Advice on national air quality monitoring in airsheds

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Executive Summary

In 2015 the Parliamentary Commissioner for the Environment (PCE 2015) highlighted a gap in New Zealand's Air Quality Regulations, specifically the lack of standards or controls for $PM_{2.5}$ in New Zealand. This was despite these being commonplace worldwide and being considered the most important standards in many countries. This led to a proposal to introduce a National Environmental Standards for Air Quality (NESAQ) for $PM_{2.5}$ which was released for public consultation by the Ministry for the Environment (MfE) in 2020. So far, a Standard for $PM_{2.5}$ has not been adopted. The Ministry for Environment (MfE) sought guidance from NIWA in 2021 regarding the use of air quality standards and guidelines, which explored an exposure reduction approach to managing air quality (Coulson and Longley, 2021). This report follows on from that work and explores the practicalities of introducing an exposure reduction framework.

In October 2021 the World Health Organisation (WHO) released an update to their air quality guidelines (WHO 2021). The update emphasised that there was no evidence of zero-effects threshold concentrations and therefore all exposure reduction has health benefits.

To reflect this, the update also significantly lowered the guideline values for $PM_{2.5}$, as well as for most other criteria pollutants, to values below the NESAQ. The NESAQ sets limits for permissible concentrations of pollutants in the air, as do many air quality management regimes around the world. This approach focuses on keeping ambient concentrations below fixed thresholds, with management strategies typically oriented around areas of highest concentrations. An alternative regime is to manage the exposure of the population in a way that benefits a greater proportion of the population.

An "exposure reduction" paradigm is designed to more explicitly place reducing the burden of air pollution on human health at the centre of air quality management. Therefore, in order to assess progress towards policy objectives, the change in "exposure" needs to be measured and reported, not only the change in concentrations.

An important aspect of the exposure reduction paradigm is that it also implies a shift in the way air quality improvements are managed and planned for. The objective of the NESAQ is to set a guaranteed minimum level of health protection for people living in New Zealand. The current paradigm in effect poses poor air quality as a problem to be discovered, addressed and then solved (by achieving compliance with the NESAQ). In contrast, an exposure reduction paradigm assumes continual action is required with no short-term endpoint. This is consistent with approaches to mitigate climate change through reductions in carbon emissions.

The work described in this report focusses on the feasibility of options for changes in air quality monitoring requirements and guidance that would enable the reporting on progress towards exposure reduction across the country. It also takes the opportunity to explore how such changes may also address current inconsistencies in the treatment of urban areas arising from gaps in current guidance.

More specifically, this work addresses the following technical questions:

- What are the options and recommendations, with key decision points and implications, for determining a) airshed definitions and b) airshed boundaries that would enable single-location monitoring to best represent exposure of an entire area?

- What are the options for selecting monitoring location(s) that are representative of the exposure for most of the population in each airshed?
- What level of accuracy and precision is required for each airshed?

This work is informed by 20 years of air monitoring data and experience accumulated since the NESAQ came into effect, as well as the NIWA air quality research programme (and work of other researchers) that has been operational during that same timeframe. It also explores the opportunities provided by the substantial changes in monitoring technology that have become available in that time which broadly offer more information for less cost.

In this work we present options for re-defining airsheds – the geographical area for which air quality is to be reported – including where they are located and how their boundaries are determined. These options involve a moderate initial cost and relatively low periodic review cost. They aim to deliver greater consistency in the way each town and region is treated for monitoring purposes.

In our view, characterising the spatial variation in air quality in each airshed is an essential component of being able to use monitoring data from specific sites to represent human exposure across the airshed. Existing methods lead to that linkage being largely implied and inconsistently applied. We introduce a number of options which exploit recent technological and methodological developments to reduce uncertainty and improve consistency. The options vary in cost and robustness.

We also present options for relaxing the currently stringent requirements that airshed air quality monitoring comply with ANZ Standards. These requirements were appropriate when introduced but are suitable for updating to take account of recent technological change and innovation. In particular we explore the development of criteria to judge the acceptability of new generation monitoring technology in certain applications.

Although we present a range of options, in our expert view we find that recent developments in monitoring technology now enable a liberalisation of monitoring practice that potentially offers more information for lower cost. Current regulations and guidelines, however, which were limited by the assumptions of technology available when they were formulated, have constituted a barrier to innovation. We believe that legitimate concerns from practitioners over the past two decades about the accuracy and performance of new technology monitors have now been addressed or can satisfactorily be managed. We recommend that guidance be liberalised so that the flexibility and efficiencies that new technologies offer can be realised.

1 Introduction

1.1 Background

1.1.1 Air quality regulation in New Zealand

Since 2005, the National Environmental Standards for Air Quality (NESAQ) have determined the responsibility for monitoring against a set of ambient air quality standards. Five pollutants are controlled by the NESAQ including one measure for airborne particulate matter 10 micrometres in aerodynamic size or smaller (PM_{10}).

Maximum concentration limits set for air pollutants in the NESAQ were based on guidance published by the World Health Organisation (WHO, 2005). The NESAQ also set a deadline for consistently meeting these concentration limits. In 2011, the NESAQ were amended to extend these deadlines and allow ‘offsets’ to be used as an air quality management tool, where new polluters were applying to discharge contaminants to air in already polluted airsheds (MfE, 2011 (updated 2014).

More recently, a process to review the NESAQ was instigated by the Ministry for the Environment (MfE) after a review of the State of the Environment Air Domain report (MfE 2014) by the Parliamentary Commissioner for the Environment (PCE 2015). The PCE highlighted a gap in the regulations with the lack of standards or controls for $PM_{2.5}$ in New Zealand, despite these being commonplace worldwide and being considered the most important standards in many countries. This process led to a proposal to introduce an NESAQ for $PM_{2.5}$ which was released for public consultation in 2020. So far, a Standard for $PM_{2.5}$ has not been adopted.

In addition, the Climate Change Response (Zero Carbon) Act passed into law in 2019. This set domestic targets for reducing New Zealand’s total greenhouse gas emissions to net zero (excluding biogenic methane) by 2050. Although not directly working on the air pollutants controlled by the NESAQ, the overlap in sources (that is, combustion sources) means downward pressure in greenhouse gas emissions should also impact air pollution levels.

The Ministry for Environment (MfE) sought guidance from NIWA in 2021 regarding the use of air quality standards and guidelines, which explored an exposure reduction approach to managing air quality (Coulson and Longley, 2021). This report follows on from that work and explores the practicalities of introducing an exposure reduction framework.

1.1.2 Progress under the current regulations

Since the ambient air quality standards came into force in 2005, improvements in air quality have been mixed. Some cities have seen substantial improvements, such as Christchurch and Nelson. Others have regularly met the NESAQ but have not seen improvements in concentrations (such as Auckland) and many places continue to struggle with poor air quality, particularly in the South Island in winter. In addition, many population centres have only periodic or no air quality monitoring to allow assessment of, or track changes in air quality.

This range of experiences have occurred under the same regulations as emissions in air pollutants have changed to a varying manner across the country, due to shifts in modes of domestic heating and the introduction of cleaner emitting vehicles. In addition, the country’s population grows, particularly in the larger cities, meaning more people are exposed to air pollution in New Zealand than ever.

1.1.3 Changes in scientific understanding

Since 2005, when ambient air quality standards came into force and the WHO guidelines published, scientific understanding of air quality has advanced significantly, in two ways in particular:

- Air quality standards required monitoring which generated a large increase in the amount and variety of air quality data available for analysis,
- These data enabled a large increase in the creation of epidemiological evidence of adverse health effects from air pollution (for example, Hales *et al*., 2012, 2021).

In New Zealand, ongoing data collection allowed for a solid and improving understanding of how airsheds function and the risk factors involved in episodes of poor air pollution. Additional to regulatory monitoring, research projects including GNS's chemical speciation analyses (for example, Davy *et al.*, 2011, Davy and Trompetter, 2019) and NIWA's research on monitor representativeness (for example, Longley, 2023a and 2023b) have deepened the understanding of New Zealand's unique oceanic position and source mixture.

In October 2021 the WHO released an update to their air quality guidelines (WHO 2021). The update emphasised that there was no evidence of zero-effects threshold concentrations and therefore all exposure reduction will lead to health benefits.

The update dramatically lowered guideline values for $PM_{2.5}$, as well as most other criteria pollutants, and meant that the proposed $PM_{2.5}$ NES, and indeed all of the NESAQ, were no longer wholly consistent with WHO guidance. Due to the magnitude of the changes, the 2021 WHO guidelines do allow for interim targets, which encompass some of the existing NESAQ values.

1.1.4 The Exposure Reduction paradigm

An "exposure reduction" paradigm is designed to more explicitly place reducing the burden air pollution places on human health at the centre of air quality management. It requires that to assess progress towards policy objectives, the reduction in "exposure" needs to be measured and reported. In simple terms this means combining pollutant concentration data with population data. In practice it also means greater progress will be achieved where larger populations benefit from reductions in concentrations. The concept is discussed more fully in Coulson & Longley (2021).

A form of exposure is already assessed and reported in New Zealand within the Health and Air Pollution in New Zealand (HAPINZ) projects (Fisher *et al*., 2007, Kuschel *et al*., 2012, 2022). To date, these projects have been *ad hoc* and internally inconsistent. This is because some airsheds have detailed monitoring data, some have little (or the data was historic and outdated) and some have none, but all require a PM_{10} exposure value. This leads to varying uncertainties between airsheds. Combined with changes in available data between updates this has partly contributed to a difficulty in tracking trends across HAPINZ updates. The HAPINZ 3 assessment is published by StatsNZ (https://www.stats.govt.nz/indicators/human-health-impacts-of-pm2-5-and-no2) but is not routinely updated. However, the changes explored in this work would be a step towards making exposure reporting routine and fully embedded into air quality monitoring practice.

An important aspect of the exposure reduction paradigm is that it also implies a shift in the way air quality improvements are managed and planned for. Whereas the current paradigm in effect poses poor air quality as a problem to be discovered, addressed and then solved (by achieving compliance with the NESAQ), an exposure reduction paradigm assumes continual action is required with no short-term endpoint. This is consistent with approaches to mitigate climate change through reductions in carbon emissions.

In air quality management this change breaks the current link between identification of an air quality problem (the declaration of a gazetted airshed) and the necessity of implementing monitoring and emission reduction actions that incur cost, because those actions are required anyway for continuous improvement in exposure. **In other words, management becomes guided by, but is no longer contingent on the presence of monitoring**.

1.2 Goals of this work

The work described in this report is meant to inform policy advice and central government decision-making about the future structure and purpose of air quality monitoring and regulation in New Zealand. It focusses on the feasibility of three main areas:

- Options for changes in air quality monitoring requirements and guidance that would enable the reporting on progress towards exposure reduction across the country
- How such changes may improve the consistent treatment of all urban areas, regardless of climate, geography or emission profile
- The opportunity to reduce systematic errors in monitoring, reporting and health impact assessments occurring under the current monitoring regime.

More specifically, MfE asks the following questions:

- What are the options and recommendations, with key decision points and implications, for determining a) airshed definitions and b) airshed boundaries that would enable single-location monitoring to best represent exposure of an entire area?
- What are the options for selecting monitoring location(s) that are representative of the exposure for most of the population in each airshed?
- What level of accuracy and precision is required for each airshed?

1.3 Scope and assumptions

The focus of this work is on $PM_{2.5}$. Many of the principles discussed will also apply to PM_{10} and other contaminants.

This work assumes that an annual mean $PM_{2.5}$ standard and exposure reduction targets may be implemented in the near future.

This work does not, however, directly consider or critique the current daily PM_{10} standard and the associated monitoring guidance, except where it overlaps with, or is in conflict with an annual standard and exposure reduction regime. In other words, all or any of the changes mooted in this work could be implemented without any changes to how the daily PM_{10} standard is implemented and managed. However, some changes might be considered to be more efficient.

This work considers "airshed monitoring" only. We interpret this to mean monitoring that is intended to assess the state of air quality across the majority of an airshed, especially where people are resident. In our view this does not therefore include monitoring along the transport network (major roads, rail corridors, around ports) as these locations cover a minority of the area of any airshed. It also does not include consent compliance monitoring as, again, this pertains to a small proportion (spatially) of any airshed.

The majority of this work focusses on changes to regulations and practice that might support adoption of an exposure reduction objective. This is not necessarily intended to replace or compete with the current objectives of achieving compliance with the NESAQ. Whereas those options are available, exposure reduction requirements may also complement and be additional to the rules and practices associated with compliance.

1.4 Approach

The monitoring process collates raw data and processes it to quantify outcome indicators which report on progress with respect to policy questions. There are two major known error sources in this process: measurement error and representativeness error. This work effectively reviews this process, considers the opportunity to change the outcome indicators to better align with policy questions, and also how changes to monitoring guidance might reduce the sources of error.

Whereas these issues are inter-dependent, we (initially) consider each one in isolation. We then look at synergies and inter-dependencies and come up with draft recommendations.

