM_{2.5}$ monitors for the NAPS network should be restricted to those that have received EPA Class III FEM designation or any instruments that meet the performance criteria of Class III FEM monitors. The Monitoring Protocol also states that the FEM Class III performance criteria be adopted as the NAPS continuous $PM_{2.5}$ monitor equivalency.*
>
> *Most provinces have deployed or will be deploying continuous $PM_{2.5}$ monitors that satisfy the EPA Class III FEM designation or that meet the performance criteria. To ensure comparability of $PM_{2.5}$ data across Canada, it recommended that jurisdictions strive to have deployed by December 31, 2012 $PM_{2.5}$ monitors which meet these requirements. This would ensure that the achievement status of the 2015 and 2020 standards in provinces and territories are all based on comparable data."*

Quality Assurance/Quality Control (QA/QC) and data management standards are important elements of any monitoring program. The Monitoring Protocol identifies NAPS procedures as the standards to be applied to ambient monitoring of $PM_{2.5}$ and O_3. As a minimum, participating networks should meet NAPS Quality Assurance and Quality Control Guidelines (EC, 2004).

Continuous samplers permitted under the Monitoring Protocol include:

- TEOM, TEOM-FDMS
- BAM-1020
- GRIMM particle monitor
- Synchronised hybrid ambient real-time particulate (SHARP) monitor

Due to the requirement for $PM_{2.5}$ speciation, $PM_{2.5}$ sampling using non-continuous sampling methods is also permitted. The Monitoring Protocol permits the following gravimetric determinations for $PM_{2.5}$:

- Dichotomous samplers, complying with US EPA Class II FEMs
- US Federal Reference Method (FRM)

Further details may be accessed directly from the Monitoring Protocol[3].

[3] https://www.ccme.ca/files/Resources/air/pm_ozone/pm_oz_cws_monitoring_protocol_pn1456_e.pdf

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6. SUMMARY AND CONCLUSIONS

A summary of the definitions, purposes, macro and micro scale siting criteria as identified and discussed in the report are provided in the following:

Table 17 **Comparison of definitions**

Table 18 **Comparison of purposes**

Table 19 **Comparison of macro scale siting criteria**

Table 20 **Comparison of micro scale siting criteria**

Table 21 **Comparison of monitoring methods**

Several points of consistency can be identified between the definitions of background monitoring including:

- The reference to homogeneous land use and geographies (Australia and United States);
- The distance from large pollutant sources (United State, European Union and Canada); and,
- Scales of 10's to 100's of kilometres (United States and European Union).

Population density is not specifically mentioned apart from in European Union definitions (lower population density) and briefly in US EPA regulations where regional scale measurements of $PM_{2.5}$ should be applicable to "sparsely populated areas". No specific values of population densities have been identified in any guidance.

In relation to the purposes of background air quality monitoring, these stations can be used to assess compliance, although are more often used to inform the potential contribution from long range transport of pollutants (especially fine particulate [often speciated], and O_3), and to support source apportionment analysis and management, which is the case in the US IMPROVE network. It can also be used to determine the influence of natural events from other sources for the assessment of criteria achievement.

In terms of siting, several points of commonality have been identified.

- All jurisdictions require that the stations are located so as to provide information representative of the broader location in which they are situated which requires placement away from local sources of pollutants being monitored.
- Regional scale measurements of $PM_{2.5}$ (speciated) and O_3 are most commonly discussed in reference to that spatial scale, and in the case of potential precursor transportation ($PM_{2.5}$ and O_3), Canada also requires measurements of NO, all oxidised nitrogen compounds (NO_Y), NH_3, SO_2 and VOC (including speciation).

- When siting an O_3 monitor for regional scale background measurements, the US EPA requires that meteorological analysis of trajectories and emission patterns be performed to assist that determination.
- When siting a BAQM, a hierarchical approach is likely to be the most successful, with the determination of the purpose of the background monitoring being the key consideration. Site selection criteria, including the macro and micro scale criteria presented within this review, should be considered according to the purpose, with station and plot design being an important but lower order consideration when compared to the overall purpose of monitoring.
- Spacing from trees is specified as being required as:
  - 10 m from the drip line (US EPA)
  - 20 km from the tree canopy (Canada)
  - Clear sky angles (various) (Australia, EU)

This is a significant difference in the required spacing from trees in the different jurisdictions reviewed.

