The state of air quality in New Zealand

Commentary by the Parliamentary Commissioner for the Environment on the *2014 Air Domain Report*

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Parliamentary Commissioner for the Environment
Te Kaitiaki Taiao a Te Whare Pāremata

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Photography

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Contents

Contents 3

Overview 5

1 Introduction 9

1.1 The reason for and purpose of this commentary 11
1.2 Air pollution in New Zealand – the basics 12
1.3 The *2014 Air Domain Report* 14
1.4 What comes next 15

2 Assessing the *2014 Air Domain Report* 17

2.1 A clear conclusion on the state of each domain 18
2.2 Indicators and other data – relevance and limitations 20
2.3 Reporting on location – where is air quality an issue? 21
2.4 Dealing with variation and uncertainty 21
2.5 Vehicle emissions – what is really happening with NO_X? 22
2.6 The modelling of health impacts 23
2.7 Natural sources of pollutants 24
2.8 In conclusion 24

3 A closer look at particulate pollution 25

3.1 PM_{10} – How well is New Zealand doing? 26
3.2 $PM_{2.5}$ – How well is New Zealand doing? 28
3.3 More on the WHO guidelines 30
3.4 Looking back and forward 34
3.5 In conclusion 38

4 Managing particulate pollution 39

4.1 Perceptions about particulate pollution 40
4.2 Keeping homes warm and dry 44
4.3 The other 'air problem' – greenhouse gases 46

5 Conclusion and recommendations 49
5.1 Improve environmental reporting 50
5.2 Review the PM_{10} rule 51

Notes 54

References 61

Overview

I grew up in Christchurch when it was a city running on coal from the West Coast. Like everyone else, we lived in an uninsulated house heated by an open fire with a coal bin by the back door. Periodically, the 'coal man' – huge to our childish eyes and blackened with coal dust – would heft sacks of coal off his truck, carry them round the house and empty them into the coal bin. Frosty winter nights were thick with smog, and most people in the city accepted it as just the way things were. I certainly had no notion that many decades later, I would be immersing myself in the subject of air quality.

Several months ago, a report on air quality, the *2014 Air Domain Report* was released by the Secretary for the Environment and the Government Statistician. It is the first of what is expected to be a series of regular reports on the state of New Zealand's environment. In this new reporting system, I (and those who succeed me as Commissioner) have the role of preparing independent commentaries on the reports. This is the first such commentary.

The science of air quality is complex and much is unknown. The task of reporting on air quality is open-ended and far from straightforward, and those who worked on the *2014 Air Domain Report* are to be commended for what they were able to achieve in a limited time. In Chapter 2 of this commentary I have outlined areas for improvement in future reports.

What is the purpose of such environmental reporting? Without a clear purpose, a state of the environment report risks being little more than a collation of data. It is my view that a state of the environment report should be a diagnosis of the health of our environment to help us decide what to worry about the most, and what to worry about the least – to get beyond the reactionary and the fashionable. Prioritisation is critical – time and resources spent addressing one environmental issue often means there is less available to address others. So how does air quality in New Zealand measure up?

Our long narrow country sits squarely in the path of the Roaring Forties – the strong winds that swept sailing ships rapidly eastward across the Pacific Ocean. Most of the country is subject to these prevailing winds that swiftly blow air pollutants away. However, when the wind dies down, air pollutants linger. In some towns and cities temperature inversions form on cold, still winter days, trapping air pollutants close to the ground.

The air pollutant of most concern in New Zealand is particulate matter (abbreviated to PM) – the collective term for the tiny airborne particles that can damage respiratory and cardiovascular health. In the summary of the *2014 Air Domain Report,* I found myself intrigued by the results for PM_{10} – airborne particles measuring less than a hundredth of a millimetre across.

Air pollution is monitored by regional councils in the towns and cities where it may not meet guidelines and standards. In these locations, the 'pass rate' was 87% for *long-term* exposure to PM_{10} in 2012, but only 50% for *short-term* exposure. I found myself wanting to understand what this meant.

My curiosity led to an exploration of particulate pollution in Chapters 3 and 4 in this report.

The World Health Organization has four guidelines for levels of PM in air. There are two for PM_{10} – one for long-term exposure and the other for short-term exposure. There are also two guidelines for so-called fine particles – $PM_{2.5}$, again one for long-term exposure and the other for short-term exposure.

Over recent years, scientists have discovered that the smaller airborne particles are, the greater is the damage to the health of the population exposed to them. Fine particles can penetrate deep into the lungs and ultrafine particles can find their way into the bloodstream.

It has also become clear that while spikes of air pollution on still winter days can be harmful to those suffering from respiratory ailments, it is long-term exposure throughout the whole year that has the greater impact on the population as a whole.

Thus, the most important of the four World Health Organization guidelines is that for long-term exposure to $PM_{2.5}$. It also follows that the least important is that for short-term exposure to PM_{10}. Yet it is this guideline that is the basis for New Zealand's standard for particulate matter.

For this and a number of other reasons, I recommend in Chapter 5 that this standard be reviewed and brought up to date with current scientific understanding.

The World Health Organization points out that in pursuing improvements in air quality, decision-makers are usually faced with difficult tradeoffs. In many countries beset with year-round smog, there is a major tension between economy and health – between encouraging coal-fuelled industry and reducing air pollution. In New Zealand, the tension has been mostly between two desired health outcomes – keeping warm in winter and cleaning up the air.

Visitors from overseas are often struck by how cold our homes are. New Zealand has been a laggard when it comes to improving the thermal integrity of our houses, but attitudes have changed over recent years, and it is good to see double-glazing now required in much of the country. But even when retrofitted with insulation, old draughty houses can be difficult to heat.

Regional councils struggling to reduce the winter spikes in air pollution know well how much many people love their fires. Indeed, log burners have much to commend them. They will keep an old house warm and dry, and are unaffected by power cuts. When it comes to climate change, the 'other air problem', wood is close to carbon-neutral. The same cannot be said of coal, especially the lignite burned in the south of the country; burning lignite also emits more particulates than burning wood.

However, log burners can be used irresponsibly by, for instance, burning treated wood and thus emitting arsenic into the air, or burning wet wood and releasing more particulates. It is great to see innovations like the Good Wood Scheme in Nelson, whereby firewood retailers have agreed to sell either seasoned wood or green wood well before it will be burned.

One of the advantages of shifting to a particulate regulation based on long-term exposure is that it would widen council perspectives beyond home heating. The current rule puts the spotlight solely on the winter spikes, and it is easy to assume that home fires are the only source of particulates, or at least, the only source we should worry about.

The same still winter days and temperature inversions that trap the particulates from home fires will also trap the particulates from diesel vehicles – and the nitrogen dioxide and the sulphur dioxide. One of the most interesting discoveries during this investigation was how ‘clean’ petrol exhaust is compared with diesel exhaust.

Near the beginning of this overview, I said that the purpose of a state of the environment report is to help us prioritise our concerns about the environment. What are the big issues that deserve a lot of attention? Conversely, what are the issues that do not matter so much? As my staff began to assess the *2014 Air Domain Report*, foremost in my mind was the question of how serious a problem air pollution is in New Zealand.

I have a set of criteria that I use as a guide for considering the relative importance of various environmental issues. For instance, I worry more about an environmental problem if it is cumulative, if it builds up over time. I worry more about an environmental problem if its impacts are not only increasing, but accelerating, and so on.

When I apply these criteria to air pollution, it does not look like an important environmental issue. Air pollutants do accumulate on still days, but only until the wind blows them away. Moreover, air quality has improved dramatically since the ‘bad old days’, and has continued to improve over recent years. This is due to a mix of market trends and actions taken by central and local government, including the increasing use of electricity for heating, the availability of natural gas, the replacement of open fires with log burners, the retrofitting of insulation, the increasing thermal integrity of new buildings, and the emission limits on new vehicles driven by air quality standards in other countries.

Yet the epidemiological studies reveal real evidence of harm from even relatively low levels of particulates and other air pollutants. Damage to respiratory and cardiovascular systems leads to hospital admissions, days of work lost, and the shortening of some lives. Air pollution may not look like an important environmental issue, but it is undoubtedly an important public health issue.

That the management of air quality falls to regional councils is a consequence of the way we have structured our public sector. Under the Resource Management Act, regional councils are responsible for *“the control of discharges of contaminants into air”*.

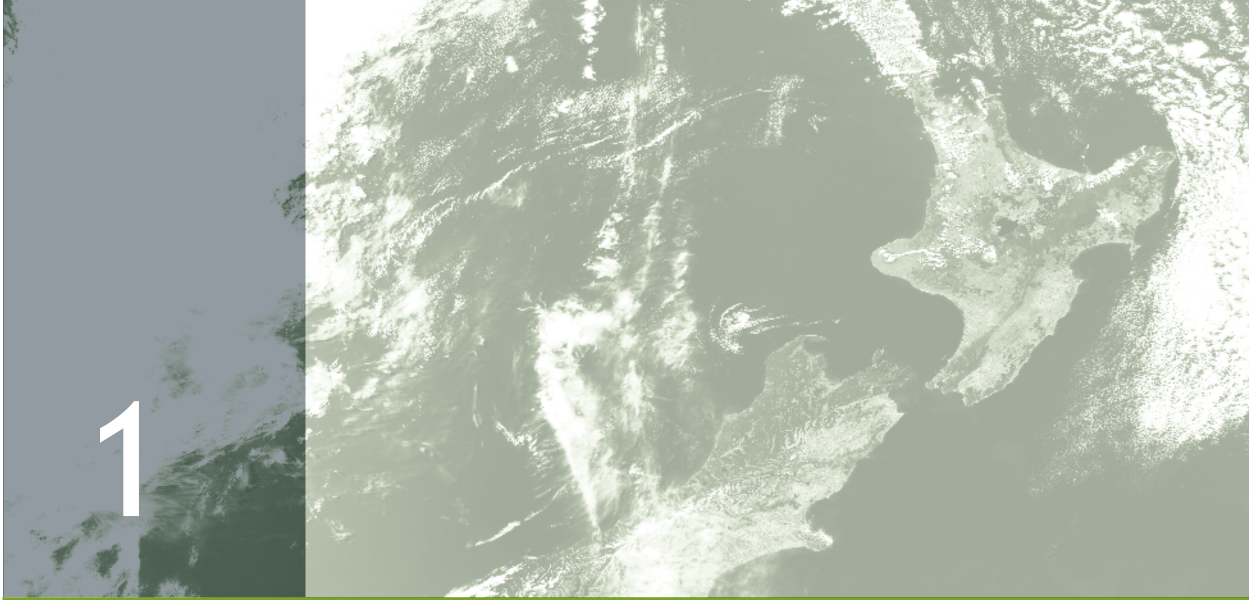
It may be that public money spent by regional councils subsidising ‘clean heat’ appliances would be better spent on smoking cessation programmes. But the boundaries between what regional councils are responsible for and what public health agencies are responsible for mean that the question cannot even be considered.