1.5 Stakeholder workshop

Air quality managers from regional councils of various sizes around the country were invited to take part in an extended discussion regarding the three questions asked by MfE. The workshop took place early in the timeline of this work and so no specific options were put to the group for evaluation.

The participants engaged in a detailed discussion about the management of air quality, particularly in the context of introducing an exposure-based approach. They raised concerns about the practical application of such a framework, especially in terms of managing issues that affect a small number of people and the financial constraints associated with additional monitoring.

Urban development and its impact on airshed boundaries were discussed, with a focus on the need for updated modelling to account for changes and the natural shift away from wood burners in new housing developments. The annual stability of $PM_{2.5}$ patterns, especially in coastal towns, was questioned, and the importance of monitoring both PM_{10} and $PM_{2.5}$ was emphasized.

The conversation also touched on the need for more consistent guidance in defining airsheds, the limitations of the current act that restricts different types of monitoring, and the advocacy for the ability to screen areas outside of designated airsheds to protect all populations. The potential for hybrid monitoring methods and the financial concerns related to declaring an airshed were acknowledged.

Participants expressed frustration with the lack of local council action on air quality and the representativeness of monitoring data for population exposure. The importance of understanding health equity and the exposure of vulnerable communities was emphasized.

The meeting concluded with discussions on the limitations of the HAPINZ model and its impact on interpreting air quality data, the experiences with $PM_{2.5}$ winter monitoring and summer dust monitoring for incident investigation, and the importance of purpose when deciding on monitoring strategies. The potential for real-time source apportionment and the need for timely data to reflect the impact of interventions on air quality improvements were also discussed.

In summary, the meeting highlighted the complexities of air quality monitoring and management, the need for a strategic approach to address these challenges, and the importance of having accurate and timely data to support decision-making and improve monitoring capabilities. Participants advocated for a tiered approach to monitoring, a national monitoring framework, and the integration of new technologies to enhance air quality management.

2 Airshed reporting statistics

2.1 Choice of reporting statistics

This work is based on the assumption that new airshed reporting statistics are adopted. We assume that the key statistic will be annual mean $PM_{2.5}$ for specified airsheds. However, there are several options to chose from in terms of **where** this statistic refers to. Each option is described below.

2.1.1 Annual mean $PM_{2.5}$ at the monitoring site

The rationale for introducing an annual mean statistic is that this is intended to be more representative of chronic exposure and hence health outcomes amongst the airshed population than daily statistics (such as exceedances of daily standards).

In the current regulations air quality statistics are compiled directly from data from specified monitoring sites. As these sites are intended to represent the peak concentration within the airshed they are not representative of “exposure” across the airshed by design.

2.1.2 Spatially-averaged annual mean $PM_{2.5}$

This statistic, in principle, represents the average concentration in space across the airshed. In principle this would be assessed through dividing the airshed into equally sized units, each of which contains an air monitor. The statistic would then be the mean of the annual mean concentrations from each monitor. There are other methods where greater simplicity may also introduce greater uncertainty. These are discussed in more detail in chapter 4.

A significant weakness of this method is that it is quite sensitive to the delineation of airshed extent, such that the statistic will be artificially lowered if more low-density peri-urban land is included in the airshed.

2.1.3 Population-weighted annual mean $PM_{2.5}$

A population-weighted statistic has the advantage of providing a more representative indicator of what’s going on across the whole airshed. By introducing population (rather than just a spatial average) bias from low-density areas that have a relatively high area but low population is reduced.

This method requires not just for long-term average concentration data across the whole airshed, but also annual population data. Methods for generating the concentration data are discussed in more detail in chapter 4. Annual population data may need to be generated through inter-census estimates.

The introduction of population into the reporting statistic means that population may be driving more of the change in the statistic than air quality. Whether this is a problem or advantage is open to interpretation. A simple solution is to report at least two sets of statistics – with and without population weighting – to provide a more complete narrative.

2.1.4 Total intake and health burden associated with annual mean $PM_{2.5}$

In principle, intake is the total mass of PM inhaled by all people in the airshed over a year. In practice, a proxy for intake is calculated by multiplying the annual mean concentration by the population exposed to that concentration.

The advantage of intake as a statistic is that it emphasises the multiplying effect of population. Its main disadvantage is that it is an unfamiliar term for most people expressed in unfamiliar units of mass per unit time (e.g. micrograms per hour, grams per day or kg per year).

When multiplied by an agreed-upon exposure-response function (ERF) for a health outcome of interest, a pollutant-related health burden for the airshed can be calculated. At present this is the approach used in the "HAPINZ" health risk assessment at the census area unit level. The total health burden for any larger geographical area is then calculated by summing health burden across all units within that area. Hales *et al*. (2021) describes how exposure-response functions are derived.

The two major advantages of health burden as a metric are that it most closely represents the primary policy outcome of interest and that it can be expressed in monetary terms if required.

Calculating intake and health burden requires no additional air quality data beyond establishing population-weighted $PM_{2.5}$, i.e. long-term average concentration data across the whole airshed.

3 What and where are airsheds?

3.1 What are airsheds and how are they currently used?

Within the international air quality science community, the term "airshed" is broadly understood to mean a geophysically defined region within which emissions to air from that region have a measurable impact upon the region, especially when wind speeds are low. Another definition is the outdoor air volume within which air pollutants might accumulate. In practice this will typically be a valley, basin or plain with significant emission sources.

However, in the context of air quality management in New Zealand the term has the more specific meaning as the geographical unit of air quality management. Where Councils have identified airsheds that are known, or have the potential to have, air quality that breaches the NESAQ, the airshed is "gazetted" (publicly notified through the New Zealand Government Gazette).

There are currently 89 recognised airsheds in New Zealand and 73 gazetted airsheds. In Otago, 4 separate airsheds (Alexandra, Clyde, Cromwell and Arrowtown) have been combined into a single gazetted airshed - Otago Zone 1 - and 18 other airsheds are combined to form Otago Zone 2.

Gazetted airsheds need to be monitored if a breach of the NESAQ is likely within its borders. Our understanding is that 61 gazetted airsheds have had monitoring at some point in recent years, and 43 are currently monitored (Otago Zone 1 is monitored at 4 locations and Otago Zone 2 at 3 locations).

It is therefore the process and rules for identifying airsheds which defines which towns and cities require airshed air quality monitoring, and which do not, which in turn is a major factor determining the cost of that monitoring to Councils.

Furthermore, gazetted airsheds perform the additional role of defining the areas that will be subject to local air quality management policies and rules (also known as Local Air Quality Management Areas).

3.2 How are airshed boundaries set and what are their implications?

As part of the gazetting process an airshed's boundaries need to be defined. This role currently lies with Regional Councils. Councils are largely free to choose their own boundaries.

In practice most gazetted airshed boundaries encompass a single contiguous urban area within a single geophysical airshed. However, a potential cause of inconsistency is how peri-urban areas are treated (i.e. within or outside the gazetted airshed), which is a particularly important issue in areas of urban expansion and peri-urban land-use change.

One of the major implications of the choice of airshed boundary is that the boundary is used to demarcate where air quality management policies and rules apply.

3.3 What are the current problematic issues?

3.3.1 Some large population centres go unmonitored

The current approach prioritises airsheds with the worst air quality for monitoring. This approach leaves some significant gaps. The most striking example is Palmerston North which, despite being NZ's 8th largest city with a population of over 80,000, is not a gazetted airshed, and therefore has no air quality monitoring. Whereas this is justified in terms of the city deemed to not being at risk of a breach of the NESAQ (although how this can be verified in the absence of air quality monitoring is challengeable) it is less consistent with the intentions of the Environmental Reporting Act 2015 that environmental data should provide a full representation of the state of the environment across the country, not just in the worst locations. It is also problematic when air quality monitoring data is to be used for national risk assessments, such as the HAPINZ report or the StatsNZ health impacts indicator. This is because monitoring data for Palmerston North (and some other towns and cities[1]) is not available meaning exposure data needs to be estimated involving considerable uncertainty.

3.3.2 Inconsistently applied boundaries leading to perceived bias and inequity

The lack of clear guidance over the delineation of airshed boundaries can lead to a situation of perceived unfairness and bias. A boundary that includes more peri-urban or even rural land will mean more of the airshed coming under local air quality management rules, most likely introducing more costs of compliance to peripheral locations where concentrations are usually lower introducing what can be perceived as a disproportionate burden.

There appear to be some regional disparities. Airsheds in Hawkes Bay, Manawatu-Whanganui and Otago - and to a lesser extent Nelson and Northland – tend to include more peri-urban land effectively forming a managed buffer around the respective urban areas (Figure 3-1, left). In contrast airshed boundaries in Auckland, Canterbury and Waikato tend to be more aligned with urban land-use (Figure 3-1, right).

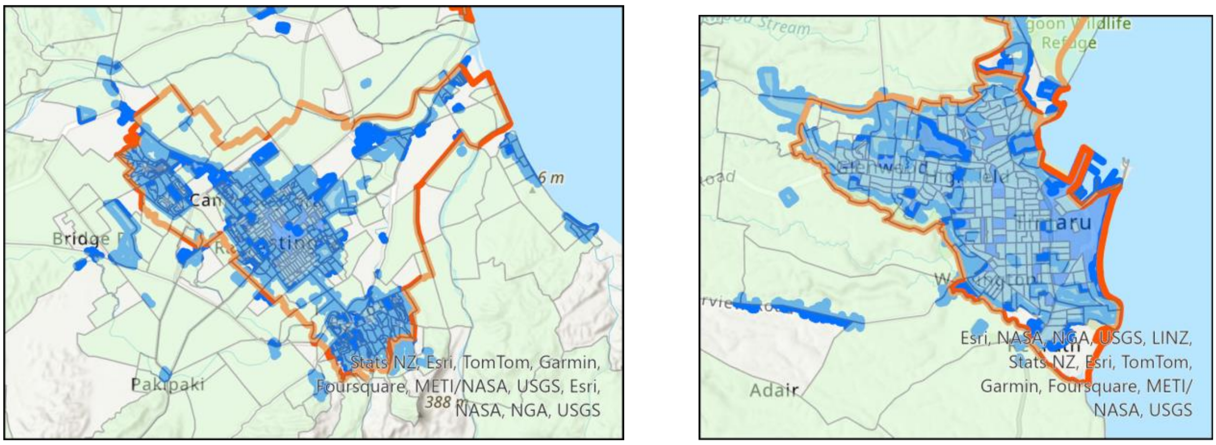


Figure 3-1: Examples of current airshed boundaries (red line) and urban areas (blue) with peri-urban land included (Hastings, left) and excluded (Timaru, right).

[1] Other large towns and cities without air quality monitoring include Hibiscus Coast, Porirua, New Plymouth, Whanganui, Kapiti Coast, Rolleston, Queenstown and Cambridge. These towns alone represent a population of over a quarter of a million.

3.3.3 Land-use changes

Many areas that were previously considered non-urban and were not included within airshed boundaries are now being urbanised or may become so in the future. At present these areas can be subject to inconsistent rules compared to neighbouring older urban areas that lie within the airshed. Without airshed re-definition they could be excluded from exposure monitoring.

At present the re-drawing of boundaries to include such areas is conducted *ad hoc* by Councils. A recurring risk is that the redrawing of boundaries is considered unnecessary unless (or until) the newly urbanised areas risk a breach of the NESAQ. However, the lag times involved in removing emission sources, especially domestic heating appliances, means that the exclusion of such areas from airsheds can lead to emission sources accumulating and remaining in place for years to decades and the opportunity for preventative action being missed. Current practice can also mean that the emergence of a local air quality problem arising from new urban development can go unmonitored.

Examples of this phenomenon include Pukekohe (predicted to grow by 50,000 in the next twenty years (Nettleship, 2023)), Rolleston and Queenstown (whose populations have grown by 68% and 59 % respectively in the last 5 years to just under 30,000 each[2]), but neither are gazetted airsheds, or "new" towns like Pegasus or Lake Hayes.

The Auckland airshed is a special case in being by far the largest gazetted airshed in the country. However, urban expansion means that there are large populations living at medium densities outside of the current airshed boundary.

3.4 What are the objectives of boundary change for exposure monitoring?

Redefining airshed boundaries to allow for a change to an exposure reduction regime would aim to achieve the following,

- A better balance of air quality monitoring between coverage of high **concentration** airsheds and high **population** airsheds, in an attempt to even out differences in the uncertainties in reporting statistics, especially population exposure, between airsheds
- Greater consistency in the delineation of airshed boundaries to reduce biases and inequities
- Airshed definitions and boundaries that are best suited to the purposes of reporting on exposure and exposure reduction in that they define the population whose exposure is being assessed (i.e. reduce absolute uncertainty). We show below in chapter 4 how this favours more tightly defined airsheds with limited inclusion of peri-urban and rural land
- Better allowance for land-use changes since airsheds where previously delineated, and for future land-use changes
- Avoid increasing the costs of monitoring and achieve reductions in cost where possible.