- Micro scale siting criteria are generally similar between jurisdictions and do not have any varying requirements depending on station type (i.e. BAQMS or other).
- No discussion of any variation in monitoring techniques from urban through to background scales is provided within any of the documentation reviewed. A more detailed review of the technical specifications of monitoring techniques which are currently approved for use within NSW, and selection of those with a broader range, or lower minimum threshold could be investigated.
- No specific requirements for the measurement of meteorological parameters at BAQMS is provided within any of the literature reviewed. As outlined within the case studies, some sites do not measure these parameters at all, some do, and some rely on modelled data. The implementation of meteorological monitoring should be aligned with the purpose(s) of the BAQM.
- It is clear from this review that any specific monitoring station does not have to meet the requirements appropriate for 'background' for all pollutants. Often (see case study for California in **Section 3**), a station will be representative of background or regional conditions for one pollutant, but be representative of a completely different scale for another. In the case study for the UK in **Section 4** however, the station reviewed is located appropriately to be representative of background conditions for all pollutants monitored.

Further to the above, from review of the reference material for all jurisdictions, a background monitoring station can be pollutant-specific, or monitor multiple pollutants, so long as the relevant siting criteria are satisfied. Adopting a common rationale may conclude that an existing station in the NSW OEH network may be suitable for background monitoring purposes for a specific pollutant, although analysis (especially of sources of emissions and meteorology) should be performed prior to that designation.

As may be expected, no pre-determination is provided in the reviewed guidance prescribing a concentration of air pollutants that may be considered to represent a 'background' condition. This is expected as the background will be determined by the geography, source strength and location and a variety of other factors including topography, distance between agglomerations etcetera.

Table 17 Comparison of definitions

Jurisdiction	Definition	Source
Australia	"Background sites are located in urban or rural areas to provide information on background levels. Background sites are usually in areas of homogeneous land use and geography. These sites can be especially useful for assessing transportation of pollutants into a region."	AS/NZS 3580.1.1:2016
United States	"Regional scale—Defines usually a rural area of reasonably homogeneous geography without large sources, and extends from tens to hundreds of kilometres."	40 CFR Part 58
European Union	" 'urban background locations' shall mean places in urban areas where levels are representative of the exposure of the general urban population" Rural background station - "Station located in areas with lower population density, e.g. with natural ecosystems, forests, at a distance of at least 20 km from urban and industrial areas and away from local emissions; avoid locations which are subject to locally enhanced formation of near-ground inversion conditions, also summits of higher mountains; coastal sites with pronounced diurnal wind cycles of local character are not recommended" Further site 'types' are provided in the CAFE Directive including 'traffic', 'industrial' and 'suburban'. The UK DEFRA have adopted these site classifications to represent the nature of the surrounding area (urban, suburban, or rural) and the type of pollution sources involved (traffic, industrial, or background [i.e. not located close to any specific emission source]). Sites can then be described as (for example) urban traffic, or rural background.	Directive 2008/50/EC
Canada	"Background concentrations are the ambient levels resulting from anthropogenic and natural emissions outside North America and natural sources within North America". There is also a scientific definition of "background concentrations", where the levels originate from natural sources only."	GDAD for the CAAQS

Table 18 Comparison of purposes

Jurisdiction	Purpose	Source
Australia	-	-
United States	Assessment of compliance against NAAQS, emergency control, real time reporting, trends analysis, research	40 CFR Part 58
European Union	"The main objectives of such measurements are to ensure that adequate information is made available on levels in the background. This information is essential to judge the enhanced levels in more polluted areas (such as urban background, industry related locations, traffic related locations), assess the possible contribution from long-range transport of air pollutants, support source apportionment analysis and for the understanding of specific pollutants such as particulate matter. It is also essential for the increased use of modelling also in urban areas"	Directive 2008/50/EC
Canada	Demonstrating transboundary influence and influence from background levels and natural events for achievement determination.	CCME 2011