Overall, air quality in New Zealand is a good news story. One of the graphs in this report shows a 75% reduction in airborne particles in Auckland over the last fifty years. Similar progress has been made in some other towns and cities across New Zealand. I am glad that Christchurch is no longer the smoggy city of my childhood.

J. C. Wright

Dr Jan Wright

Parliamentary Commissioner for the Environment



1 Introduction

Almost all OECD countries require regular reporting on the state of the environment at a national level. In New Zealand the Ministry for the Environment has produced two State of the Environment reports, one in 1997 and the other ten years later in 2007, but this was not required by law. That is now changing with the Environmental Reporting Bill before Parliament. In 2014, the first of a new series of reports – on air quality – was produced by the Ministry for the Environment and Statistics New Zealand. This is a commentary on that report.

Pollutants in the air have many effects. Some, like unpleasant odours and poor visibility, are nuisances. Others damage plants or buildings, or mix with rain to pollute soil or water. However, the main concern with air pollution in New Zealand is the impact of harmful chemicals and tiny particles on human health.

In 1952, a particularly severe 'pea souper' dubbed the Great Smog enveloped London for four windless days. Over the following weeks several thousand people died and many more became ill.[1] This event was pivotal in raising awareness of the connection between air pollution and public health in the United Kingdom, and 'clean air' legislation quickly followed.

Today air pollution is a visible and very significant health problem in many large cities around the world, particularly those undergoing rapid industrialisation. One major source is the burning of coal which produces sulphur dioxide, nitrogen oxides, and soot. Another is traffic exhaust; under certain conditions, pollutants in traffic fumes can react with sunlight to produce 'photochemical' smog containing toxic substances like ozone.[2]

Concern about air pollution is rising fast in China. In November 2014, when the Asia-Pacific Economic Cooperation Forum (APEC) was held in Beijing, the Chinese Government set out to deliver six days of clean air and blue skies. Hundreds of factories and construction sites were closed and the number of cars in the city was halved.

Different parts of the world have different air quality problems. In Africa, South America, and Asia the greatest problem is often indoor smoke from unflued cooking fires. In Australia, high levels of pollution can come from bushfire smoke and dust storms. Air quality in New Zealand has its own characteristics.

In New Zealand, concern about polluted air is far from new. As towns and cities grew, the cumulative effect of thousands of coal fires in winter frequently filled the air with thick smog. In the 1930s, the 'Sunlight League' was formed in Christchurch to "*stimulate efforts for the abatement of smoke*".[3]

In the 1970s, Parliament passed a Clean Air Act giving powers to the Director-General of Health to control air pollution. Since the 1990s, air quality has been managed under the Resource Management Act, which includes "*safeguarding the life-supporting capacity of air, water, soil, and ecosystems*" in its purpose.

The 1997 State of the Environment report concluded that the country is "*thought to have good air quality by international standards but this judgment is based on little, but increasing, monitoring*". The 2007 report was more definitive: *"New Zealand has good air quality in most locations for most of the time…[except] in about 30 locations, particularly during winter"*.

In a major 2013 survey of how the public perceive the environment, air quality was scored very positively.[4]

Source: N T Stobbs [CC BY-SA 2.0 (http://creativecommons.org/licenses/by-sa/2.0)], via Wikimedia Commons

Figure 1.1 Nelson's Column as seen during London's Great Smog in December of 1952, by far the most severe of the city's so called 'pea soupers'.

1.1 The reason for and purpose of this commentary

In February 2014, the Environmental Reporting Bill was introduced to Parliament and is currently before a select committee for consideration. The Bill would require the Secretary for the Environment and the Government Statistician to produce state of the environment reports at regular intervals.

The Bill envisages that a comprehensive 'synthesis' report be prepared every three years. At six monthly intervals between synthesis reports, a report on one of five environmental 'domains' would be produced. The five domains are:

- Air
- Climate and atmosphere
- Freshwater
- Marine
- Land

It had been proposed some years ago that state of the environment reports be produced by the Parliamentary Commissioner for the Environment to ensure their independence from the government of the day. The Bill proposes a different role for the Commissioner, namely, that of commenting on the reports.

Clause 17 of the Bill states that the Commissioner may comment, at his or her discretion, "*on an environmental report and the processes that produced it*". This commentary role fits well with the Commissioner's existing functions under the Environment Act 1986.

Although the Bill has yet to be enacted, the first domain report has already been produced. The *2014 Air Domain Report* is a review of air quality in New Zealand.

The purpose of this commentary is to provide an independent examination of the *2014 Air Domain Report*. Appropriately, the Environmental Reporting Bill does not limit in any way the nature of this or future commentaries by the Commissioner.

This commentary is a report to the House of Representatives pursuant to s 16(1) of the Environment Act 1986.

1.2 Air pollution in New Zealand — the basics

The major source of air pollution in New Zealand is combustion, whether it be from the burning of coal and wood to generate heat, or the burning of petrol and diesel in vehicles.[5] Combustion creates particles and gases that affect human health.

Tiny particles called 'particulate matter' can cause a range of effects on human health, from minor irritation through to significant disease and shortening of life. The particles themselves can physically damage the respiratory and circulatory systems. Moreover, a range of toxic substances can be carried into the lungs attached to the particles. One example is arsenic, which ends up in the air when treated wood left over from construction is burned.

Particulate matter can result in a range of health effects depending on where it ends up in the human body. Fine particles can penetrate deep into the lungs, and ultrafine particles can find their way into the bloodstream.[6,7] The most vulnerable are the very young, the elderly, and people with pre-existing respiratory or cardiovascular disease.

Some particles – seaspray salt and windblown soil – are 'natural', and tend to be relatively large. They are not considered to be a major threat to human health.

Particulate matter (PM) is commonly measured in two size categories:

- PM_{10} refers to particles that have a diameter less than 10 microns.
- $PM_{2.5}$ refers to particles that have a diameter less than 2.5 microns. $PM_{2.5}$ is a sub-set of PM_{10}.[8]

Some gaseous pollutants, such as sulphur dioxide, nitrogen oxides, and carbon monoxide, can also be produced along with particulates, and affect human health. Sulphur dioxide can react with other substances in the air and form small particles of sulphate. Carbon monoxide can stop the blood from absorbing oxygen. The highest concentrations of these gases are generally found around busy roads.

A critical point is that carbon dioxide and other greenhouse gases that are causing climate change are not air pollutants in the sense used in this report. In the reporting system being set up in the Environmental Reporting Bill, emissions of greenhouse gases will be included in the 'atmosphere and climate' domain.

In most towns and cities around the world afflicted by air pollution, it is a year-round problem. The pollutants come mostly from the exhaust pipes of vehicles and the smokestacks of industries, with no seasonal respite.

It is very different in some parts of New Zealand where many homes are heated with wood, and in some cases, coal. Thus, particulate emissions are highest in winter, and particularly so where winters are coldest.

But high *emissions* of pollutants do not necessarily lead to high *concentrations* of pollutants. In Otago, the towns of Balclutha and Alexandra have similar sized populations and emissions of air pollutants. Yet Alexandra has much poorer air quality in winter than Balclutha.[9]

Balclutha lies on open flat land near the coast, and is well-ventilated by coastal winds. Alexandra lies in an inland basin, and is subject to temperature inversions. (A 'temperature inversion' occurs when a layer of cold air becomes trapped under a blanket of warmer air, and the air pollutants are unable to rise and disperse.)

Thus, levels of air pollution in New Zealand towns and cities typically vary throughout the year, and are generally highest on still, cold days in winter.

The high peaks or 'spikes' in air pollution that occur on such days have somewhat different health impacts from the lower levels of air pollution that are present all year round. Consequently, assessment of health impacts generally distinguishes between the effects of *short-term* exposure to these spikes and *long-term* exposure to the ongoing pollution.

Short-term exposure to transitory high levels of particulates – spikes – has the greatest effect on people with compromised respiratory systems such as asthmatics and sufferers from chronic obstructive pulmonary disease (COPD).

Long-term exposure to particulates progressively reduces lung function, and increases the risk of respiratory and cardiovascular disease, particularly among vulnerable groups and those susceptible for other reasons such as smoking.[10]

In its 2013 review of the epidemiology of air pollution, the World Health Organization (WHO) concluded that:

"The effects of long-term exposure are much greater than those observed for short-term exposure, suggesting that effects are not just due to exacerbations, but may also be due to progression of underlying diseases."[11]

Guidelines and standards for air pollutants generally measure short-term exposure as *daily* averages of pollutant concentrations, and long-term exposure as *annual* averages of pollutant concentrations.

To illustrate this, the WHO guidelines for particulates are shown in Table 1.1.

	Daily average concentration ($\mu g/m^3$)	Annual average concentration ($\mu g/m^3$)
PM_{10}	50	20
$PM_{2.5}$	25	10

Table 1.1 Maximum levels of PM_{10} and $PM_{2.5}$ in micrograms of particulate matter in a cubic metre of ambient air ($\mu g/m^3$) recommended by the World Health Organization.[12]

1.3 The *2014 Air Domain Report*

In May 2014, the Ministry for the Environment and Statistics New Zealand released the *2014 Air Domain Report* – the first in the new environmental reporting series.[13]

As required by the Environmental Reporting Bill, a pressure-state-impact framework is used in the report.

- *Pressures* on air quality are sources of pollutants and weather conditions that influence how they concentrate in air.
- *States* are concentrations of pollutants in air.
- *Impacts* are the effects of air pollutants on human health.

The report contains three indicators – one for pressure, one for state, and one for impact. These are summary measures that are intended to show change at a national level. The three indicators are:

- *Pressure* – estimated on-road vehicle emissions.
- *State* – national annual average level of PM_{10} weighted by population.
- *Impact* – estimated health impacts of human-made PM_{10}.

The second indicator is a composite of measurements, whereas the first and third indicators are based on models.