[2] https://www.infometrics.co.nz/article/2023-09-where-is-new-zealands-next-top-town

3.5 What additional issues might arise under an exposure reduction regime?

Under an exposure reduction regime, it is necessary to be able to report progress in the reduction of population exposure. This implies that it is the exposure of a specific population that is being reported. It is a natural step to use the airshed boundaries to define the residential population whose exposure is to be reported upon, using monitoring data from within that airshed where it is available or required.

Furthermore, an exposure reduction regime clearly places more weight on population size as a criterion for determining which airsheds should be monitored. There is a risk of small populations exposed to higher concentrations being overlooked.

3.6 Options for changes to regulations and guidance

3.6.1 De-coupling airsheds for monitoring from management

The current dual purpose of airsheds as defining both an area to be monitored and reported upon, and an area within which local air quality management policies and rules apply, is not the only option. We find no particular reason why the best airshed boundary for the purposes of monitoring (especially monitoring of exposure) and for management would be the same.

It may therefore be worth considering the de-coupling of the two functions. This will give local authorities greater flexibility to respond to local needs, conditions and sentiment, such as seeking more equitable approaches. It also means that airshed boundaries can be set for the purposes of reducing uncertainty in exposure monitoring without being compromised by conflicting objectives.

In practice, perhaps the most pertinent example of this would be limiting airshed boundaries for monitoring purposes to urban areas (reducing uncertainty – see chapter 4), while extending management areas to include peri-urban areas if peri-urban emission sources are making a significant contribution to urban concentrations.

3.6.2 Introducing population criteria to determine which airsheds require monitoring

In order to properly implement an exposure reduction regime consistently across the country, and to achieve consistent air quality reporting, it may be necessary to add to the current requirement that monitoring is conducted where a breach of the NESAQ is likely. For instance, it may be appropriate to require that all airsheds with a population over a threshold will be monitored, regardless of whether an NESAQ breach is deemed likely or not. Table 3-1 indicates how many currently unmonitored airsheds would require monitoring under different population thresholds.

Table 3-1: Number of currently unmonitored airsheds with populations above 4 different criteria.

Population threshold	Number of additional airsheds requiring monitoring	Airsheds
50,000	4	New Plymouth, Palmerston North, Porirua, Hibiscus Coast
30,000	2 more (6 total)	As above, plus Kapiti Coast and Whanganui
20,000	3 more (9 total)	As above, plus Cambridge, Queenstown and Rolleston
10,000	9 more (18 total)	As above, plus Feilding, Havelock North, Hawera, Levin, Lincoln, Oamaru, Te Awamutu, Te Puke and Wanaka
1,000	113 more	

In our view the only disadvantage in this option is the additional cost to Councils of monitoring, and clearly the cost increases as the threshold population decreases. A threshold of 10,000 would appear to be the practical minimum as the number of airsheds increases dramatically below a population of 10,000.

The increase in costs, however, could be offset by allowing these additional airsheds to be monitored using non-standard methods (discussed in more detail in chapter 5) to reduce costs, so long as the probability of a breach of the PM_{10} NESAQ remains low. Alternatively (or additionally), a secondary population threshold could be used. For example, if monitoring is required over 10,000 by non-standard methods are permitted below 30,000 then 14 out of the 18 additionally monitored airsheds could be monitored using non-standard methods, substantially reducing the total cost of monitoring. Although the use of non-standard methods introduces new uncertainty, it nevertheless reduces uncertainty relative to the current situation where no observational data is available at all.

Further cost savings could potentially be gained by relaxing the requirement for standard monitoring in airsheds with populations below 10,000. Currently there are three airsheds with populations smaller than 2,000 that have permanent airshed monitoring, due to relatively or very high PM_{10} concentrations occurring there[3], and another eight with populations between 2,000 and 5,000[4], and another five between 5,000 and 10,000[5]. Figure 3-2 illustrates how the three-band approach enables increased coverage and consistency whilst enabling non-standard methods to offset costs.

[3] Clyde, Reefton and Taihape.
[4] Arrowtown, Geraldine, Milton, Putaruru, Taumarunui, Te Kuiti, Waimate and Winton.
[5] Alexandra, Cromwell, Gore, Morrinsville and Thames.

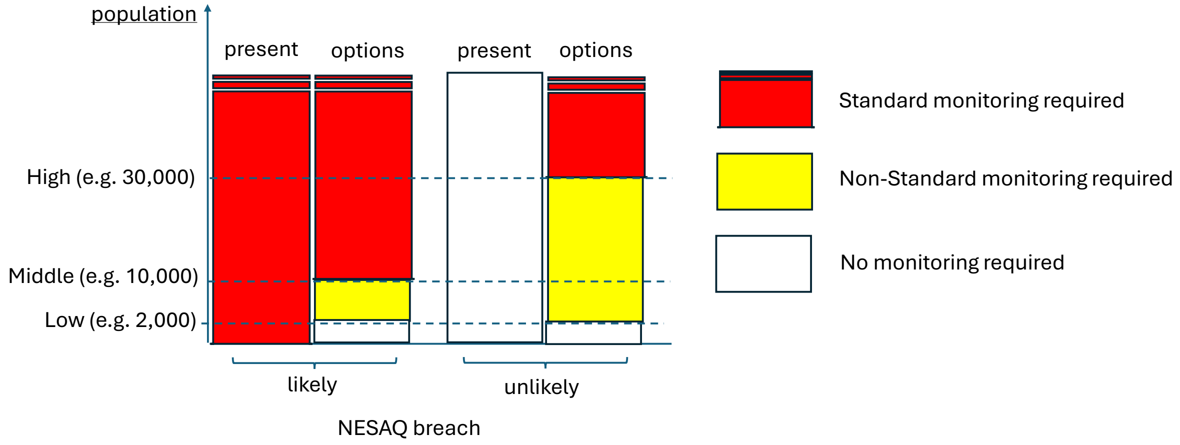


Figure 3-2: Example of how population criteria could be used to determine airshed monitoring requirements.

3.6.3 Changing the criteria for how monitoring is to be conducted

An obvious objection to an expansion in the number of gazetted airsheds would be the implied increase in the cost of monitoring as additional airsheds would require monitoring. However, this could be addressed by expanding the definition of "monitoring". Chapter 5 below discusses how non-standard and hybrid monitoring approaches can be used in certain circumstances to reduce monitoring costs where it introduces no significant loss of data accuracy.

3.6.4 Require regular review of airsheds and their boundaries

This option is intended to directly address the issue of urban growth and land-use change, and avoiding new air quality issues arising undetected and unmanaged. It also allows any new information gained about spatial variation in air quality within and around the airshed (e.g. from spatial surveys – see chapter 4) to be incorporated. An example could be if monitoring or modelling identifies a previously unknown concentration hot-spot or elevated concentrations in a low-population area then its inclusion into, or exclusion from the airshed could be re-considered.

3.7 Options for changes to how airsheds are identified and delineated

We explore how a refresh of the definition and process for nominating and delineating airsheds to deliver improved consistency may be implemented.

3.7.1 Resolving issues identified **without** redefining airsheds

The issue of a lack of monitoring in airsheds that have not been gazetted (like Palmerston North) could be addressed simply by having an additional requirement on Councils to report air quality statistics and/or exposure for all towns and cities over a certain population. This simple requirement would leave the Council free to choose the method for doing this (e.g. monitoring or modelling).

In addition, either a specific method or an approved set of methods could be specified, or a requirement to demonstrate how the statistics meet an uncertainty criterion could be specified, leading the Council to demonstrate how their preferred method meets that criterion.

We show below in chapter 4 how well-defined airsheds are a requirement for reducing the uncertainty in airshed-wide exposure statistics, and some statistics can be quite sensitive to the choice of airshed boundary, especially inclusion of peri-urban land. It is not clear to us how this can be addressed without redefining airshed boundaries.

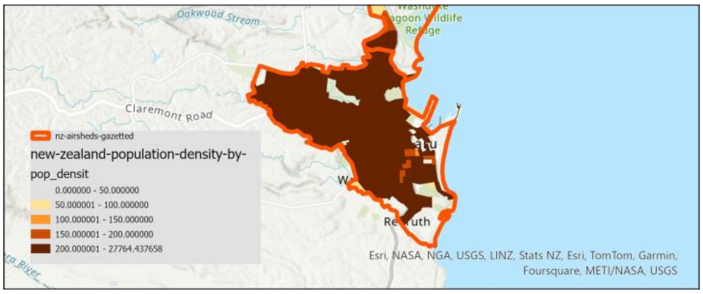
3.7.2 Redefining airsheds using geophysical features only

Although this would introduce consistency, we see no advantage in this approach as most geophysical airsheds are dominated by rural land-use. The requirements on monitoring to represent exposure across large swathes of rural land would be excessive.

3.7.3 Using a population density criterion to define airshed boundaries

One of the simplest options for a consistent national rule would be that airsheds are defined by population density using census data. A rule that airsheds are comprised of census area units with a population density above 200 km^{-2} would have the effect of yielding airsheds that largely correspond to what is generally considered to be urban areas. Discretion should still be used to include non-residential urban land-uses (commercial, industrial, urban parkland, etc) that have low population densities.

Lowering the population density criterion to 100 km^{-2} or 50 km^{-2} would lead to the inclusion of some peri-urban areas but in a consistent way. In those locations where population density falls abruptly with distance from the urban area (for example, Timaru) the choice of criterion would make little difference. In other areas (such as Wellsford) the difference would be substantial (Figure 3-3).



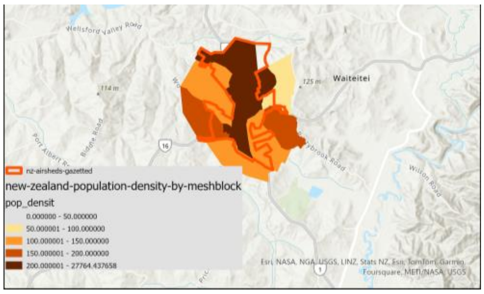


Figure 3-3: Population density per census area unit for Timaru (left) and Wellsford (right).

These medium-density peri-urban areas may suffer from some degradation of air quality due to rural sources, or the advection of urban-sourced pollution. However, their exclusion from the airshed would be justified on the grounds of low population exposure and removing the need to assess concentrations and exposure. It is generally more difficult to locate monitoring sites on rural land due to limited access, conflict with farming activities, lack of reserves and lack of street furniture for mounting small-form monitors. The general lack of monitoring data makes modelling more uncertain due to the lack of validation data. Areas like these may still be considered important sites of exposure if, for example, a sensitive receptor is located there. However, in these cases local discretion could be applied to modify a generic method.

3.7.4 Clarification of process for merging or splitting airsheds

In our view two airsheds can be considered to function as one if it can be shown that air quality statistics (particularly daily mean PM concentrations) in each are reasonably correlated (i.e. high concentrations in one are a strong predictor of concentrations in the other). Such a criterion would need to be specified in more detail, including the measure and threshold of correlation and the requirements around the origin, volume and coverage of data used for the assessment. An example criterion could be that the coefficient of determination (R^2) between a minimum of eight months of daily mean concentrations (including a minimum of two months' data from May to August) measured simultaneously at sites in each airshed is greater than 0.6. The criteria may be hard and prescriptive or could be more subjective and flexible. Two examples – one which does not meet the example merging criteria and one that does – are shown in are shown in Figure 3-4 and Figure 3-5.

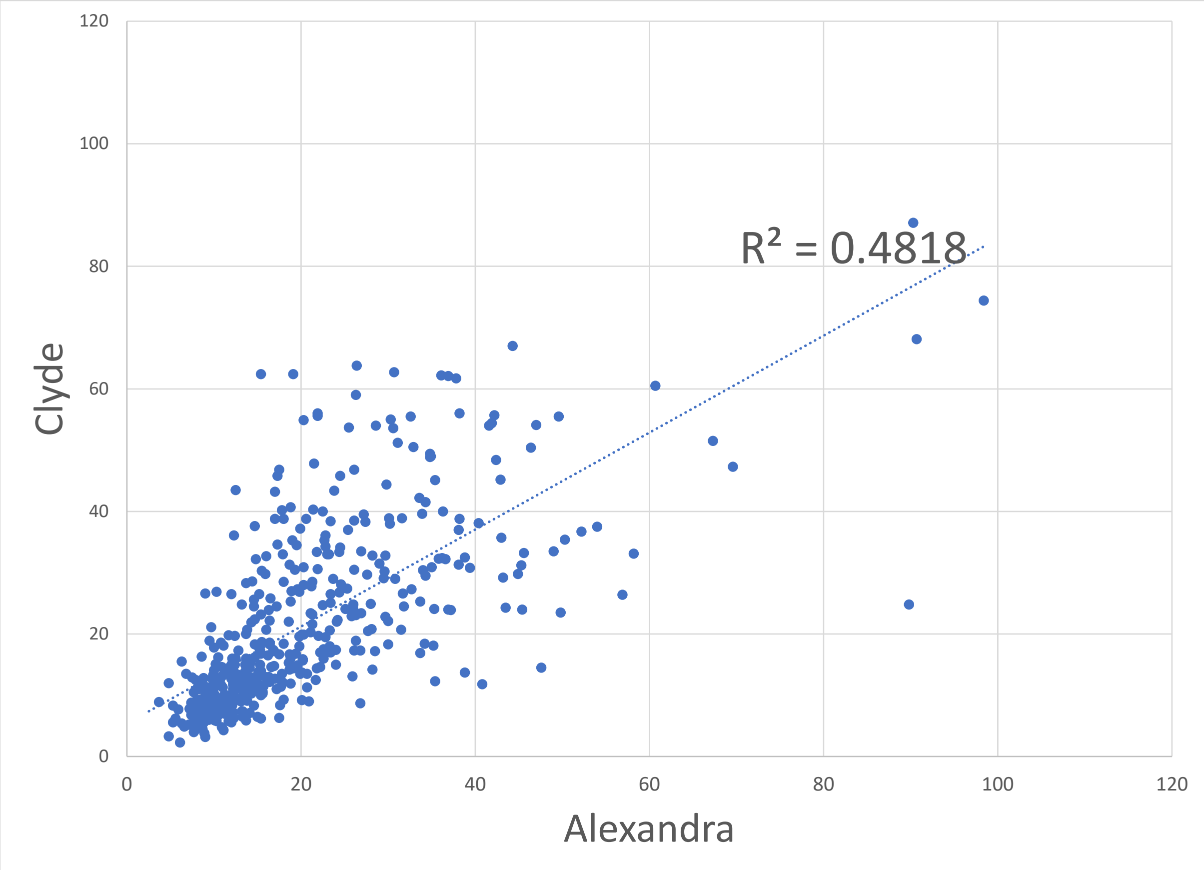


Figure 3-4: A linear correlation of nearly three years of daily mean PM_{10} data from Clyde and Alexandra has an R^2 value below 0.6. Using our example criteria this indicates the two airsheds are not sufficiently correlated to be merged.