Table 19 Comparison of macro scale siting criteria

Jurisdiction	Criteria	Source
Australia	"it is essential that the sampling unit be situated so as to yield data which are representative of the location. It should not be unduly influenced by immediate surroundings unless those influences are specifically being monitored."	AS/NZS 3580.1.1:2016
United States	Pollutant specific. $PM_{2.5}$ - regional scale measurements are applicable to generally sparsely populated areas O_3 - The determination of a location for a regional scale background O_3 monitoring location should be performed through meteorological analysis and analysis of trajectories and emission patterns Rural NCore stations are required to be located to the maximum extent practicable at a regional or larger scale away from any large local emissions source, so that they represent ambient concentrations over an extensive area.	40 CFR Part 58
European Union	Where the objective is to assess rural background levels, the sampling point shall not be influenced by agglomerations or industrial sites in its vicinity, i.e. sites closer than five kilometres Where contributions from industrial sources are to be assessed, at least one sampling point shall be installed downwind of the source in the nearest residential area. Where the background concentration is not known, an additional sampling point shall be situated within the main wind direction	Directive 2008/50/EC
Canada	Jurisdictions should measure $PM_{2.5}$ (including chemical speciation for major inorganic ions as a minimum), ozone and local winds at this site using standard methods accepted by the National Air Pollution Surveillance (NAPS) Monitoring Network or the Canadian Air and Precipitation Monitoring Network (CAPMoN). If it is likely that precursor pollutants are being transported from the upwind jurisdiction and are contributing to $PM_{2.5}$ or ozone levels in the community, then jurisdictions should measure ambient concentrations of NO, all oxidized nitrogen compounds (NO_Y), NH_3, SO_2 and VOC (including speciation) Depending on the pollutant in question, jurisdictions should measure $PM_{2.5}$ (including chemical speciation for major inorganic ions as a minimum), ozone and local winds at this site using standard methods accepted by NAPS or CAPMoN.	CCME 2011

Table 20 Comparison of micro scale siting criteria

Jurisdiction	Criteria	Source
Australia	Avoid restricted airflows (near to buildings, trees, walls etc). Sampling inlet generally needs a minimum clear sky angle of 120º. Avoid sites near objects which may adsorb or absorb the pollutant being monitored (e.g. trees) Consider other pollutant sources near to the site and how these may influence measurements Ground level sampling sites are generally preferable Consider the potential for changes in local activities surrounding the site Take into account the distances from roads	AS/NZS 3580.1.1:2016
United States	Avoid restricted airflows (near to buildings, trees, walls etc). Sampling inlet generally needs a minimum clear sky angle of 120º. Avoid sites near objects which may adsorb or absorb the pollutant being monitored (e.g. trees). Especially important for O_3. Monitoring agencies are required to take steps to consider the impact of trees on ozone monitoring sites and take steps to avoid this problem. Consider other pollutant sources near to the site and how these may influence measurements Take into account the distances from roads	40 CFR Part 58
European Union	Consider other pollutant sources near to the site and how these may influence measurements Consider the placement of the sampler exhaust such that recirculation may be avoided	Directive 2008/50/EC
Canada	Required spacing from pollutant sources: Up to 100 km from large cities, between 20 m and 100 from roads Required spacing from trees: 20 km from tree canopy	CCME 2011

Table 21 Comparison of monitoring methods

Jurisdiction	Methods
Australia	As defined within AS/NZS 3580.1.1:2016
United States	Federal Reference Methods (FRM) or Federal Equivalence Methods (FEM)
European Union	European Committee for Standardisation (CEN) methods
Canada	US EPA Class III FEM designation or equivalent, or Class II FEM for $PM_{2.5}$

The measurement parameters differ between stations depending on the requirement for BAQM. It is also noted that no technologies are recommended for use at background stations when compared to any other station type, within the documents reviewed. Consideration of 'low-level' pollutant detection may be required at some pristine monitoring sites, such as Cape Grimm for example, although such monitoring is not the focus of the regulations subject to this review.

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