Data that is considered to be unsuitable for use as indicators, either because it does not meet Statistics New Zealand criteria or because it is unavailable at a national level, is presented in the form of case studies.[14]

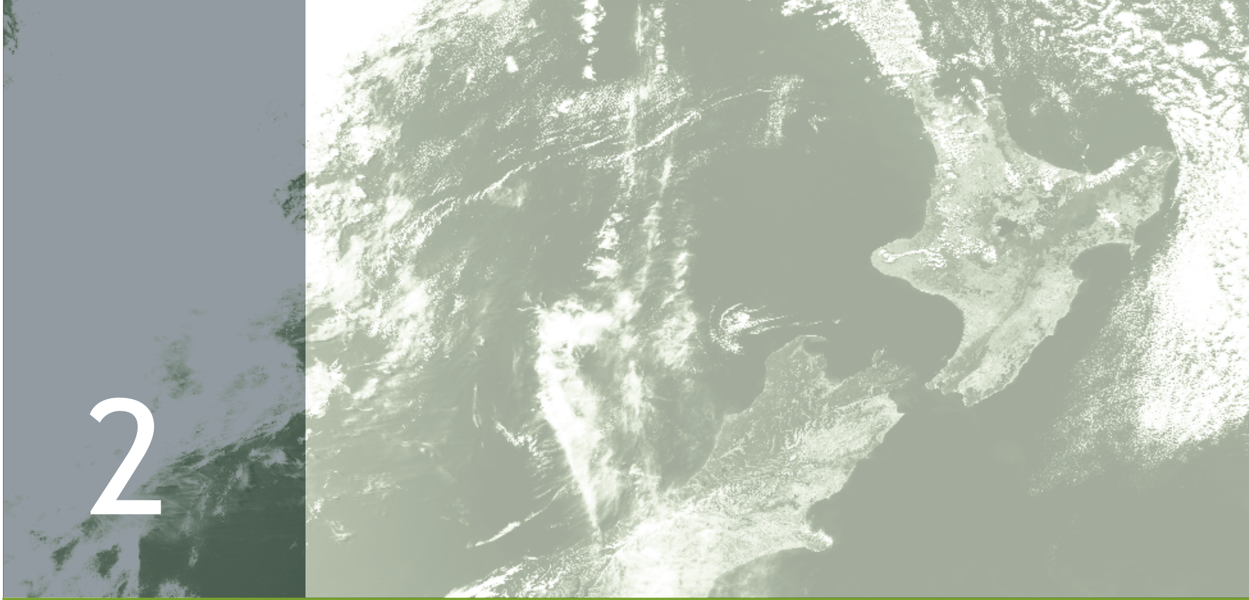
1.4 What comes next

The remainder of this report is as follows:

- Chapter 2 is an assessment of the *2014 Air Domain Report.*
- Chapter 3 is an examination of particulate pollution in New Zealand.
- Chapter 4 is focussed on the management of particulate pollution.
- Chapter 5 contains the Commissioner's conclusions and recommendations.

Source: Colin Monteath / hedgehoghouse.com

Figure 1.2 A winter inversion layer in Christchurch in 2010. The spire of the cathedral can be seen in the distance.



Assessing the *2014 Air Domain Report*

The *2014 Air Domain Report* is the first in what is envisaged as a sequence of reports on the state of the environment that will be prepared jointly by the Secretary for the Environment and the Government Statistician.

The process for preparing these reports and the content they are to contain is to be specified in legislation. As noted in Chapter 1, the Environmental Reporting Bill is under consideration by Parliament's Local Government and Environment Committee. Although some details may well be changed before the Bill is enacted, it is anticipated that the major features of the system will be as outlined in the Bill. The *2014 Air Domain Report* therefore serves as a 'pilot' for the reporting system envisaged in the Bill.

Clause 17 in the Bill describes the role of the Parliamentary Commissioner for the Environment in the new reporting system. The Commissioner may choose to comment on matters that:

"*include, but are not limited to, –*

a) analysing environmental reports:

b) identifying trends:

c) discussing the implications of environmental report findings:

d) recommending responses to environmental report findings."[15]

This chapter is focused on the first of these – it is an *analysis* of some aspects of the *2014 Air Domain Report*, aimed at assuring the quality and balance of reporting.

Preparing a state of the environment report is inherently difficult and complex. The Government Statistician, Secretary for the Environment, and their officials have assembled a large amount of data and pulled it together into a useful report in a short space of time.

The purpose of this chapter is to provide guidance on key matters. It contains seven sections, each identifying a specific area for improvement in future reports.

2.1 A clear conclusion on the state of each domain

A basic purpose of environmental reporting is to convey to the public and policymakers the relative seriousness of different environmental issues – to tell them what to worry about the most, and conversely, what to worry about the least.

The overall conclusion of the *2014 Air Domain Report* is the following:

"From 2006 to 2012, our national air quality indicators showed some improvement to the pressures on air quality, state of air quality, and impacts of air quality in New Zealand."[16]

This statement does not tell us whether air quality has improved from, for instance, 'very poor' to 'poor' or from 'good' to 'very good'.

The summary of the state of New Zealand's air lists the report's findings on how different pollutant concentrations measure up against guidelines and standards. But there is little explanation of the significance of these results.

For instance, there are two findings on PM_{10} in 2012, namely:

- 87 percent of PM_{10} monitoring sites met the WHO long-term guideline.
- 50 percent of monitored airsheds experienced levels that exceeded the national short-term PM_{10} standard.

The first finding sounds as if New Zealand is doing well with regard to particulate pollution – an 87 percent 'pass rate'. But this is followed by a 50 percent 'pass rate' in the second finding which sounds like New Zealand is doing quite poorly.

Such results need to be interpreted more fully and conclusions drawn.

Reaching overall conclusions on the state of different aspects of the environment is challenging but can be done. Australia's 2011 state of the environment report concludes that:

"Air quality in Australia's urban centres is generally good, with levels of all the criteria pollutants usually falling well below national standards."[17]

This conclusion is based on a scorecard system that rates the air quality in the major cities on a scale ranging from 'very poor' to 'very good'. This system is described in Box 2.1.

Box 2.1 The Australian system for assessing air quality

In Australia, a system for assessing the state of air quality in major cities has been developed. Each city is scored for PM_{10} (and ozone), using a two-stage method.

In stage 1, the average PM_{10} concentration each day is measured relative to the benchmark of 50 μg/m^3. Thus, a measurement of 10 μg/m^3 is 20 percent of the benchmark, and a measurement of 70 μg/m^3 is 140 percent of the benchmark. Each day is then scored as follows.

Day score	Percentage of benchmark
Very good	0–33%
Good	34–66%
Fair	67–99%
Poor	100–149%
Very poor	150% or greater

In stage 2, the daily scores are converted into annual scores. These conversions are done based on how many days in the year are very good, how many are good, and so on.

For instance, suppose two cities – A and B – have the following daily scores over a year.

Day score	City A Number of days	City B Number of days
Very good	153	14
Good	123	44
Fair	76	67
Poor	10	138
Very poor	3	102
	365	**365**

Overall, for the year, City A would be scored as having ‘good’ air quality with regard to PM_{10}. In contrast, City B would be scored as ‘poor’ for the year.

The method has been developed by a panel of experts and is described clearly in the *Australia State of the Environment 2011* report. It has two features that distinguish it from New Zealand’s approach to air quality.

- The daily scores are based on ‘distance’ above or below the benchmark of 50 μg/m^3.
- The annual scores take account of air quality on every day – the good days as well as the poor days.

2.2 Indicators and other data — relevance and limitations

National indicators are commonly used to report on economic and social matters. Despite their limitations, such indicators play a valuable role in developing policy and assessing its effectiveness over time. The development of a set of national environmental indicators is a laudable goal of the new reporting system.

However, choosing a set of national environmental indicators is no easy task. Nor should we expect it to be – some of the economic and social indicators used today were developed over many years.

The information in the *2014 Air Domain Report* is presented in a hierarchy – the high status national indicators, then case studies, and finally commentaries on topics where there is very little data available.

Three of the eighteen 'topics' in the *2014 Air Domain Report* have an associated national indicator – one for pressure on air quality, one for the state of air quality, and one for the impact of air quality. For an environmental statistic to be considered a national indicator it is expected to meet a number of criteria with two – relevance and accuracy – deemed mandatory.[18]

'National representativeness' is regarded as a significant part of relevance and accuracy, presumably because this is a national environment report. Problems can arise if this is applied too literally.

In the *2014 Air Domain Report*, the concentrations of several air pollutants are not given national indicator status because they are not 'representative of New Zealand'. This may be entirely reasonable, but in preparing future reports, it should be borne in mind that the great majority of environmental problems are local or regional in nature. It is important not to ignore or average away 'hot spots'.

Further, attention needs to be given to explaining the limitations of the chosen indicators and how these limitations affect the final conclusions. This is to avoid the potential for incorrect inferences being drawn.

For instance, modelled transport emissions (the pressure indicator) is only partly responsible for the average annual PM_{10} level (the state indicator). But because it is presented as the only pressure indicator, it could be (incorrectly) inferred that transport emissions are responsible for all changes in air quality.

It will be a continuing challenge to develop environmental indicators that are both relevant and accurate since, in practice, there will sometimes be a trade-off between the two. Information that is most relevant for measuring the state of the environment will often be only indicative with incomplete geographical coverage, short time series, and inconsistent sampling methods.

This will be especially so for issues that are emerging. In some instances, the only data sets that are considered to be sufficiently accurate or nationally representative may have been those developed for managing natural resources, not for monitoring the health of the environment.[19]

2.3 Reporting on location — where is air quality an issue?

Air pollution is inherently a local environmental problem. How good or bad it is in a particular location depends on two things. The first is the sources of pollutants. The second is the local weather and the lie of the land – the poorest air quality tends to occur on still days in winter especially when temperature inversions form and trap pollutants at ground level.

The *2014 Air Domain Report* provides relatively little information on where air pollution is a significant issue and where it is not.

For instance, there are five figures depicting annual average PM_{10} levels. The first four show results for various unidentified locations – the first for cities, the second for medium-sized towns, the third for small towns, and the fourth for rural areas. The fifth figure does show results for specific locations, though only for five cities.[20]

Presenting information in this way has some value in comparing New Zealand's environment with those of other countries. However, it is important in a national state of the environment report to make clear where air quality is good and where it is poor.

2.4 Dealing with variation and uncertainty

Environmental data is often highly variable. In such cases, statistical analysis is used to judge whether an observed change is likely to be real or illusory.

Air pollutant levels are strongly influenced by windspeed and temperature. On windy days, concentrations are lower because the wind blows pollutants away from their sources. Cold temperatures increase the chance of inversion layers forming in some locations, creating pockets of still air that trap pollutants. Also on cold days, more wood and coal is burned to heat homes, and thus more pollutants are emitted. Consequently, air pollutant levels vary from day to day and from year to year.

The main conclusion of the *2014 Air Domain Report* is that air quality in New Zealand has improved between 2006 and 2012. However, no statistical analysis has been carried out to support this conclusion.

For instance, Figure 8 in the *2014 Air Domain Report* shows a small decline in the national indicator for the state of air quality – annual average PM_{10} level weighted by population. The eight percent drop in the indicator has been calculated by simply comparing the 2012 value with the 2006 value. The statistical significance of this change has not been tested. Moreover, the short time series of just six years makes it particularly difficult to determine with confidence whether the decline is real.[21]

Statistical analysis should also be done before making claims about changes in particular locations. Figure 12 in the *2014 Air Domain Report* shows the annual level of PM_{10} in five cities, and the claim is made that "*For every city, the concentrations were lower in 2012 than 10 years before.*" This may be the case but the evidence is lacking.[22]

Because many environmental datasets will be incomplete and statistical testing may not be possible, other approaches should be considered. One such approach is 'expert elicitation' – using a panel of experts to evaluate the available information and produce an assessment of the state and trend of environmental indicators.[23]

Simple adjustments can also help to deal with variation in measurements. In the *2014 Air Domain Report*, data from a single year (2012) is frequently used as an indicator of the current state of air quality. Three-year averages could have been used to take some of the 'noise' out of the data.