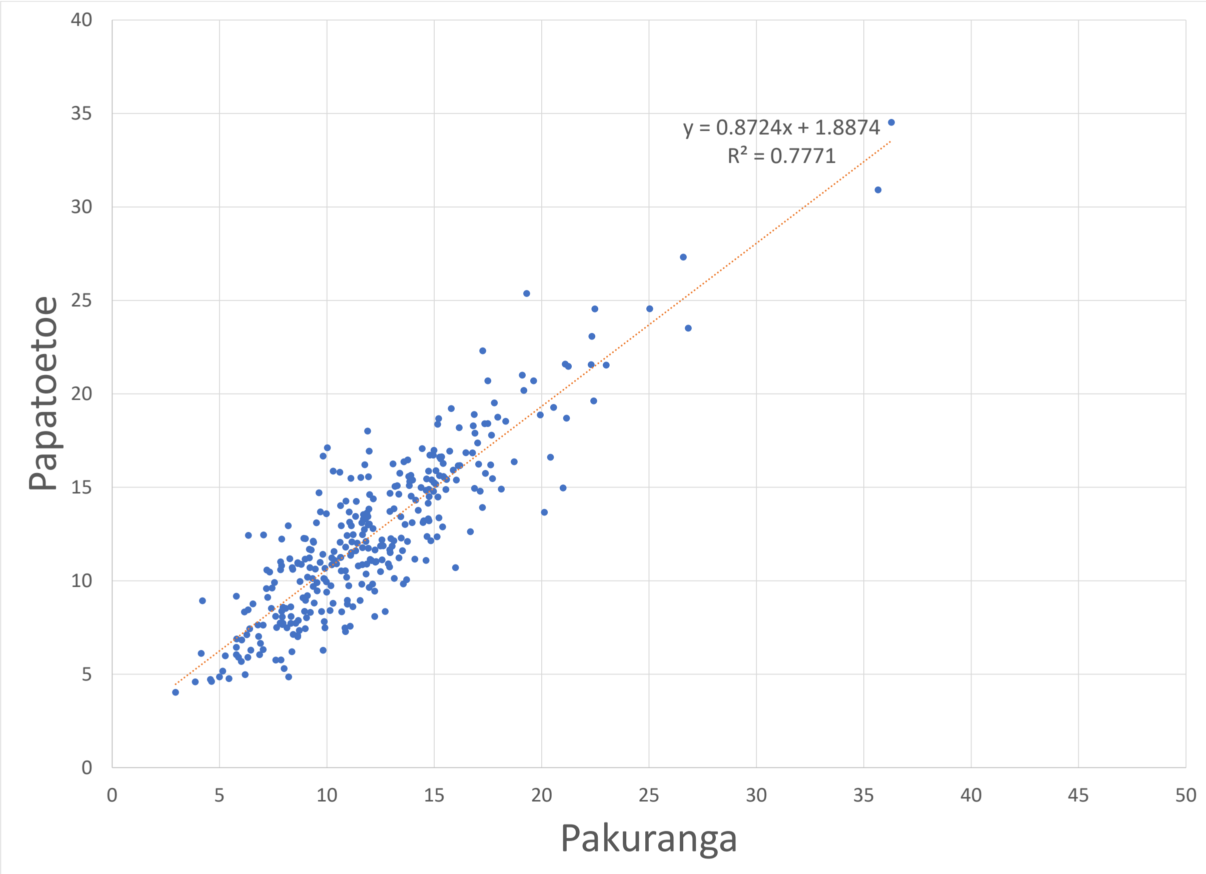


Figure 3-5: A linear correlation of one year (2022) of daily mean PM_{10} data from Papatoetoe and Pakuranga has an R^2 value above 0.6. Using our example criteria this indicates that these two sites are effectively in the same airshed**.**

3.8 Evaluation of options

Table 3-2 presents a simplistic comparison and evaluation of options.

Table 3-2: Summary of options to change the definition and delineation of airsheds.

	needs				
	Improve coverage	**Improve consistency (reduce bias)**	**Reduce uncertainty**	**Future-proof**	**Cost**
Options					
De-couple monitoring and management		Yes			$
Minimum population criterion (e.g. 10,000) for monitoring	Yes	Yes			$$$
Population criterion for non-standard monitoring	Yes	Yes			-$$
Regular airshed review				Yes	$
Low population density criterion for airshed boundaries				Yes	$
High population density criterion for airshed boundaries		Yes	Yes	Yes	$
Clarify airshed merging/splitting criteria		Yes			$

3.9 Recommendations

In our view the current approaches to airshed definition serve the purposes of the current Air Quality Regulations well, but there are two major flaws.

The first flaw is the lack of air quality monitoring in some large population centres based on the assumption that a) a breach of the NESAQ is unlikely, and b) that air quality information for that airshed is not sufficiently useful for other purposes to justify its existence. Not only will the first assumption need to be revisited if a $PM_{2.5}$ standard is introduced, but also an exposure reporting requirement will fulfil that “other purpose” creating the additional rationale for monitoring.

In chapter 4 below we show how assessing exposure across an airshed is more complex, costly and uncertain the more peri-urban and rural land is included within an airshed. In chapter 5 we show how the cost of monitoring in more locations can be offset by using non-standard and hybrid techniques.

This leads us to conclude that the following package of options will best deliver the needs identified in this chapter in the most cost-effective way:

- De-couple airsheds for monitoring purposes from local air quality management areas (i.e. they can have different boundaries)
- Introduce a requirement on Councils to report on exposure in all airsheds with populations above at least 20,000, allowing the use of approved non-standard methods where a breach of the NESAQ is deemed unlikely
- Require airshed boundaries to be reviewed and updated regularly (e.g. every 5 years)
- Introduce consistent criteria for airshed definition. We recommend an airshed is formed of census area units within an urban area with a population density above 200 km^{-2}. Discretion should be allowed to fill minor gaps and include commercial, industrial, parkland and similar land-uses within the recognised urban area
- Introduce a centrally approved (by MfE) process for the merging or splitting of airsheds.

4 How is airshed-representative monitoring established?

4.1 What is representative airshed monitoring?

Monitoring is conducted at a point in space (the monitoring site), but we wish to report and understand on air quality across whole airsheds. This chapter deals with how we ensure that monitoring represents its airshed.

Over the last two decades many research and investigative projects have generated enough evidence to show that air quality varies in space as well as time within all airsheds. The key question for monitoring the long-term compliance of the airshed with the NESAQ, and for tracking trends in the exposure of the population, is whether the spatial pattern changes, or is stable, on the timescale of interest.

As an illustrative example, Figure 4-1 shows the daily average $PM_{2.5}$ concentrations reported using 40 monitors on consecutive days in winter in Alexandra (Longley, 2023a). Although the concentrations vary substantially from day to day, the spatial pattern varies very little, with the location of peak concentrations occurring no further than 200 m from a central point.

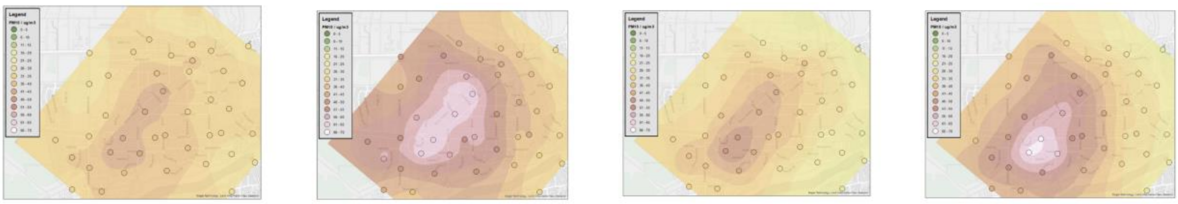


Figure 4-1: 24-hour mean $PM_{2.5}$ concentrations from 40 monitors (including interpolated contours) for four example consecutive days in June 2023.

Although we do not claim this occurs everywhere all the time, this phenomenon has been observed in NIWA research frequently in several other towns. Where the spatial pattern is stable in this way it follows that a monitoring site placed at the location of maximum concentrations will report not the average exposure across the airshed, but rather the maximum. In the example shown in Figure 4-1, this maximum concentration was 33 % higher than the mean concentration across the monitoring grid, and 89% higher than the minimum.

Spatial stability means that the relationships between concentrations at different sites are also reasonably stable, i.e. that the airshed mean concentration can also be estimated using data from a peak monitoring site. Furthermore, full spatial stability means that the maximum and mean concentration can be estimated from **any** monitoring site. In other words, a “representative” monitoring site is any site from which the airshed maximum and mean concentration can be estimated to within an acceptable error.

There are situations where we may expect the spatial pattern to not be consistently stable. Some airsheds may be “bi-modal” in that two different spatial patterns may occur related to different wind directions or other meteorological conditions. Some airsheds may have seasonally varying spatial patterns, i.e. differently shaped patterns in winter compared to summer due to changes in climate, but more likely changes in the emission source mix, and especially in airsheds with solid fuel heating as the dominant emission source. If these factors are suspected the representativeness of any monitoring site cannot be assumed, and may be conditional (i.e. only representative at certain times or in certain conditions). Another way of expressing this would be that the uncertainty in the representativeness can vary, along with the error in estimating representative airshed statistics. Solutions to this issue are discussed below.

4.2 What is the current guidance and its implications?

The current regulations require airshed monitoring to be conducted at "peak" sites, i.e. where the highest daily concentrations are likely to occur. Airshed compliance is judged using data directly from the peak site. This represents the rationale that if the peak site is in breach of the NESAQ, then so is the whole airshed – having a single monitor at the peak location then becomes an efficient solution. There is no current requirement to assess or report airshed-wide exposure.

4.3 What are the current problematic issues?

In general, Councils have had the freedom to interpret the peak site requirement in their own way. However, a major constraint is that the logistical requirements for a site tend to place major limitations on where a monitoring site can be established. The most desirable sites are often not available, and compromises usually have to be made.

The peak-site requirement leads to several problems:

- How do we know if a site is a peak site?
- Does the location of concentration peak move over time?
- Do monitoring locations need to have persons exposed for a specified time (e.g. 24 hours a day, which is the averaging period of the PM_{10} standard)?
- Is a "hot-spot" the same as a peak site?

NIWA research has begun to evaluate how well current airshed monitoring sites meet the peak site requirement in a few airsheds. For instance, in 2023 we established that (for a period in late winter) the location of the maximum daily $PM_{2.5}$ concentration in Invercargill moved across the city but was more frequently in the south-west of the city close to the regulatory monitoring site (Longley, 2023b). Although data from the regulatory site was not strictly "peak" (there was always somewhere reporting a higher concentration), the site probably is the best logistically-feasible solution using a single site. However, we also found that Alexandra's regulatory monitoring site reports concentrations below the town-wide average and falls far short of any definition of a peak site (Longley, 2023a). This means that Alexandra's air quality statistics have been artificially and systematically low relative to other airsheds, since the site was adopted in 2017.

This illustrates how airsheds may not be currently compared on a fair and consistent basis. This has implications for the allocation of limited resources, for unnecessary stigma and some local air quality issues going under-reported and unaddressed.