2.5 Vehicle emissions — what is really happening with NO_X?

The national indicator used for 'pressure' on air quality is the modelled emissions of air pollutants from on-road vehicles. Carbon monoxide, nitrogen oxides (NO_X), PM_{10}, $PM_{2.5}$, and volatile organic compounds are all reported as declining between 2006 and 2012. These results have been obtained by running the Vehicle Emission Prediction Model.[24]

NO_X is the term used for nitric oxide (NO) and nitrogen dioxide (NO_2). After particulates, NO_X is the pollutant of most concern.[25] The 'pressure' indicator shows NO_X falling by 21 percent between 2006 and 2012.

The Vehicle Emission Prediction Model generally performs well. Emissions predicted by the model match actual emissions reasonably well, especially for petrol vehicles. However, the model is much less accurate when it predicts NO_X emissions from diesel vehicles.[26,27]

In contrast to the modelled 21 percent reduction in NO_X in the 'pressure' indicator, the New Zealand Transport Agency's network of 128 monitoring sites show a 15 percent *increase* in annual average concentrations of NO_2 between 2007 and 2012.[28]

When information obtained from running models is used in future environmental reports, every effort should be made to 'ground truth' the model results with actual measurements. If this cannot be done, it should be made clear why this is the case.

2.6 The modelling of health impacts

The national indicator used for 'impacts' is also derived from a model – Health and Air Pollution in New Zealand (HAPINZ).

The HAPINZ model is used to generate estimates of premature deaths and sickness due to air pollution. In the *2014 Air Domain Report*, premature deaths due to human-made PM_{10} are estimated to have fallen by 14 percent between 2006 and 2012, with similar declines in sickness from the same cause. However, unlike the Vehicle Emission Prediction Model discussed in section 2.5, the HAPINZ model cannot be 'ground truthed' directly – no death certificate lists poor air quality as a cause of death.

Exposure to air pollution – particularly long-term exposure – shortens the lives of some, often acting in concert with other conditions or diseases they might have. Thus, the health impacts of air pollution must be estimated using epidemiological studies.

The HAPINZ model bases its estimates of premature deaths from air pollution on a New Zealand epidemiological study.[29,30] While there is no doubt that air pollution is associated with premature death and illness, all such studies have limitations and it is important to convey the degree of uncertainty in the results.

One limitation in New Zealand studies is that because comprehensive measurements are available only for PM_{10}, all health impacts tend to be attributed to PM_{10}.[31] Yet the inversion layers that trap particulates on cold winter days also trap NO_X and other pollutants.

A sense of the extent of the uncertainty can be seen by comparing the New Zealand estimate of premature deaths with the estimate done in Australia where the annual average concentrations of PM_{10} in the major cities are similar to those in New Zealand. The HAPINZ model estimates about 2,000 premature deaths are attributable to air pollution in New Zealand each year, whereas the estimate in Australia is 3,000, although the population is five times that of New Zealand.[32]

Putting aside any queries about the underlying epidemiological data, there are problems with the way in which the HAPINZ model was used to estimate the information needed for reporting on the national 'impacts' indicator in the *2014 Air Domain Report*.

To estimate the change in health impacts over the time period used for the first two indicators, the HAPINZ model was run for 2006 and again for 2012. However, only health impacts due to 'human-made' PM_{10} were presented in the domain report.[33] This required total PM_{10} levels to be split into natural sources (like salt and soil) and 'human-made' sources (like fires and vehicles).

This is inconsistent with the second indicator which is a measure of total PM_{10}. Moreover, different estimates of natural and 'human-made' PM_{10} were used in the two model runs, and this has had the effect of increasing the estimated change in impacts. Finally, as discussed in section 2.4, the change in PM_{10} between 2006 and 2012 that has been used in the runs has not been statistically tested.

2.7 Natural sources of pollutants

The *2014 Air Domain Report* has a section on natural sources of pollutants. This is important because such sources are clearly very significant and it is likely this is not widely recognised. But the significance of these sources is given insufficient attention.

A major focus of the *2014 Air Domain Report* is on the numbers of different locations with PM_{10} levels that 'comply' with the WHO guidelines and the National Environmental Standard for Air Quality (Figures 8 through 13 in the *2014 Air Domain Report*). The section on natural sources of pollutants shows that they can be responsible for as much as half of the total PM_{10}, but there is no mention of the questions this raises.

For instance, which natural sources emit harmful particulates and what is the degree of that harm? Sea-spray salt is generally considered relatively harmless. Pollen – dubbed the 'forgotten air pollutant' in Australia's state of the environment report – is not.

Another important question concerns the proportion of salt in particulate matter. Is it significantly higher in New Zealand, a windswept coastal nation, than in other countries?

Figure 27 in the *2014 Air Domain Report* shows the contribution of natural sources to PM_{10} at selected locations – six in Auckland and eight from elsewhere in the country. Unfortunately, it does not include data from most of the locations where air quality is poorest, such as Christchurch, Invercargill, and Timaru. It would have been useful to point this out and explain why.[34]

Finally, as noted in section 2.6, there is the confusing inconsistency between the 'state' indicator and the 'impact' indicator – the first is based on total PM_{10} and the second is based on only human-made PM_{10} with natural sources omitted.

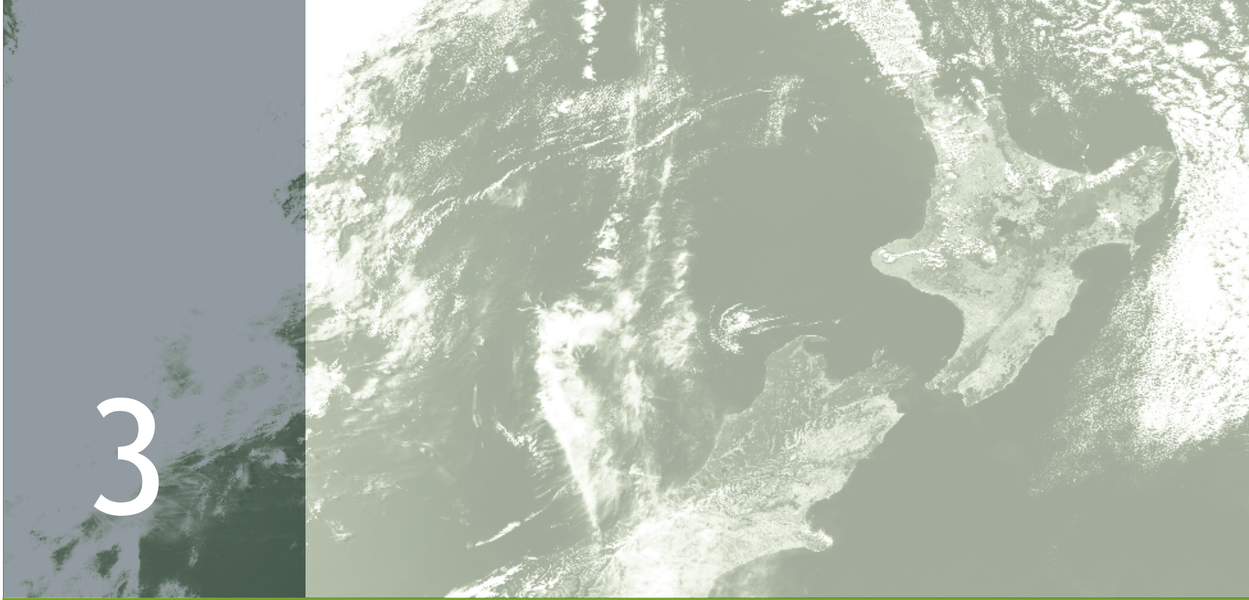
2.8 In conclusion

The difficulty and complexity involved in reporting well on the state of New Zealand's environment should not be underestimated. Those who have worked on this first report prepared under what is expected to become the Environmental Reporting Act 2015 are to be commended on what they have achieved in a limited amount of time.

Seven areas for improvement have been identified in this chapter. The most important of these is the first – the need to reach a clear conclusion on the state of air quality in New Zealand.

The air pollutant of most concern in New Zealand is particulate matter – the term used for the tiny airborne particles that affect respiratory and cardiovascular health. Although the *2014 Air Domain Report* contained a number of precise statistics on particulate matter, it lacked a clear statement on how serious this environmental problem is in New Zealand.

In the next chapter, information on particulate matter is analysed further.



3

A closer look at particulate pollution

The *2014 Air Domain Report* is largely focused on particulates – the tiny particles from many sources that when inhaled can damage respiratory and circulatory systems. This is entirely appropriate – particulate matter is New Zealand's major air pollution problem.

As described in Chapter 1, particulate matter is generally measured in two size categories – PM_{10} and its subset $PM_{2.5}$.

In the *2014 Air Domain Report* two findings on PM_{10} are presented, namely, that in 2012:

- 87 percent of PM_{10} monitoring sites met the WHO long-term guideline for PM_{10}.
- 50 percent of monitored airsheds complied with the national short-term rule for PM_{10}.

Two similar findings on $PM_{2.5}$ are also presented.[35]

These results prompt a number of questions. For instance:

- Which is more important – long-term or short-term exposure to particulates?
- Which matters more – PM_{10} or $PM_{2.5}$?
- Where is particulate pollution an issue and where is it not an issue?

The purpose of this chapter is to explore the data on particulate pollution and present it in a way that makes it possible to reach a clearer conclusion about how serious this issue is in New Zealand. The chapter contains five sections.

The first section is focused on exposure to PM_{10}. Daily and annual average concentrations of particulates are compared against the WHO guidelines for short-term and long-term exposure.

The second section follows the same pattern as the first section, but is focused on exposure to $PM_{2.5}$.

The third section examines the relative importance of the four main WHO guidelines on particulates for assessing health impacts.

The fourth section looks at how particulate pollution has changed over recent decades and considers what will influence it in the future.

The fifth section summarises the implications of the analysis in the chapter.

3.1 PM_{10} - How well is New Zealand doing?

The term PM_{10} refers to airborne particles that measure less than 10 microns across. It is thus a mix of relatively coarse, fine, and ultra-fine particles.

The WHO has set two guidelines for exposure to PM_{10} – one for short-term exposure and one for long-term exposure.

The guideline for **short-term** exposure to PM_{10} is:
The **daily** average concentration should not exceed 50 $\mu g/m^3$ on more than three days every year.