The existing guidance requires the monitoring site to be a location where people are likely to be exposed over the time frame of the NESAQ, i.e. 24-hours in the case of particulate matter. Some have interpreted this to mean that a monitoring site cannot be set up on the grounds of a school, for instance, as the school is not occupied for 24 hours-a-day. In practice, schools are popular options for monitoring sites due to a degree of open space, locations within residential areas and good access. The alternative interpretation is that the term "location" can be interpreted over a slightly wider spatial scale, such that it refers to the neighbourhood within which the school is situated, rather than the school property itself.

It should be noted that the peak site requirement means that monitoring data does not directly represent population exposure by design. However, monitoring data from these sites is used to represent exposure in health risk assessments like HAPINZ. As above, this means that such reporting currently includes biases and errors that can lead to the misidentification of priority problems.

The term "hot-spot" is not defined in the current regulations. Here, we use it to distinguish between two different types of "peak" location. Firstly, we assume that a peak location is one which, if used as the site of a permanent monitor, can be used to determine if the **whole airshed** meets the NESAQ or not (the intention of the peak site requirement). We, then, use the term "hot-spot" to describe a small area (order 10 – 100 m) that is either temporarily or sporadically the location of the highest concentrations in the airshed (e.g. in response to an atypical irregular emission such as bushfires, or an irregular industrial process), or is so highly localised that it is not a characteristics of the airshed, and/or the exposed population is very low (e.g. a major traffic intersection). In these cases, air quality in the hot-spot is generally unrelated to and uncorrelated with air quality in the majority of the airshed.

At present, whether or not a hot-spot of this sort constitutes a peak site is unclear in the regulations making every case open to interpretation. Resolving this issue may improve consistency and inform better allocation of resources.

4.4 What additional issues might arise under an exposure reduction objective?

The fundamental basis of an exposure reduction regime is the reporting of trends in exposure. This puts of more explicit requirement on monitoring to be representative of exposure and therefore the whole airshed (or at least the more populated parts of it). It should also be noted that the policy goal is not so much compliance with the NESAQ as ongoing progress in the reduction of exposure. The key decisions to be made are how representativeness is implemented and demonstrated, and to what level of uncertainty? It also becomes important to define whose exposure is being represented by any given monitor or statistic.

4.5 What are the objectives of representative monitoring?

Using representative monitoring to allow for a change to an exposure reduction regime would aim to achieve the following,

- Remove ambiguity and ensure consistency between airsheds so that they can be compared on a fair and robust basis
- Reduce uncertainty in the identification of peak and representative sites

- Enable population exposure to be reported in a consistent manner without large spatial variations in uncertainty.

4.6 Methods for assessing monitoring site representativeness

A number of methods are available for assessing site representativeness. However, they vary substantially in terms of cost, complexity and uncertainty. We present some options below. A direct comparison of these methods has not, to our knowledge, been undertaken making our evaluation necessarily subjective.

4.6.1 Assessment of site representativeness – general principles

The assessment of site representativeness effectively represents a review of a monitoring plan based on data from a specific period of time (e.g. one specific year). In principle, if the emission and dispersion characteristics of the airshed do not change with time, then neither does representativeness, and the assessment does not need to be repeated. However, given that changes are likely in most airsheds, it is probably more suitable to review representativeness on a regular basis (e.g. every 5 years).

The more sophisticated methods can be thought of as systematically "mapping" the airshed in terms of generating an understanding of the long-term spatial variation in $PM_{2.5}$ concentrations across the airshed. This is a vital requirement if either spatial- or population-based averaging of concentrations is to be implemented.

The outputs from an assessment are the evidential basis on which representativeness is established, and any spatial adjustment equations that are to be used in order to report representative statistics. Probable outcomes of the assessment would be a monitoring plan, specifying whether existing monitoring sites are to continue as the airshed representing the airshed, or whether any new sites are proposed to better meet the requirements.

As an input, mapping requires air quality data which can be gathered in one of three ways:

- Air quality data is assessed (through observation or modelling) for quasi-random points across the airshed
- Air quality data is assessed (through observation or modelling) for regular gridded points across the airshed
- Air quality data is assessed (through observation or modelling) at or near the centroid of each census area unit (or other spatial unit for which population data is available)

In all cases we would recommend that data collection includes data from existing or feasible future regulatory monitoring sites.

These data can then be used in the following ways:

- To create a spatial average concentration field and temporal variability field. A recognised spatial interpolation method such as kriging is best suited using data from a regular grid (our ongoing research is currently exploring this in more detail)

- To create estimates of average concentration for spatial extents for which population data is available so that an airshed population-weighted concentration can be calculated. In practice, census area unit is likely to be the preferred spatial unit. We suggest this is best done in a GIS using a spatially interpolated concentration field based on gridded data. However, it could also be done without interpolation if the input data is already designed to represent individual population areas
- To establish the relationships between concentrations at individual sites and the airshed average and maximum concentrations, in order to assess existing or proposed future sites in terms of their representativeness.

Whereas in practice these processes could be conducted with data from as few as four sites, more sites will tend to reduce uncertainties, although there may be diminishing returns above a certain number of sites. Our ongoing research is seeking to quantify this relationship, but at the time of writing we use a value of 28 sites as a first approximation of an optimum number of sites.

Mapping air quality across an airshed is likely to have additional benefits. These may include:

- Identifying previously unknown or under-appreciated emission sources (more likely if a monitoring-based approach is used)
- Identifying equity issues and highly impacted sub-communities
- Aiding communication and engagement with local air quality issues, policy initiatives and supporting voluntary emission reductions.

The following section covers the different methods available to generate the data for such an assessment, in order of decreasing sophistication and increasing uncertainty.

4.6.2 Direct observation - Dense non-standard monitoring

In our view this is the most robust method yielding the least uncertainty. Until recently this approach has not been viable. This is because of the costs involved in achieving monitoring with the requisite accuracy and consistency, the size and logistical footprint associated with maintaining monitors at controlled environmental conditions, and the security and access consideration as associated with a monitoring site. These factors have limited the practical number of monitoring sites to one, or just a few per airshed. This has tended to rule out direct observation of spatial variation as a practical option.

However, the emergence of smaller-form and lower-cost monitors in the last few years that possess the required performance but also have a much smaller logistical footprint (e.g. easily implemented mounting on street furniture rather than needing to secure land) has not only made this method viable, but also, in our view, superior in terms of the quality and comprehensiveness of the information it generates. It may be the most expensive but should have the lowest uncertainty. It has the advantage of identifying any errors in the airshed delineation (i.e. parts of the airshed that are more correctly in a different airshed), identifying hot-spots (locations strongly impacted by some local influence, e.g. an intense point source), identifying seasonal changes in air quality patterns (and hence monitoring representativeness), and identifying atypical events and patterns (allowing them to be excluded from analysis where appropriate).

The best way of establishing representativeness is to measure concentrations at multiple locations across an airshed for a year. This allows locations to be identified that are unrepresentative – most likely due to a hot-spot, an atypical emission source or because they are outside of the airshed (i.e. there is an error in the airshed delineation). In simple airsheds with consistent patterns this may not require a full year of data, but can be extrapolated (to an acceptable level of accuracy) from a few months of data.

There are trade-offs to be considered in terms of monitor density and monitoring duration versus cost and uncertainty. Based on our ongoing research, as an indication we would recommend for the typical airshed a grid of approximately 28 monitors deployed for 12 months, regardless of the airsheds physical size. The number 28 arises from a regular grid of 4 x 7 which matches the shape of many NZ towns. Ongoing research is indicating that a minimum grid width of 4 appears to be optimal for spatial interpolation.

Our recent assessment of the Alexandra airshed revealed a relatively stable spatial air quality patterns (although the observational campaign was limited to May and June). Although this work showed the current regulatory site failed to fulfil any reasonable definition of a peak site, we found that it **was representative**, on account of there being a stable relationship between concentrations at the regulatory site and both at the actual peak site, and the town-wide average. This exercise showed that the goals of reporting peak concentrations **and** population exposure in the way envisaged by this work, could - in principle - both be met using either the existing monitoring site, or a new site at the peak location, or a new site anywhere in the assessed grid.

4.6.3 Reduced observational screening

An observationally-based assessment based on a sub-optimal grid (for example, 10 or fewer sites, and/or shorter duration) will be subject to greater uncertainty, although the exact amount is likely to be specific to each airshed, and the particular monitoring locations chosen. So called 'screening' assessments have been conducted in a number of airsheds by various Councils over the years, typically using 4 – 6 sites. Further research based on datasets already captured by NIWA should quantify the rise in uncertainty involved with using smaller networks or shorter monitoring durations.

4.6.4 Mobile monitoring data

NIWA and several Councils have explored the use of air quality monitors being carried by vehicles and driven around specific airsheds. Although it is possible to make high quality and high-resolution measurements in this way, there is considerable complexity and uncertainty involved in the analysis.

The major limitation of this method is that it usually covers a very short span of time, relative to the long-term patterns of interest. Even airsheds with consistent spatial patterns on a daily basis (e.g. Alexandra, see above) have substantial spatial variation on hourly timescales, meaning that spatial variation strongly interacts with temporal variation and this needs controlling for. In particularly stable airsheds this can be done using a fixed reference site and normalising mobile data to that fixed site. However, any breach of the spatial stability assumption can introduce substantial error.

In principle, a spatial survey repeated every hour over a year could produce a highly detailed and valid result but at significant cost. Given our substantial experience in this area we believe a fixed grid of monitors (see above) is significantly superior in terms of much lower uncertainty and complexity, and probably cost.

4.6.5 Emission-Dispersion modelling

Before reliable lower-cost sensors became available, this was the most sophisticated method available. It can be subject to considerable uncertainty, however, due to:

- Common lack of sufficiently local meteorological data
- Limitations in the validity of dispersion models in low wind and low boundary layer conditions
- Limitations in the validity of dispersion models in describing dispersion near ground level in urban topography
- Lack of data on the number, location, intensity and time-variation of emissions, especially from home heating
- Limited ability to describe atypical conditions and emissions.

Advantages of this method include:

- The ability to run multiple scenarios to explore sensitivities and reduce uncertainties related to missing data
- The ability to use the model for other purposes, especially future scenario and budget planning and compliance activities
- The ability to place receptors in any location, regardless of the logistical feasibility of the location as a monitoring site. This means (for instance) that perfect regular "virtual monitoring" grids can be created that are ideally suited for creating spatial averages. Also, the number of receptors is not limited by the cost of monitoring but could 9if desired) run into the hundreds or thousands
- Modelling studies can be conducted at any time and can therefore be completed much more quickly than observationally based methods.

Projects that have explicitly compared dispersion model predictions to dense observational data are rare. In New Zealand we are aware of only one ongoing project that is incomplete at the time of writing.

Despite the inherent uncertainties, emission-dispersion modelling can still provide indicative or interim information that may be sufficient until better data can be collected.

4.6.6 Empirical modelling (e.g. land-use regression, or LUR)

An LUR model is a mathematical model that expresses correlations between predictor variables and dependent variables. The presence of underlying causal processes is implied but not explicitly described in the model. In other words, an LUR expresses how two variables (like temperature and PM10) might be connected, but not why.

Generally, the application of an LUR to the assessment of spatial variation in airsheds means building a model based on the correlations between concentrations and land-use observed (or modelled) in an airshed with high quality spatial concentration data, and applying them to another by assuming those correlations will translate. This assumption is significant and may introduce uncertainty.

However, this method may provide interim data that can be validated in the future with a medium density monitoring campaign, or replaced with a full monitoring campaign.

Although this method has been widely used overseas and for research projects, we are not aware of any such study to map airsheds in New Zealand. This is largely because it depends on the sort of dense monitoring data (see above) that has only recently become available.

A LUR model is self-validating and so does not suffer from the same limitations as an emission-dispersion model. However, its validity can still be highly variable, depending on comprehensive the input data is. If the physical processes impacting local air quality are not captured by variables in the LUR model (usually because they are not available or are only weak proxies) then the model is liable to contain significant prediction errors.

4.6.7 Rule of thumb

This is, in effect, a very simple empirical model. Our research data to date suggests a very broadly consistent picture of PM concentrations, with peak concentrations being 2 – 3 times the minimum concentrations within the urban area. As more observational (or modelling) assessments are conducted generalised patterns such as these could be combined to describe the "typical" pattern across a "typical" airshed. Although this may incur significant uncertainty it should be more accurate than no model at all, and may fulfil an interim role until better data can be collected. Such a simple model could be combined with expert elicitation – i.e. best guesses based on local knowledge or other sources of data (visual observations, complaints, etc).

4.6.8 Subjective or anecdotal evidence

This includes any method where data from sources other than air quality monitors are used to infer high and low levels of air pollution. This may include webcam or other visual data, air quality complaints, survey data, etc. We are aware of no project that has sought to explore the validity and uncertainties in such methods. The clear disadvantage of this method is that it is unlikely to generate quantitative data and therefore cannot meet quantitative criteria.

4.7 Representativeness in complex airsheds

For the purpose of this discussion, a "complex" airshed is one in which there is not a single stable spatial pattern in concentrations. This is more likely in airsheds where the dominant emission source in different in summer compared to winter, or where spatial patterns are strongly impacted by meteorological conditions, especially wind direction. It will also apply to airsheds with a relatively localised intense emission sources, such as a major industrial installation.

We consider the following approaches could be used:

- Base assessment on the most common spatial pattern and accept the resulting error
- Where 2 "modes" are observable (e.g. winter and summer, or easterly and westerly winds), filter the available data and conduct separate assessments for both modes. If the preferred sites for each mode are in significantly different locations, then either:
  - Have separate monitoring sites for each mode
  - Have separate adjustment equations for each mode

- Adopt the best performing site and equations and accept the resulting error.

4.8 Options for changes to the definition and requirements of representative monitoring

4.8.1 Enabling calculated statistics

Greater flexibility can be achieved if reporting statistics can be based on calculated values in certain circumstances. This is already permitted within the current regime, where data from one type of instrument are routinely adjusted to be consistent with another (e.g. data from a BAM is adjusted to be consistent with a TEOM or Hi-Vol sampler).

One of the most useful options would be to allow the use of a spatial relationship equation to estimate airshed-mean concentrations from data from a site where concentrations are above or below that mean, for example from a peak site. This would enable the reporting of airshed mean concentrations using the existing monitoring sites, regardless of where they are located. The key would be to place requirements around verification of the adjustment equation.

In principle, this could be done “in reverse” in that peak concentrations could be calculated form non-peak sites, subject to the same caveats.

Adopting these options gives Councils the choice of either relocating monitoring sites to true peak and average locations, or keeping existing sites and adjusting the data to compensate for non-ideal locations. Without these options Councils would either have to meet representative requirements by moving sites that do not meet the criteria, or will simply fail to meet the criteria leading to an ongoing bias in the data.

4.8.2 Specifying the requirements for airshed reporting

Options include:

- Specifying that Councils need to report air quality statistics (daily and/or annual means) from a peak site
- Specifying that Councils need to report airshed statistics representative of the exposure of the majority, or all of the residents of the airshed, either:
  - Annual mean $PM_{2.5}$ at a site representing airshed-average concentrations, or
  - Spatially-averaged annual mean $PM_{2.5}$, or
  - Population-weighted annual mean $PM_{2.5}$.

An “average” monitoring site, i.e. one where annual mean concentrations are effectively equal to the average concentration across the airshed (i.e. analogous to the situation where a peak site is one where annual mean concentrations are effectively equal to the maximum concentration across the airshed). This has the advantage of being able to use monitoring data directly without any further manipulation any adjustment. Its main limitation is similar to that for peak sites – how is its status as an “average” site established, verified and re-verified over time? It is also quite possible that such a site is not logistically feasible or available.

The spatial and population weighted options allow the statistics to be derived indirectly from data from one or more representative sites. Population weighting adds a requirement of sourcing population data. Census data is readily available at census area unit level, but not every year. This therefore requires the use of inter-census estimates. The main advantage of population weighting is that it reduces the bias arising from spatial variation in population density, and especially the inclusion of peri-urban land within the airshed boundary.

4.8.3 Clarifying the definition of peak sites

It could be useful to clarify that peak sites are not hot-spot sites, i.e. they should meet the following criteria (values are suggestions and could be modified following consultation):

- are expected to be at, or close to (e.g. within 200 m of) the location of airshed-maximum concentrations on more than 50% of days annually, and
- are impacted by emission sources impacting more than 50 % of the airshed.

This will provide more certainty over site purpose and validity and further reduce bias and inconsistency between airsheds and Councils.

4.8.4 Setting requirements for site representativeness

A range of methods for assessing site representativeness and calculating spatially and population weighted annual concentrations are presented above.

The option arises to either specify the requirements of such assessments, or allow Councils to conduct assessments as they see fit.

Examples of these requirement include:

- The acceptable level of error or uncertainty when airshed statistics are calculated
- Minimum number of locations considered in a spatial assessment
- Whether any methods are to be excluded from consideration, or a list of methods are to be approved
- Minimum duration or temporal coverage of input data
- Performance or validation criteria for models
- Minimum correlation to consider a site representative
- Review period for assessment.

The advantage of setting requirements is to achieve consistency between Councils, reducing variation in uncertainty between airsheds and Councils. The disadvantage is the cost of the process to establish those requirements, and addressing potential challenges.

4.9 Evaluation of options

Table 4-1 presents a simplistic comparison and evaluation of options.

Table 4-1: Summary of options to improve monitoring representativeness.

	needs				
	Improve coverage	**Improve consistency (reduce bias)**	**Reduce uncertainty**	**Future-proof**	**Cost**
Options					
Enabling calculated statistics		Yes			-$$
Reporting for peak site only					-
Reporting spatial average			Increases		$ to $$$
Reporting population-weighted average		Yes		Yes	$ to $$$
Distinguish peak from hot-spots sites		Yes	Yes		-
Setting requirements for representativeness		Yes	Yes		$ to $$$

5 How might airshed monitoring be optimised? Non-standard monitors and hybrid monitoring

5.1 What are standard and non-standard monitoring?

This chapter specifically focusses on the monitoring the mass of particulate matter per unit volume of air, i.e. $PM_{2.5}$ and PM_{10}. Although similar trends and issues also apply to other air quality metrics the specifics are different.

5.1.1 Overview of the PM monitoring technology available when the current regulations were formulated

A variety of methods have been developed for monitoring PM over the years, which are available in a range of monitoring technologies from numerous manufacturers. Unlike gas molecules, in principle every airborne particle may be unique. Different technologies attempt to quantify different characteristics of an aerosol (i.e. a suspension of particulate matter in the air).

$PM_{2.5}$ and PM_{10} are defined as measures of the mass of particulate matter per unit volume of air. "Gravimetric" methods that attempt to quantify mass by measuring weight directly have the longest history and are the simplest. These generally involve PM being collected on a filter through which ambient air is passed at a fixed and known rate, and the in weight of the filter being measured at least two points in time.

Gravimetric methods are not well-suited to providing highly time-resolved (e.g. hourly) data, and even daily data is labour intensive. Commonly used alternative methods that provide hourly (or faster) data include the Tapered Element Oscillating Microbalance (TEOM) and Beta Attenuation Monitor (BAM). The TEOM aims to measure mass inertially by observing the change in oscillation frequency of a microbalance whose mass changes when impacted by particulate matter. The BAM aims to infer mass by observing the change in beta radiation attenuation inducted by particulate matter accumulating on a substrate target.

A nephelometer (or optical monitor) is another class of device which infers the mass of particulate matter in an aerosol by the degree that it scatters a beam of light. Nephelometers come in a range of degree of sophistication with many able to distinguish particle size (with varying uncertainty) by detecting scattered light at differing scattering angles.

Other methods have been developed but are currently used only for research purposes and are not employed in the air quality management domain.

Each method has its own strength and weaknesses. Foremost amongst these is differential sensitivity to particles of different sizes, shapes and composition. This means that the accuracy (and uncertainty) of any given instrument can only be specified for very specific and consistent aerosols, in other words when sampling ambient aerosols (which are nearly always mixed and variable in their composition) any PM instrument's accuracy and uncertainty is also continuously variable. In conclusion, no method is therefore inherently more accurate than any other.

5.1.2 What is the current guidance?

The current Regulations require that airshed monitoring used for the purposes of assessing compliance with the NESAQ is conducted using an approved, or "standard" method (meaning compliance with an Australian/New Zealand Standard). Three such methods are specified:

- a gravimetric method meeting the demands of AS/NZS 3580.9.6:2003 (in brief a high-volume sampler with a size-selective inlet), which constitutes a "reference" method, against which the performance of other methods should be compared
- A TEOM meeting AS/NZS 3580.9.8:2003
- A BAM meeting AS/NZS 3580.9.11:2003.

By implication, other methods, including all optical methods, cannot be used for airshed compliance monitoring. The primary reason for this is the perceived inability of these other methods to meet the performance requirements (specifically accuracy) that is needed, given the financially and economically significant implications of airshed non-compliance.

5.1.3 Technological developments since the current guidance was formulated

Since the Air Quality Regulations were introduced, and the Guidance supporting the NESAQ (MfE, 2011), there has been continuing and significant developments in particulate matter monitoring technology. The main development has been the emergence of small-form and low-cost optical sensors that became available from several manufacturers in the early 2010s.

Early models typically suffered from drift, interference and low sensitivity, making them unsuitable for regulatory purposes. However, in the late 2010s a new generation of sensors emerged with significantly improved stability and performance. Now many hundreds of thousands if not millions of such sensors are in use around the world.

The NIWA research team started using devices based on Plantower sensors in 2017. We have found them to be highly stable, retaining their stability typically for at least 3 years.

5.1.4 Hybrid methods

Hybrid methods exploit developments in modelling methodologies. In brief, a hybrid method is one that is partly dependent on monitoring data, but uses modelling (usually empirical) to fill data gaps. This can include extrapolating sub-yearly or non-continuous data, or using data from other airsheds to generate airshed statistics.

5.1.5 Recent developments overseas

Within the EU regulations there is now provision for indicative monitoring. Indicative monitoring is a category defined by EU Directive 2008/50/EC on ambient air quality monitoring (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32008L0050). It applies to a measurement aligned with a data quality goal lower than standard reference monitoring and can provide data on the spatial distribution of air pollutants or for the purpose of communicating current air quality to the public.

In recent years, along with the huge rise in the use of Non-Standard Monitors (NSMs), there has been a corresponding growth in projects to characterise their performance and calibrate them relative to established "standard" methods in a wide range of environmental settings, climates and aerosol mixes. Furthermore, open databases are being increasingly used to explore the transferability of calibrations between different locations (e.g. USEPA (2022), https://www.aqmd.gov/aq-spec/sensors/).

Another major development is the blending of networks of standard and non-standard monitors (with calibration adjustments applied to the latter) to greatly increase the monitoring data gathered per dollar spent. A leading example is the USEPA's Air Now Fire and Smoke Map. Begun in 2020 it now combines data from 15,000 NSMs, mostly owned privately, with around 1,000 standard regulatory monitors. The web-based map has had 50 million hits.

5.2 What are the current problematic issues?

Monitoring using standard methods is expensive. All three approved methods require regular calibration, maintenance, environmental control of the instrumentation that arises from the requirements of accuracy and stability, security and protection. Monitoring budgets are under permanent pressure to be reduced.

Among the more recently developed monitoring technologies, optical sensors in particular are available at much lower capital cost, and hybrid methods also offer the potential for cost reductions. However, additional labour costs can arise associated with the management of much larger numbers of instruments, and the much larger datasets generated, as well as more frequent replacement costs. This may be offset by increasing automation and ongoing reductions in sensor costs. Whether reductions in the total cost of monitoring functions can be achieved will partly depend on the development of good practice, but may also be enabled by changes to the current Regulations.

The key question is when should non-standard methods be permitted?

5.3 What additional issues might arise under an exposure reduction objective?

As described in the chapters above, the transition to an exposure objective would mean that exposure (and hence air quality) would be reported for most or all towns and cities above a certain population. This may result in an increase in data-generating activity by Councils. Observational data is always preferred to modelled data. We also describe in chapter 4 how limited duration observational campaigns are a high-quality option for quantifying the representativeness of long-term monitoring sites, and for developing the equations needed to relate monitoring site data to airshed-wide data. This option would also substantially increase the amount of air quality monitoring to be done in the future.

The current air quality Regulations are, or might be seen to be, a major barrier to this expansion. Conversely, changes to the regulations regarding monitoring methods might be the key change required to unlock the potential of non-standard monitoring, and make exposure monitoring not only feasible but cost-effective.

5.4 Needs/Evaluation criteria – what are the objectives?

- To remove barriers to the use of new monitoring technologies and methods, whilst retaining requirements for accuracy and performance that are commensurate with the monitoring objectives.

5.5 The options

5.5.1 General approach

We suggest that an over-arching criterion should be that non-standard monitoring may be used whenever and wherever this introduces no significant error in key statistics (significance will need to be defined).

General requirements to be fulfilled could be:

- There is no significant instrument drift, or drift can be reliably compensated for
- Differential instrument response to environmental conditions (such as variation in humidity) can be reliably compensated for
- Differential instrument response to varying aerosol composition (such as seasonal, locational and time-based variation in source mixes) can be reliably compensated for.

5.5.2 Airshed compliance reporting – method performance criteria

A simple option is to leave the current guidance unchanged, i.e. a standard-compliant method is required for airshed compliance monitoring in those airsheds where a breach of the NESAQ is considered likely. If a breach is considered unlikely, there are currently no requirements. The main weakness of this is it removes any requirements to monitor airsheds where air quality may breach the NESAQ in the future. There is an option to include future likelihood of NESAQ breach in this clause.

Another option may be to require a minimum population criterion (also discussed in chapter 3). I.e. there is the option to require standard monitoring inly in airsheds above a certain population, but allowing (specified) non-standard methods in airsheds with populations below this criterion.

5.5.3 Airshed exposure reporting – method performance criteria

We suggest a criterion that the uncertainty in the annual mean $PM_{2.5}$ statistic chosen (site-specific, spatially-weighted or population-weighted) should be less than a value ranging from 0.1 – 0.5 $\mu g\ m^{-3}$, based on the assumption that a change of this magnitude per year would be considered statistically significant.