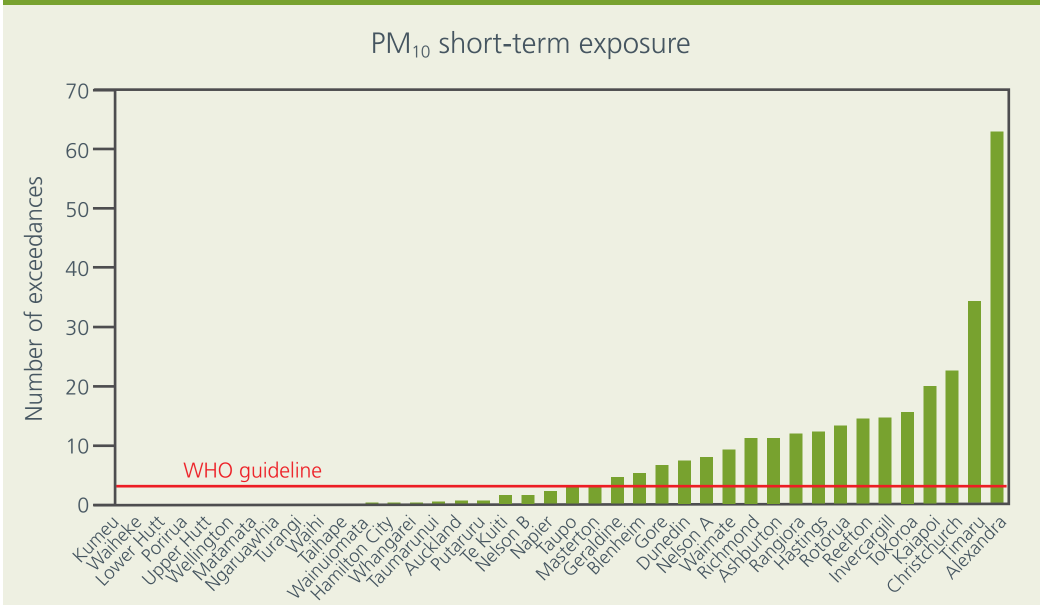
The guideline for **long-term** exposure to PM_{10} is:
The **annual** average concentration should not exceed 20 $\mu g/m^3$.

Figures 3.1 and 3.2 show how different airsheds around New Zealand 'performed' against these two PM_{10} guidelines in recent years.[36]

A considerable number of airsheds 'failed' the *short-term* guideline between 2010 and 2012 (Figure 3.1).[37] Unsurprisingly, almost all the airsheds that 'failed' are in parts of the country where winters are cold and many households rely on burning wood or coal to keep warm. Some airsheds 'pass' one year and 'fail' the next, drifting in and out of compliance depending on the severity of the winter.[38]

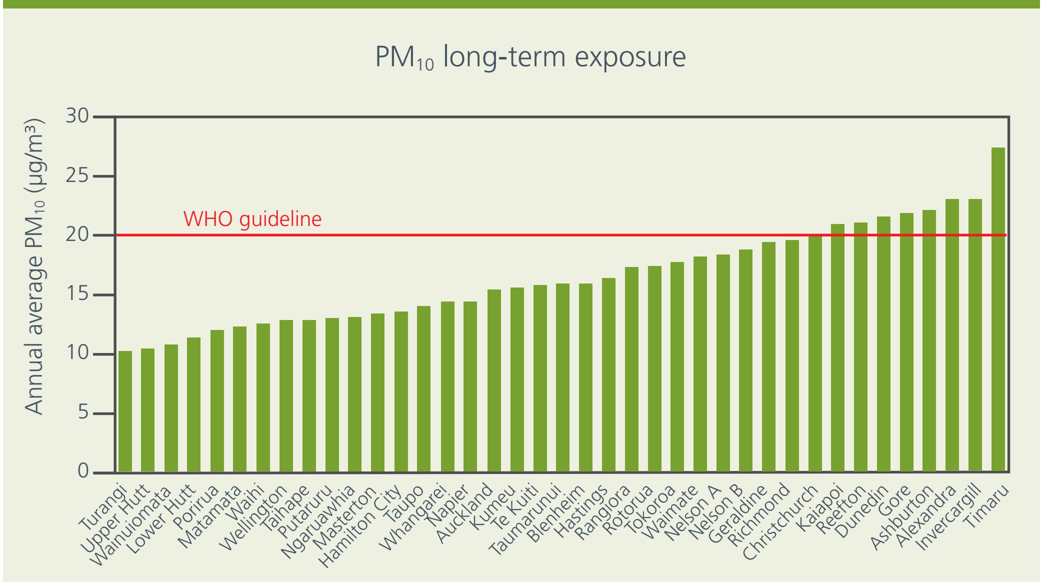
However, almost all 'passed' the *long-term* guideline in the same three years including the major population centres of Auckland and Christchurch (Figure 3.2). While short-term exposure to transitory high levels of particulates can harm the health of vulnerable people, long-term exposure has a greater impact on the health of a population.

New Zealand's National Environmental Standard for Air Quality contains a standard for PM_{10} that is based on the WHO guideline for short-term exposure. Regional councils are required to ensure the daily average concentration of PM_{10} in their airsheds does not exceed 50 $\mu g/m^3$ on more than one day each year.[39]



Source: MfE

Figure 3.1 Number of days per year on which the concentration of PM_{10} exceeded 50 µg/m³ – averaged for the three years 2010–2012. Airsheds above the red line did not 'pass' the WHO short-term guideline for PM_{10}.



Source: MfE

Figure 3.2 Annual average concentration of PM_{10} in monitored airsheds – averaged for the three years 2010–2012. Airsheds above the red line did not 'pass' the WHO long-term guideline for PM_{10}.

3.2 $PM_{2.5}$ - How well is New Zealand doing?

The term $PM_{2.5}$ refers to air-borne particles that measure less than 2.5 microns across. It is thus a mix of fine and ultra-fine particles.

As for PM_{10}, the WHO has set two guidelines for exposure to $PM_{2.5}$ – one for short-term exposure and one for long-term exposure.

The guideline for **short-term** exposure to $PM_{2.5}$ is:
The **daily** average concentration should not exceed 25 µg/m^3 on more than 3 days every year.

The guideline for **long-term** exposure to $PM_{2.5}$ is:
The **annual** average concentration should not exceed 10 µg/m^3.

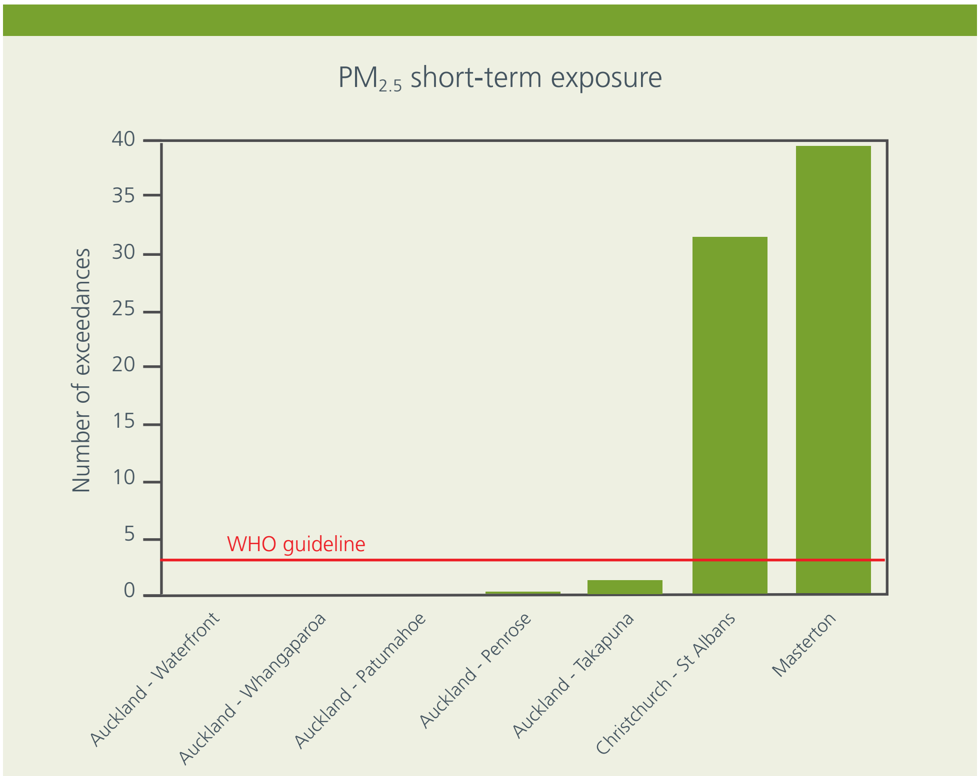
As discussed in Chapter 1, small airborne particles are more damaging to health across the population than larger particles. Thus, a particular concentration of $PM_{2.5}$ in air is of greater concern than the same concentration of PM_{10}, because the average particle size is smaller. In many developed countries, the regulatory focus has been adjusted to include regular monitoring of $PM_{2.5}$ as well as PM_{10}.[40]

In New Zealand, $PM_{2.5}$ is now being measured continuously in Auckland, Christchurch, and Masterton, and the results for short-term exposure in recent years are shown in Figure 3.3.

Performance against the long-term $PM_{2.5}$ guideline for all the sites where data is available is given in Figure 3.4.[41]

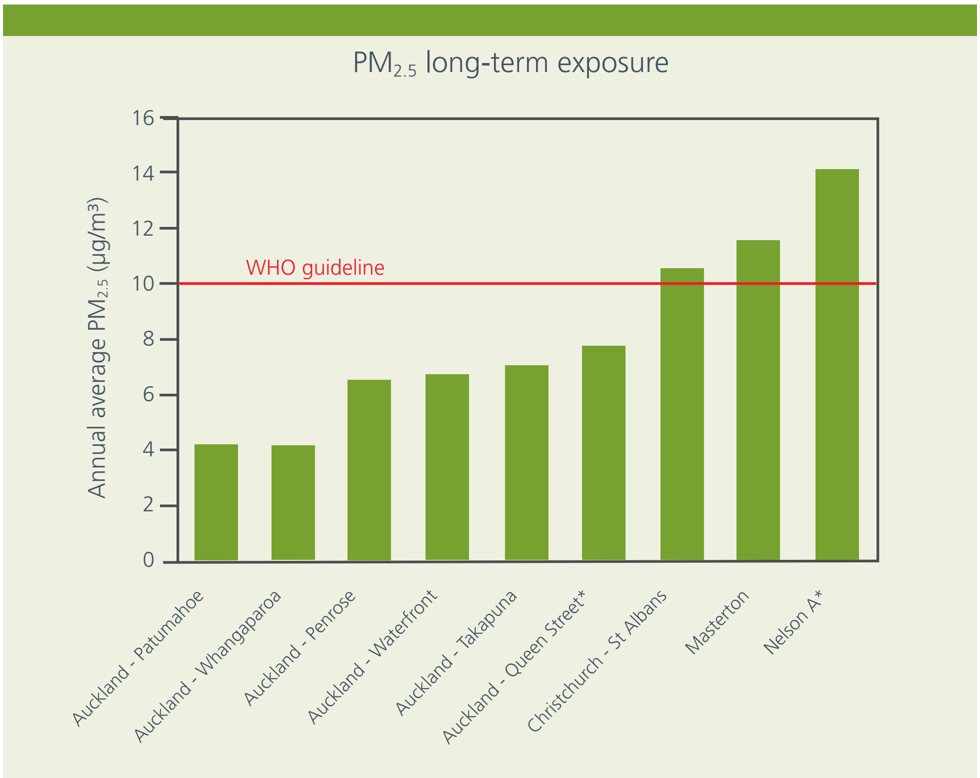
Figures 3.3 and 3.4 indicate that, as for PM_{10}, performance against the long-term WHO guideline is better than performance against the short-term guideline in the three locations where both are measured continuously.