One option is that any monitoring method that can meet this criterion is approved for the purpose of exposure reporting.

The method by which compliance with this approval criterion is judged would need to be developed.

An additional or alternative and simpler criterion would be to require a currently approved standard-compliance method if annual mean $PM_{2.5}$ is above a certain threshold, e.g. 75 % of any adopted annual NESAQ, but allow non-standard methods below it.

5.5.4 Airshed assessment/mapping monitoring – method performance criteria

It is probably not feasible to require monitoring for the purposes of airshed mapping (see chapter 4) to be conducted using standard-compliance methods.

An enabling option would be to explicitly allow non-standard methods for this purpose.

Nevertheless, performance requirements will still be suitable. Inaccurate or inconsistent monitoring may not reduce the biases involved in current monitoring (and assumption about site representativeness) and increase rather than reduce error in airshed statistics.

We recommend the development of performance criteria for non-standard methods that is both enabling (i.e. achievable using the better performing instruments currently available) and unlikely to introduce bias and error.

5.5.5 Additional criteria options

Where non-standard monitoring may be permitted for airshed monitoring, the following additional criteria may be required in order to meet the performance criteria:

- A minimum number of monitors (e.g. 4) are deployed per airshed (to check for changes in spatial patterns and spatial-adjustment equations)
- At least one site per airshed has triplicate monitors (to check for, and correct monitor drift)
- Monitor performance is to be tracked and performance requirements met at all times
- An adjustment equation for the monitors in use is established by co-location with a standard reference instrument in a location within the airshed, or within the airshed "cluster" (i.e. airsheds shown to have similar emission and climate characteristics – see below) for at least one year and is updated at least every year.
- The airshed has been mapped using approved methods.

5.5.6 Suggested process to implement the use of non-standard monitoring

In order to achieve these requirements, we suggest the following process:

- Candidate NSMs are co-located with standard instrumentation for a minimum of one year at an existing monitoring site
- Adjustment formulae are derived and used to predict standard-equivalent PM data for using the non-standard data. If monitor performance is within **prescribed criteria** the NSM could be approved for use in that location for a period based on the expected stable lifetime of the instrument
- Locations (airsheds) with known or assumed similar aerosol compositions and climates could be clustered in a piece of research which is regularly reviewed
- Empirical instrument adjustment formulae may be used at other locations within the same airshed cluster on a provisional basis. For example, NSMs may be deployed in an airshed even when no previous standard monitoring or co-location has been conducted in that airshed
- We recommend that a central authority (MfE, Te Uru Kahika or Land Air Water Aotearoa)) manage the co-location data and approvals process to maintain national consistency and facilitate inter-regional co-operation and the use of cross-regional adjustment factors.

5.6 Case-study example

Environment Canterbury (ECan) facilitated the co-location of a NSM instrument by NIWA at ECan's regulatory monitoring site in Ashburton for a year between August 2022 and July 2023. Using this data we have created an adjustment equation for the NSM data. The resulting airshed statistics are shown in Figure 5-1 and Figure 5-2. In this example the error in the reported number of exceedances of a daily $PM_{2.5}$ value of 20, 25 and 30 µg m^{-3} is +/-1. The error in the reported annual mean $PM_{2.5}$ is 2 %. I.e. the errors are small. NIWA also has a year of similar co-location data from Arrowtown that is yet to be processed, and shorter periods of co-location data from other sites that can help inform this work. Further work could combine this growing dataset to establish threshold criteria.

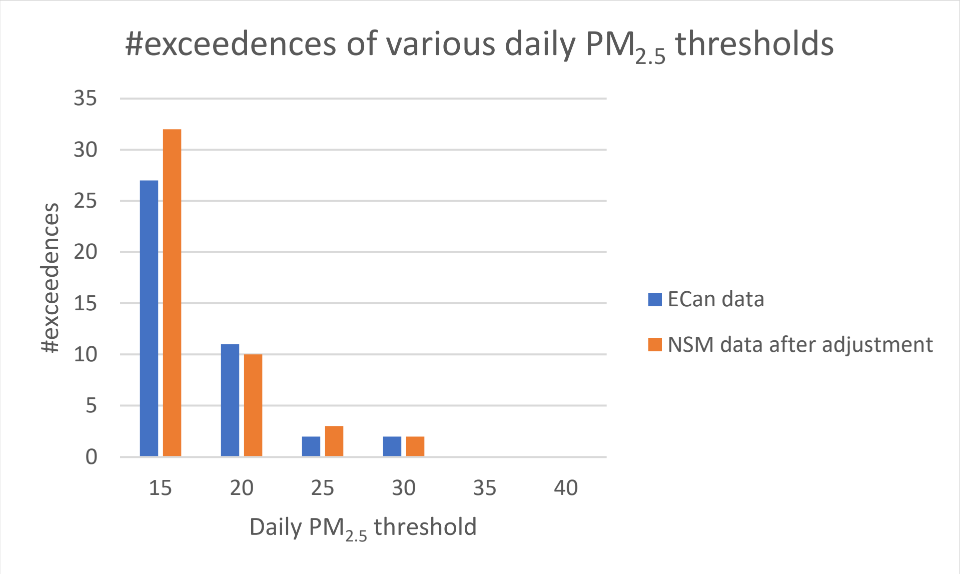


Figure 5-1: Number of exceedances of various daily $PM_{2.5}$ thresholds in Ashburton (Aug 22- Jul 23). Comparing regulatory ECan data and NSM data adjusted using an adjustment formula derived from the co-location data.

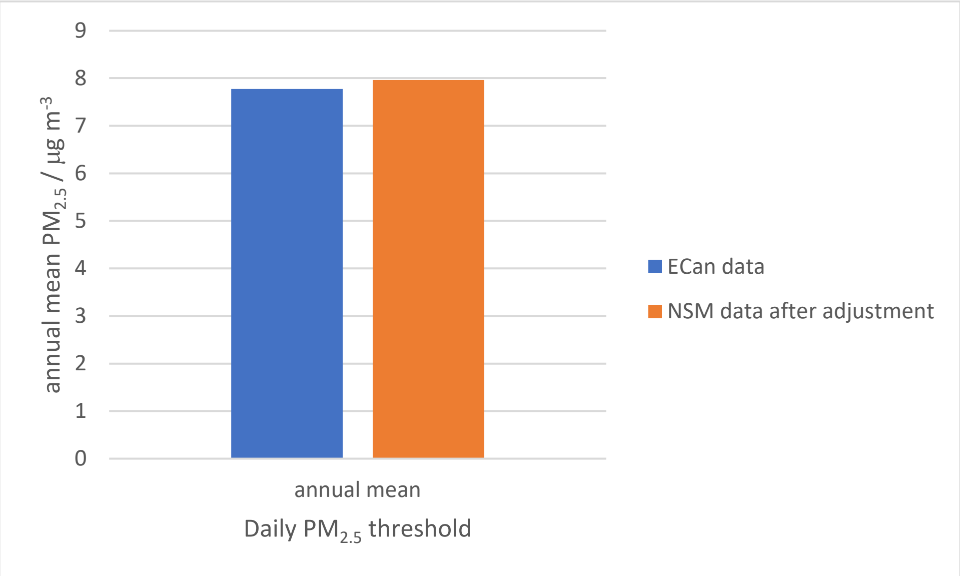


Figure 5-2: Annual mean $PM_{2.5}$ in Ashburton (Aug 22 - Jul 23). Comparing regulatory ECan data and NSM data adjusted using an adjustment formula derived from the co-location data.

5.7 Transferability of adjustment formulae and airshed clustering

Once adjustment formulae are derived from at least two locations the transferability of the formulae can be explored. For example, will a formula derived from data for Ashburton successfully apply in Arrowtown?

In principle the relationship between any two forms of PM monitor is influenced by the way different measurement technologies respond to different aerosols with different characteristics, and in particular changes in humidity (which change aerosol properties such as particle size, density, optical properties and radiation absorption). In practice this means it is reasonable to expect that airsheds with similar aerosols (i.e. emissions-source mixes) and climates would have very similar adjustment equations. This means that equations derived in an inland airshed dominated by woodsmoke emissions may well apply in all such airsheds.

This principle underpins an approach we term "airshed clustering" where airsheds may be provisionally clustered on the basis of their emission source mix (based on source apportionment analyses where available) and climate zone. This provisional clustering can be formalised once instrument co-location data is available and the transferability of adjustment equations is confirmed.

Once an airshed cluster is confirmed we find that it is reasonable to suggest that ongoing monitoring in those airsheds might be conducted using NSM only, so long as one member of that cluster retains co-located NSM and standard monitoring (so that the long-term validity of the adjustment formulae may be confirmed).

We also suggest it is reasonable that NSM could be used in an airshed where no previous monitoring has been conducted using an adjustment derived elsewhere within the relevant airshed cluster. However, the adjustment will always remain provisional if no local co-location is conducted.

Airshed clustering has the major advantage of offering the potential to substantially reduce the cost of air quality monitoring by allowing many airsheds to use NSM only.

5.8 Options for permitting hybrid methods

5.8.1 Use-case 1: Sub-annual monitoring

An example of a hybrid method is deriving annual statistics from an incomplete monitoring dataset, for example one where monitoring was discontinued before a year had elapsed, or a dataset with significant gaps. This may be due to monitor failure or may be deliberate, for example, conducting monitoring during the winter only.

One potential advantage of deliberate sub-annual monitoring could be a cost saving associated with (for example) monitoring 6 months out of 12.

As with non-standard monitoring, we propose that the criterion for acceptability is whether this method introduces significant error in the quantification of key airshed statistics. The key question is whether that error can be quantified or reasonably estimated.

In general, we suggest that the error involved in deriving annual mean $PM_{2.5}$ statistics is likely to be smaller than the error derived in predicting the number of annual exceedances of a daily standard, unless that number is likely to be zero.

In those airsheds with a significant seasonal pattern in $PM_{2.5}$ (usually peaking in winter due to domestic heating emissions), the error involved in monitoring from only January to June, or July to December is likely to be small.

We suggest that using modelling to "patch" missing data should be acceptable in lower priority airsheds.

5.8.2 Use-case 2: Airsheds without sufficient (or any) monitoring data

Another use case of hybrid methods is where there is minimal or no monitoring data.

This is typically done using a land-use similarity/regression approach. In essence this means pooling data from those airsheds across the country for which annual mean $PM_{2.5}$ data is available to establish the common land-use variables (population density, climate, landform) that predict annual mean $PM_{2.5}$. The HAPINZ assessments have used a simplified version of this in the past that excluded climate and land-form variables. This form of modelling is best conducted at a national level to avoid duplication of effort and maintain consistency.

This approach is useful if there have been major instrument failures, or high levels of public interest in a previously unmonitored airshed. It could be applied in advance of a planned screening survey (maybe to test or prime public/political interest).

5.9 Evaluation of options

Table 5-1 presents a simplistic comparison and evaluation of options.

Table 5-1: Comparison of how proposed options meet monitoring needs.

Options	needs				Cost
	Improve coverage	Improve consistency (reduce bias)	Reduce uncertainty	Future-proof	
Introduce NSM performance criteria	Yes				-$$ to $$
Introduce NSM practice requirements	Yes				-$$ to $$
Introduce criteria for hybrid methods	Yes				$
Enable transferability of instrument adjustment	Yes	Yes			-$$ to $$

6 A proposed process for managing airshed monitoring

6.1 Proposal

In this chapter we explore an illustrative example of how a region might evaluate and manage their airsheds, based on the assumption that most of the key changes suggested in this report are adopted.

In brief we propose a cyclic process, outlined in Figure 6-1. A five-year period is chosen for the example although we recognise that other time frames should also be considered and may prove more practicable.

The 5-year cycle begins with a review of existing airshed locations and boundaries. This allows for urban growth and changes in land-use to be taken into account. This review also includes a prioritisation of airsheds by each Regional Council. Prioritisation criteria may include population, average concentrations, public interest/concern, significant recent changes in emissions, and concerns over the representativeness, cost or suitability of the existing monitoring coverage. Prioritisation is discussed in more detail in section 6.2.

Prioritisation informs a 5-year plan for each region to optimise their monitoring network. The goal of the plan is to be able to demonstrate how by the end of the 5-year plan the network will meet any representativeness criteria adopted. The intention of this stage is that a region should gradually use spatial investigations to provide the data that will allow the council to transition from its existing monitoring approach to one that exploits the opportunities provided by liberalisation of the guidance regarding non-standard monitoring methods. We suggest that the plan should be updated every year as new data is obtained and the optimisation options become clearer.

At the end of the 5-year cycle each region should have an optimised monitoring plan.

We recommend that the 5-year cycle is then repeated to allow for changes in land-use, population, emissions, scientific understanding (which may result in revised criteria) and regulatory changes. While Figure 6-1 outlines the internal process within the council, Figure 6-2 illustrates the interactions between the council and MfE, which ensure national consistency in implementing prioritisation criteria.