Masterton and Nelson A 'pass' the long-term PM_{10} guideline, but 'fail' the long-term $PM_{2.5}$ guideline. This is likely to be the case in other towns and cities that have similar emissions, and still cold winters.



Source: MfE

Figure 3.3 Number of days per year on which the concentration of $PM_{2.5}$ exceeded 25 μg/m³ – averaged for the three years 2010–2012 at sites where $PM_{2.5}$ has been regularly monitored. Sites above the red line did not 'pass' the WHO short-term guideline for $PM_{2.5}$.



Source: MfE; GNS*

Figure 3.4 Annual average concentration of $PM_{2.5}$ – averaged for the three years 2010–2012 at sites where $PM_{2.5}$ has been monitored. Sites above the red line did not 'pass' the WHO long-term guideline for $PM_{2.5}$.

3.3 More on the WHO guidelines

To recap, the WHO has four guidelines for particulate concentrations:

- The two guidelines for PM_{10} discussed in section 3.1 – one for short-term exposure and one for long-term exposure.
- The two guidelines for $PM_{2.5}$ discussed in section 3.2 – one for short-term exposure and one for long-term exposure.

The WHO is clear that the long-term exposure guidelines are more important than the short-term exposure guidelines because the health impacts on the population are much greater.

"When evaluating the WHO Air Quality Guidelines and interim targets, it is generally recommended that the annual average take precedence over the 24-hour average.…"[42]

In addition, it is now widely accepted among air quality scientists that $PM_{2.5}$ concentrations are a better indicator of health impacts across the population than PM_{10} concentrations. This is because the smaller particles are, the more damaging they are to human health.[43]

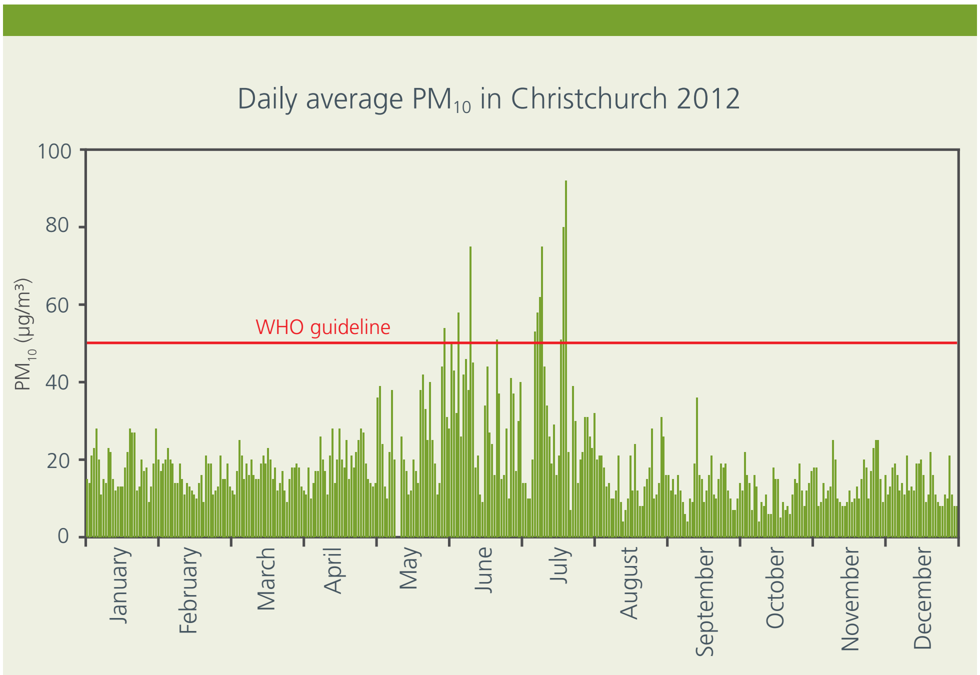
It follows that although all four guidelines are important, the most important is the guideline for long-term exposure to $PM_{2.5}$.

One site where it is possible to assess performance against all four guidelines is in St Albans in Christchurch. Figures 3.5 and 3.6 show the average concentrations of PM_{10} and $PM_{2.5}$ on every day in 2012 measured at the St Albans site.[44] On still cold days when inversion layers form over the city, particulate concentrations climb above the short-term WHO guideline levels.

How serious are such exceedances? It is easy to gain the impression that once a guideline level is crossed, the effect of particulates on people's health suddenly becomes much greater. However, this is not the case.[45] The highest exceedance in Figure 3.5 – a spike of 92 $\mu g/m^3$ – would have had a very different effect on vulnerable people than the lowest exceedance of 51 $\mu g/m^3$.

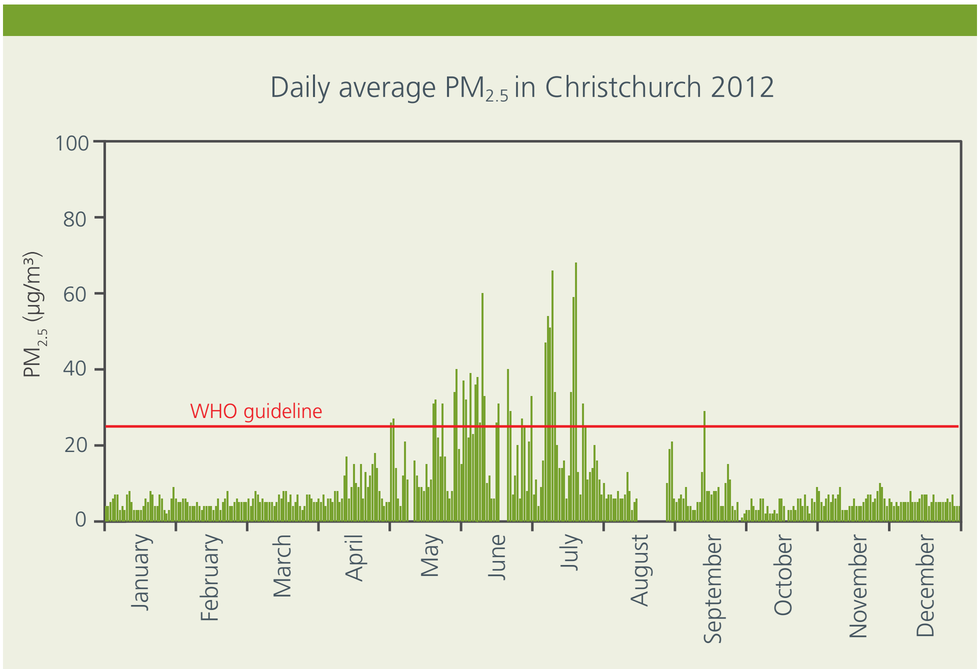
A comparison of Figures 3.5 and 3.6 shows performance against the short-term $PM_{2.5}$ guideline is worse than performance against the short-term PM_{10} guideline. However, when judged against the most important guideline – that for *long-term exposure to $PM_{2.5}$*, Figure 3.4 shows that the St Albans site only just 'fails'.

This is because in Christchurch air quality is very good on most days but poor on some winter days. The system used in Australia for judging air quality was described in Box 2.1. Under this system, air quality at the St Albans site would be classified as good to very good (Box 3.1). Nonetheless there will still be health impacts in Christchurch from particulates.



Source: ECAN

Figure 3.5 Daily concentrations of PM_{10} measured at the St Albans site in Christchurch in 2012.



Source: ECAN

Figure 3.6 Daily concentrations of $PM_{2.5}$ measured at the St Albans site in Christchurch in 2012.

Box 3.1 Applying the Australian method to $PM_{2.5}$ in Christchurch

The data in the table below is taken from the St Albans monitoring site in Christchurch.

In the Australian system, each day is scored as Very Good, Good, Fair, Poor, or Very Poor, according to the 'distance' of the daily average concentration above or below the $PM_{2.5}$ benchmark of 25 μg/m^3.

The conversion of the daily scores into annual scores has been done according to the criteria on page 135 of the *Australia State of the Environment 2011* report.

	2011 Days	2012 Days	2013 Days
Very Good	231	244	197
Good	70	56	118
Fair	25	16	26
Poor	17	21	9
Very Poor	15	11	15
	358	**348**	**365**

Year score	Very good	Very good	Good
Annual average μg/m^3	10.5	9.9	11.1
Exceedances above 25 μg/m^3	32	31	22

There is nothing intrinsically 'right' about the Australian method, just as there is nothing intrinsically 'right' about any air pollutant guidelines and rules. An expert panel set up to devise a similar system in New Zealand might choose very different criteria for deciding whether air quality is very good, very poor, or somewhere in between.[46]

Source: Jayline

Figure 3.7 This is the first wood burner that has met Environment Canterbury's ultra-low emissions standard.

Source: russellstreet [CC BY-SA 2.0 (http://creativecommons.org/licenses/by-sa/2.0)], via Flickr

Figure 3.8 Motorways and other major roads are sources of air pollutants that can affect motorists as well as those who live and work nearby. Diesel vehicles in particular produce large amounts of nitrogen oxides and particulate matter.

3.4 Looking back and forward

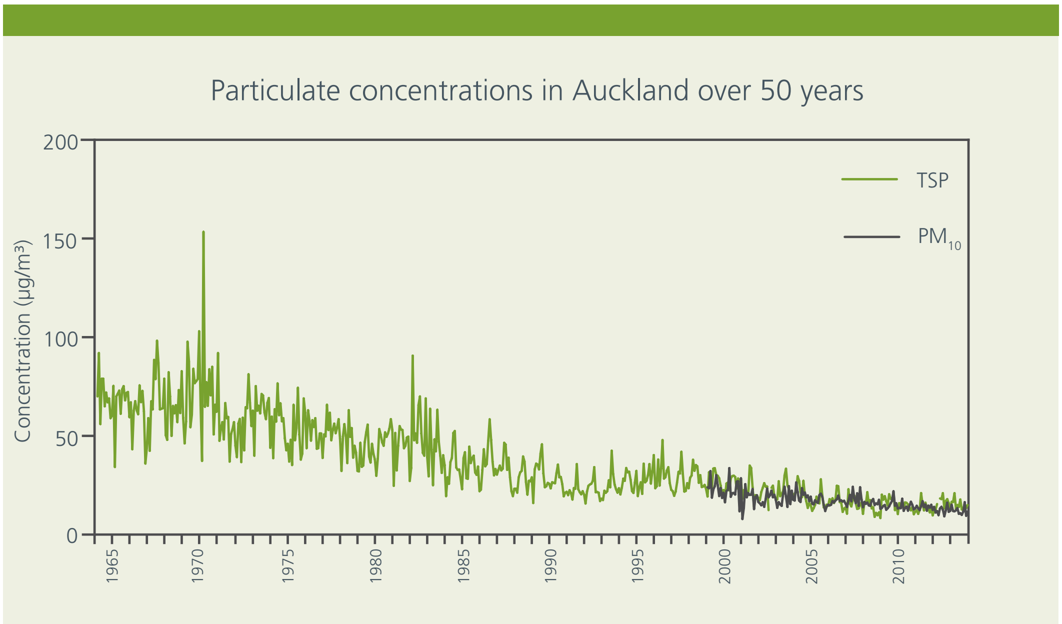
The most significant air pollutant in New Zealand is particulate matter. Many people in colder parts of the country are exposed to relatively high levels of particulates in winter. Those who live beside busy roads inhale gases like nitrogen dioxide as well as particulates.

Despite this, the analysis in this chapter has shown that most towns and cities in New Zealand perform well against the WHO guideline for long-term exposure to PM_{10}. However, indications are that performance against the equivalent guideline for $PM_{2.5}$ – the most important of the four WHO guidelines – may not be so good in some places.

Another dimension of judging how serious this issue is in New Zealand is to consider the underlying 'drivers' of changes in air quality – to look back at how and why sources of pollutants have changed in the past, and to contemplate how they can be expected to change in the future.

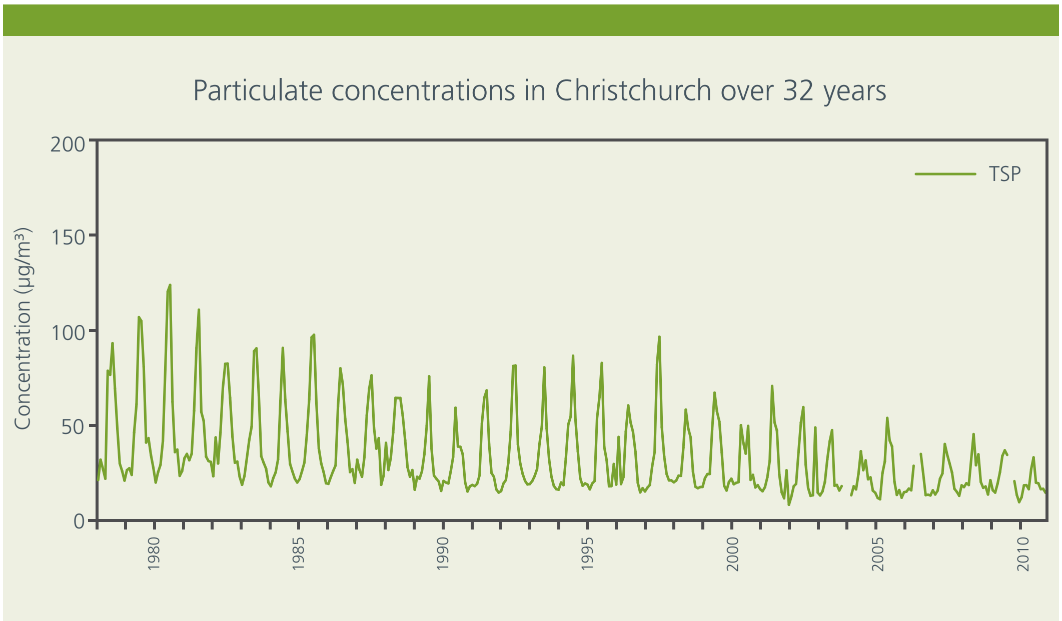
The decline in particulate pollution in Auckland over the last few decades is dramatic. The Auckland Council has measured total suspended particulates (TSP) in Auckland for the last 50 years.[47] Figure 3.9 shows TSP concentrations in Auckland falling by around 75 percent over this time.[48] Moreover, the *variation* in the monthly average has also reduced markedly, indicating that the height of the winter spikes has also reduced – the 'bad' pollution days have become less 'bad'.

Figure 3.10 shows falling TSP concentrations in Christchurch over a shorter period. Again the declining variation in monthly averages shows that the height of the winter spikes has also reduced. [49]



Source: Auckland Council

Figure 3.9 Monthly average concentrations of TSP (total suspended particulates) and PM_{10} in Auckland over a 50 year period.



Source: ECAN

Figure 3.10 Monthly average concentrations of TSP (total suspended particulates) in Christchurch over a 32 year period.

Particulates from home heating

The main reason for the decline in winter pollution is clear – a shift from heating homes with wood or coal to heating homes with electricity. In 1996, 47 percent of homes were heated with wood, but by 2013, only 37 percent of homes were heated this way.[50]

A wood burner that burns efficiently also burns relatively cleanly. The National Environmental Standard for Air Quality includes efficiency ratings for new wood burners. In some cities councils have taken a variety of actions to discourage open fires and older wood burners in their efforts to reduce air pollution.

A major factor in the switch from heating with solid fuel to heating with electricity has been the introduction of heat pumps. Over the last decade, heat pumps have been promoted for their efficiency and convenience, and hundreds of thousands have been installed.[51]

Another relevant change has been the improvement in the thermal performance of buildings. Better insulation means less heating and therefore lower emissions, as well as warmer houses. It was not until 1978 that there was any requirement for insulation in national building standards in New Zealand, and there are still many old houses that are cold and damp. When such houses are renovated they are often insulated, making them easier to heat.[52]

Looking forward, the thermal performance of New Zealand houses will continue to improve. Changes to the building standards in 2007 raised the requirement for insulation and made double-glazing compulsory in much of the country. The health benefits of warm, dry homes have now been demonstrated.[53]

The trend towards electric heating may slow but is unlikely to reverse. The population is ageing, and many elderly people prefer the convenience of electricity.

Particulates from transport

In recent decades, increasingly strict standards aimed at reducing the environmental and health effects associated with transport have been placed on both fuels and vehicles.

When it comes to considering particulates in vehicle emissions, there is a very big difference between vehicles running on petrol and vehicles running on diesel. Emissions of particulates are much higher from diesel engines than from similar-sized petrol engines.[54] Over the last decade or so, the proportion of vehicles in New Zealand that run on diesel has steadily grown.[55] Particulate matter from diesel engines is considered to be particularly toxic in part because most of the particles are extremely small – ultrafine particles measuring less than 0.1 microns across.[56] One big improvement has been the progressive reduction of the sulphur content of diesel that began in 2002.[57] Interestingly, several studies have also shown that diesel exhaust particles can induce more severe allergic reactions to pollen.[58]

Stricter exhaust emission standards have driven improvements in engine design and technology that have greatly reduced the pollutants emitted from many vehicles. But these improvements have been most clearly seen in vehicles running on petrol, where emissions of particulates, carbon monoxide, and nitrogen oxides are much lower than in the past.[59]

Diesel engines have also been subject to stricter controls, resulting in significant reductions in particulates.[60] However, ongoing tightening of emissions standards on diesel vehicles does not now seem to be resulting in further emission reductions.[61]

'Source apportionment' analysis done in Auckland shows that particulate matter emitted from diesel engines far eclipses that from petrol engines.[62]

Looking ahead, it is unclear if particulates from diesel vehicles will increase. Official projections of the consumption of diesel used in transport are for an increase of about 35 percent over the next two decades.[63] However, the phasing out of older vehicles will help to counter this increased diesel use and further technological improvements to new vehicles may occur.[64]

The impact of climate change

On still, cold days in towns and cities that are prone to temperature inversions, air pollutants are trapped close to the ground and build up to relatively high concentrations. It is on these days and in these locations that exceedances of the WHO short-term guideline occur.

One likely effect of climate change is that very cold days will occur less frequently.[65] Consistent with this, the number of frosty days each year has declined by about 16 percent in the South Island since 1940.[66] It follows that temperature inversions will also become less frequent.

On the other hand, higher temperatures may increase the incidence of 'photochemical smog' and bush fires.

Figure 3.11 A heavy frost in Alexandra in inland Otago. In Alexandra, temperature inversions often occur in winter and levels of air pollution from home fires can be very high.

3.5 In conclusion

The purpose of this chapter was to see if it was possible to reach a clearer conclusion on how serious particulate air pollution is in New Zealand.

In the analysis in this chapter, the four WHO guidelines have been used as a yardstick.

For PM_{10}:

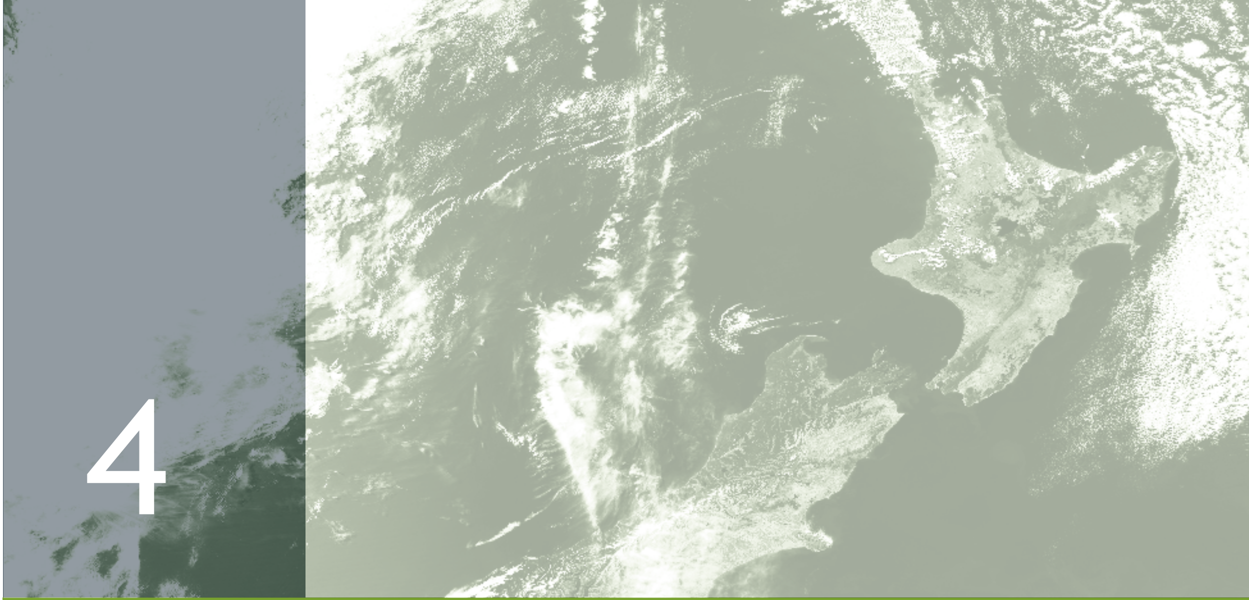
- Performance against the guideline for long-term exposure is generally very good.
- Performance against the guideline for short-term exposure is poor in some places, chiefly in towns and cities where temperature inversions form on cold winter days.