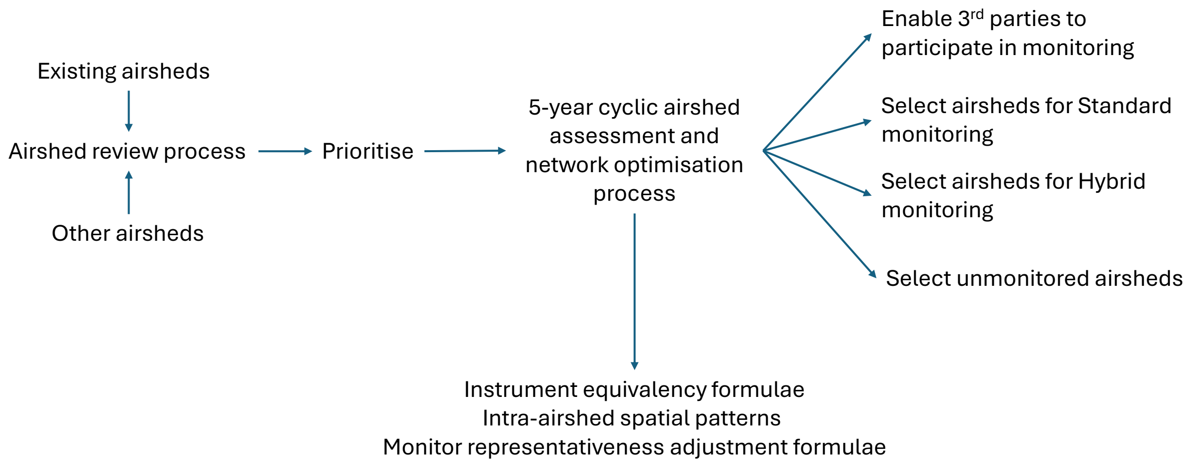


Figure 6-1: Overview of a possible airshed review process incorporating many of the options for change discussed in this report.

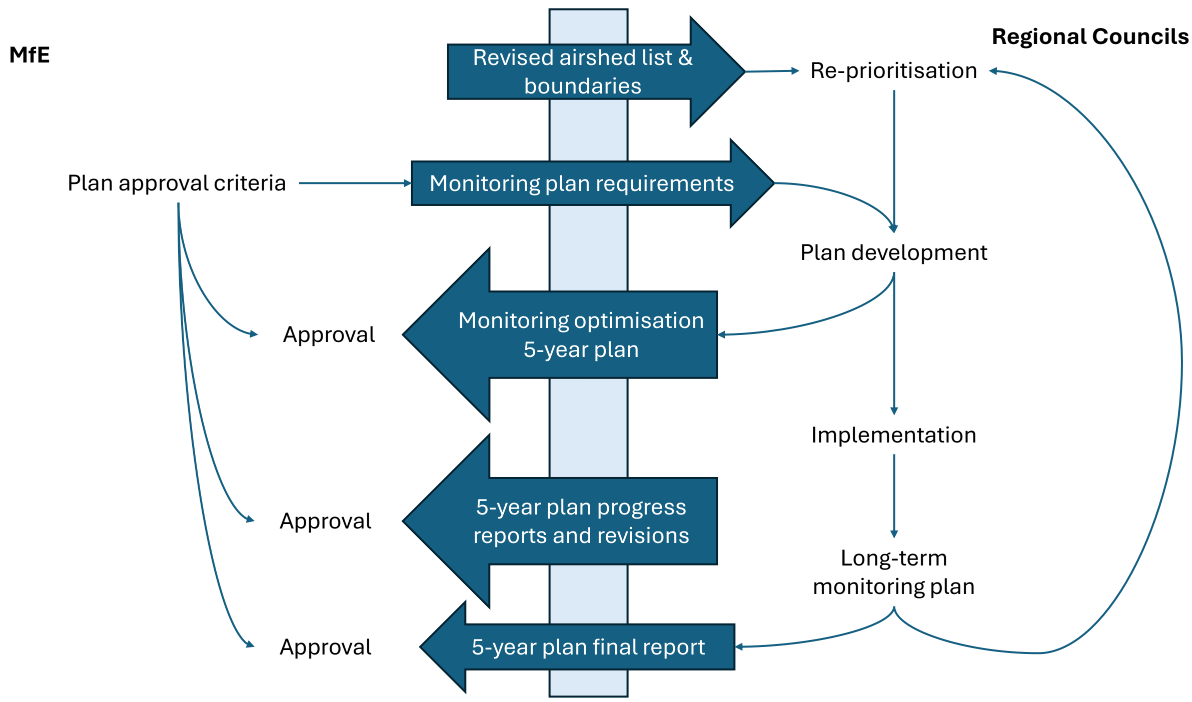


Figure 6-2: Flow diagram for a possible process emphasising the interaction between Councils and MfE.

6.2 Airshed prioritisation

We suggest a process which determines:

- Which airsheds need spatial assessment in what order using what methods
- Which airsheds must have standard monitoring
- Which airsheds can use non-standard methods for long-term airshed monitoring
- Which airshed need not be monitored.

We suggest that each Airshed is classified, for example, either as:

- A "Non-Reporting Airshed" defined as a region for which key air quality statistics will not need to be reported. One option is that there are no Non-Reporting Airsheds
- A "Reporting Airshed" defined as a region for which key air quality statistics (see chapter 3) will be reported using an approved method, or
- A "Monitoring Airshed" defined as a Reporting Airshed for which air quality reporting will need to be derived from air monitoring meeting specified criteria (discussed further below) conducted within that airshed.

The criteria for this classification will need to be agreed. Our suggestion is as follows:

- At least one urban airshed among those in a climate zone with similar emissions profiles requires monitoring using standard methods. (There is potential for Regional Councils to share a regulatory monitoring site, if they have airsheds with the same climate and emissions.)
- All airsheds must undergo a spatial assessment within a 5-year period.

We suggest that a prioritisation review is conducted by each regional council every 5 years as part of its monitoring plan update.

6.3 Hypothetical example

Figure 6-3 illustrates an example process for a single council with two existing gazetted airsheds.

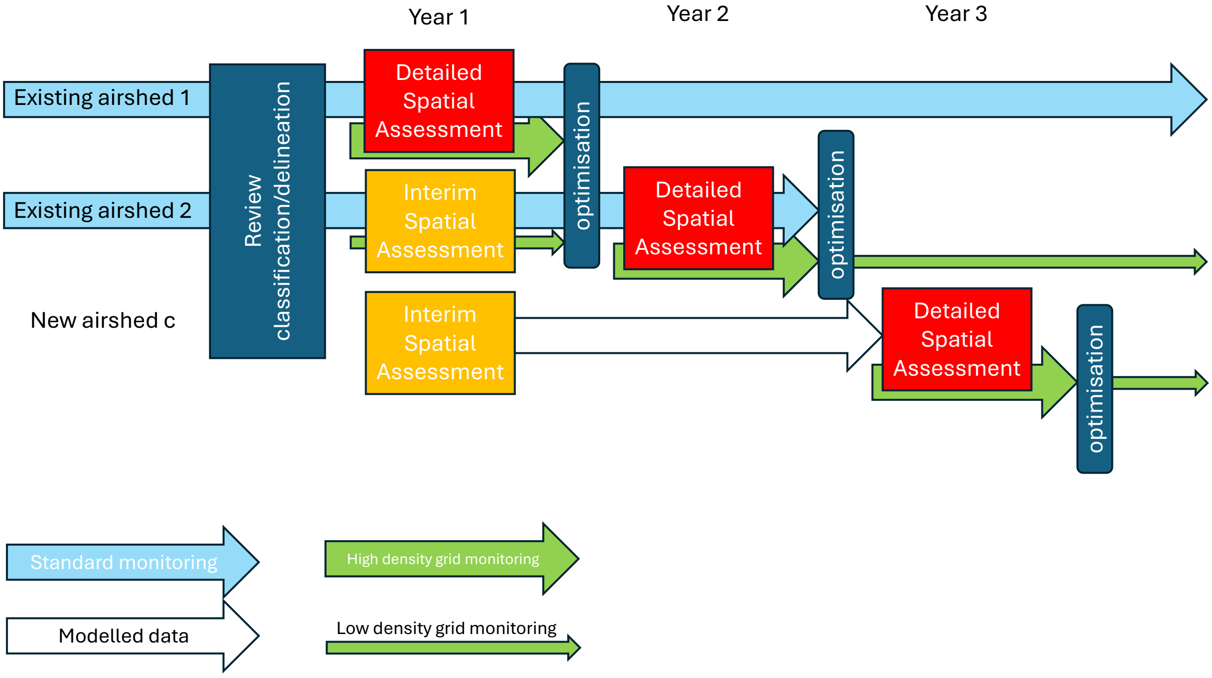


Figure 6-3: Example process of airshed review for a hypothetical council, based on the assumption many of the options for change in this report are adopted.

Commentary:

- The airshed review process prioritises airshed 1 for a detailed spatial study. This involves a high-density monitoring grid. The optimisation process delivers:
  - Spatial adjustment factors the regulatory site, which is retained
  - Conversion factors for the grid monitors relative to the regulatory monitor
- In year 1 airshed 2 receives an interim spatial assessment in which a low-density monitoring grid is deployed, delivering interim spatial adjustment and instrument conversion factors
- In year 2 airshed 2 receives a full spatial assessment. The optimisation process indicates that a small grid of (maybe 4) low-cost sensors, when combined with the conversion factors and adjustment factors, can deliver reliable data. The long-term standard monitor is then removed
- The airshed review process identified a new airshed that has never previously been monitored. An interim assessment (using an empirical model derived from airsheds 1 and 2) is applied at first so that modelled data can be reported. In year 3 a detailed assessment using only grid monitoring (and conversion factors derived from airsheds 1 and 2) leads to a small monitoring grid being deployed.

7 Conclusions

We have explored potential improvements to airshed monitoring practice that would help facilitate future changes to the NESAQ intended to support an "exposure reduction" paradigm. Those changes include adoption of a new airshed statistic of annual $PM_{2.5}$ concentration, where $PM_{2.5}$ is assessed either:

- At the existing monitoring site(s) (i.e. as at present)
- As a spatial average across the airshed
- Or with a population-weighting across the airshed.

The main difference in benefits between these options is that population-weighting is the most consistent and informative measure, and the one most representative of exposure and health burden, and thus most closely related to the implied policy goal of reduction of both of these outcomes. Spatial averaging offers limited benefits.

The recommended changes in monitoring practice are, briefly:

- Re-nomination of airsheds (which towns/areas constitute airsheds) using a nationally consistent approach
- Re-delineation of airshed boundaries
- Spatial mapping of long-term concentration patterns within airsheds to establish relationships between monitoring site data and airshed-wide statistics
- The optional use of non-standard and hybrid monitoring techniques in approved situations using approved methods which would broadly consist of:
  - A period of co-location of non-standard and standard monitors to establish instrument conversion factors
  - Establishing long-term monitoring sites or grids using non-standard monitors.

Table 7-1 below summarises our view on how important each change to monitoring practice is to support the three options for airshed reporting statistics. It shows that:

- None of the proposed changes to practice are essential for the adoption of an annual $PM_{2.5}$ standard following existing guidance
- The essential component to the introduction of spatial or population-weighted averaging is the mapping of air quality across airsheds. We have discussed a range of options of varying cost and complexity, with greater investment translating into less uncertainty in the results. A higher cost method is therefore more suitable in a high uncertainty airshed
- Despite these extra costs, there is the potential for the changes as a whole to be cost-neutral or cost-negative. This is due to the potential to reduce total monitoring costs where standard monitoring is replaced with non-standard or hybrid monitoring.

Table 7-1: Summary of options discussed in this report.

		Changes to airshed reporting statistic				
		Annual $PM_{2.5}$ standard…	…Assessed as airshed mean…	…with population weighting…	Cost to MfE	Cost to RCs
Changes to monitoring practice	Re-nominate airsheds	recommended	recommended	Highly recommended	*	*
	Re-delineate airsheds	recommended	Highly recommended	Highly recommended	*	*
	Map airsheds	recommended	Essential	Essential	*	*to***
	NSM co-location	recommended	Highly recommended	Very highly recommended	**	**
	NSM grid	recommended	Highly recommended	Highly recommended		+/-

The key to implementing the changes in practice would be the development of some tools and criteria. Although some examples have been introduced in the text of this report, table 7.2 summarises what additional work would need to be developed.

Table 7-2: Additional tasks and criteria to be developed in order to implement the changes in practice proposed in this report.

Change in practice	Criteria requiring development	Other work required
Re-nominate airsheds	Urban airshed criteria Airshed merging criteria	Geophysical airsheds to be defined
Airshed prioritisation	Prioritisation criteria	Airshed clustering
Ensure airshed representativeness	Representativeness criteria Minimum node density and monitoring duration criteria Criteria for acceptability of modelling	Develop rule-of-thumb
Non-standard monitoring	Sub-yearly acceptability criterion Performance criteria Adjustment approval criteria	Develop initial adjustment equations

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