Despite the paucity of $PM_{2.5}$ data, indications are that performance against the $PM_{2.5}$ guidelines is not as good as performance against the PM_{10} guidelines, though it follows a similar pattern.

The impact of long-term exposure on population health is now understood to be much greater than the impact of short-term exposure. It is also now known that fine particles have a greater impact on population health than coarse particles – $PM_{2.5}$ is more important than PM_{10}. Thus, the most important of the four guidelines is that for long-term exposure to $PM_{2.5}$.

On the whole, air quality in New Zealand is good. Much of the time it is very good. It must be acknowledged, though, that inhalation of air-borne particles does have real health impacts.

Much of the great improvement in New Zealand's air quality over the last few decades is due to the efforts of various councils and these should continue. At central government level also, actions such as setting wood burner standards and reducing sulphur in diesel have been effective. However, as the WHO says, "…*it becomes harder and harder to reduce marginal amounts of air pollution as air quality improves…*"[67]



4 Managing particulate pollution

One of the WHO guidelines – that for short-term exposure to PM_{10} – is used as a basis for setting a limit on the concentration of particulate matter in ambient air. This limit is one of the rules in the National Environmental Standard on Air Quality.[68] By 2016, most regional councils are required to ensure that the average daily concentration of PM_{10} exceeds 50 µg/m^3 on no more than one day each year.[69]

In this chapter, this limit, referred to as the PM_{10} rule, is discussed.

The first section examines some issues related to the PM_{10} rule. These include misunderstandings created by the rule's focus, and its inherent limitations.

The second section considers the tension between two public health issues: air pollution from wood fires and the problem of cold, damp homes.

The final section examines the 'other air problem' – climate change – and whether actions to reduce air pollution reduce or increase the emission of the greenhouse gas carbon dioxide.

4.1 Perceptions about particulate pollution

The science of air quality is complex, and it is understandable that aspects of the relationship between air quality and the impacts it has on health are sometimes misunderstood. Often this misunderstanding seems to be associated with the regulatory limit on PM_{10}.

First, in seeking to assess compliance with the PM_{10} rule, reference is often made to numbers of 'high pollution days'. These are days on which the benchmark level of 50 $\mu g/m^3$ is exceeded. But, as is sometimes particularly evident in media coverage, this can lead to the perception of a threshold or tipping point – that days below 50 $\mu g/m^3$ are safe, and days above 50 $\mu g/m^3$ are dangerous. However, there is no threshold above which the health impacts of particulate matter on the population dramatically increase.[70]

As noted in section 3.3, the degree of the exceedances (the height of the winter spikes) is not reflected in the PM_{10} rule. There is no distinction between an exceedance of 51 $\mu g/m^3$ and an exceedance of 101 $\mu g/m^3$. This reinforces the perception of a threshold.

It is possible that an airshed could comply with the PM_{10} rule while increasing particulate pollution. A year with two days at 51 $\mu g/m^3$ is a 'fail', but a year with no days over 50 $\mu g/m^3$ but 20 days at 49 $\mu g/m^3$ would be a 'pass'.

The population health impacts of long-term exposure are much greater than those of short-term exposure. Because there is not a straightforward relationship between them in New Zealand, a limit on daily concentrations may have little impact on annual concentrations.[71]

A further issue with setting a limit on allowable daily exceedances of a benchmark is the potential for 'drifting in and out of compliance'. The number of exceedances in any location can vary from year to year depending on how cold and windy the winter is. Annual average concentrations of pollutants are far less volatile than daily averages.

The focus on the PM_{10} rule may also be giving some the impression that if a regional council achieves compliance, all will be well – there will be no more (or many fewer) deaths and illness from air pollution.

Box 4.1 shows the particulate rules for different countries compared to the WHO guidelines. Australia is similar to New Zealand, with a single rule for short-term exposure to PM_{10}. However, Australia is soon to consider a proposal for four rules, covering short-term and long-term exposure to both PM_{10} and $PM_{2.5}$. [72]

Box 4.1 Particulate rules in different countries compared with the WHO guidelines.

The rules for particulate matter in a number of developed countries are shown below.[73]

PM_{10}

Country	Short-term exposure (daily average – µg/m³)	Long-term exposure (annual average – µg/m³)
New Zealand	**1** exceedance of **50** each year	—
Australia	**5** exceedances of **50** each year	—
European Union	**35** exceedances of **50** each year	Less than **40**
United States	**1** exceedance of **150** each year	—
Canada	—	—
Japan	No exceedances of **100**	—
WHO guidelines	**3** exceedances of **50** each year	Less than **20**

$PM_{2.5}$

Country	Short-term exposure (daily average – µg/m³)	Long-term exposure (annual average – µg/m³)
New Zealand	—	—
Australia	—	—
European Union	—	Less than **25**
United States	**7** exceedances of **35** each year	Less than **12**
Canada	**7** exceedances of **28** each year	Less than **10**
Japan	**7** exceedances of **35** each year	Less than **15**
WHO guidelines	**3** exceedances of **25** each year	Less than **10**

In October 2014, the Auckland Council proposed a bylaw aimed at reducing the emissions of particulates from home heating in order to comply with the PM_{10} rule.[74] Over the last five years, Auckland has averaged two exceedances of 50 $\mu g/m^3$ a year. Putting aside the merits of the bylaw, reducing annual exceedances in the Auckland airshed from two to one and thus complying with the PM_{10} rule would *in itself* have no detectable effect on health impacts.

On the other hand, the Auckland airshed could achieve compliance with the PM_{10} rule, despite an increase in the annual concentration of PM_{10} and an increase in the health impacts on Aucklanders.

Another consequence of the focus on the PM_{10} rule can be the perception that all airborne particles are equal since it is only the combined *mass* that matters for compliance. Yet fine particles are generally more dangerous than coarse particles, so $PM_{2.5}$ levels are a better measure of health risk than PM_{10} levels.

Another important difference is the *origin* of the particles.

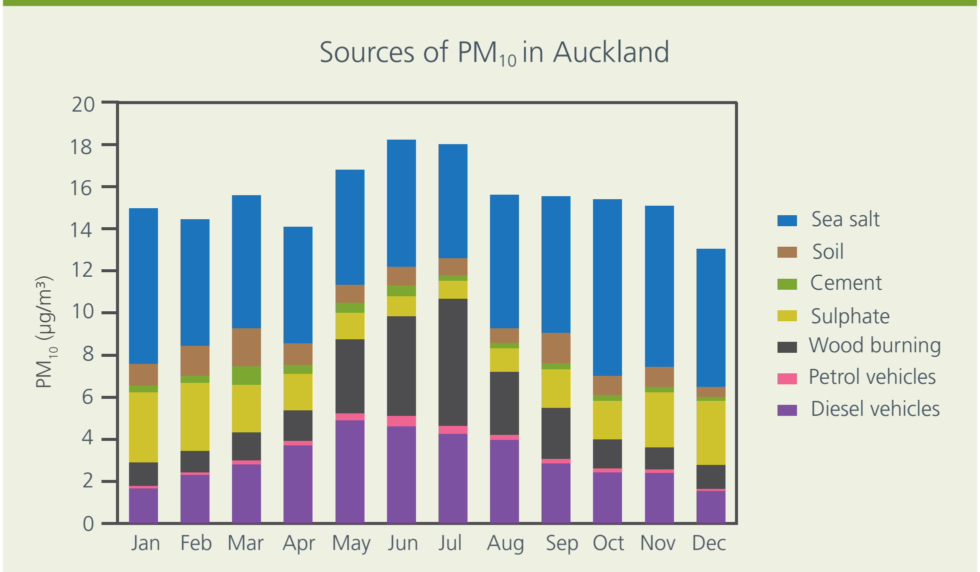
In recent years, some regional councils have contracted the Institute of Geological and Nuclear Sciences (GNS Science) to undertake 'source apportionment' of the particulates in their airsheds. Figures 4.1 and 4.2 show the sources of PM_{10} and $PM_{2.5}$ respectively, measured at the Takapuna monitoring site.[75] This site is considered by the Auckland Council to be representative of the Auckland airshed.

There is some uncertainty in the source apportionment analyses and there is considerable variation between airsheds. Nevertheless, Figures 4.1 and 4.2 reveal a key shortcoming of the PM_{10} rule. $PM_{2.5}$ comes mostly from combustion sources which are generally more harmful and easier to control, whereas PM_{10} can include large amounts of salt and dust.

Other points of interest in the two figures are the following:

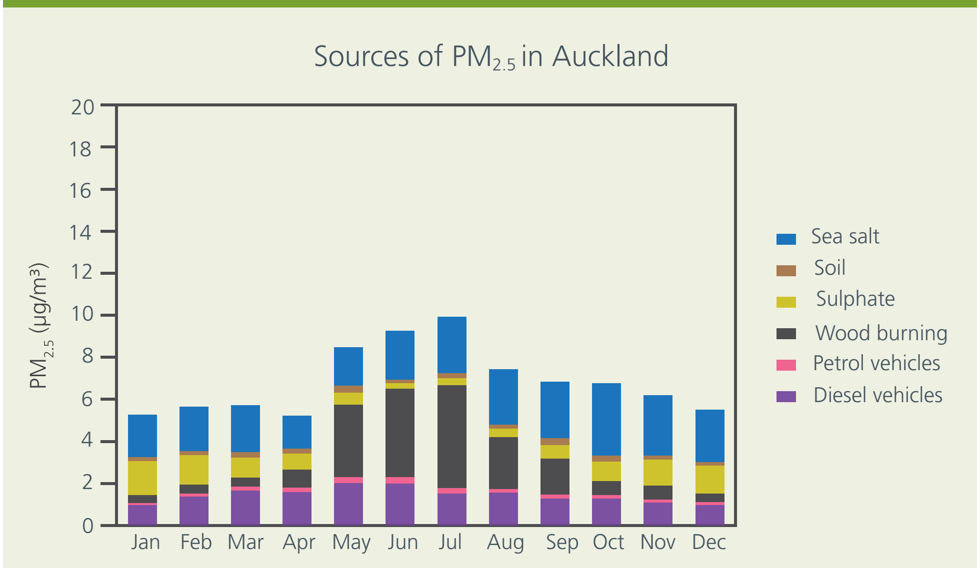
- Diesel vehicles in Auckland, despite their lower numbers, are a far greater source of particulates than petrol vehicles.
- Particulates from diesel vehicles, like those from wood burning, peak in the winter months.
- Sulphate, in contrast, is much higher in summer than winter – this is because it is produced in a series of chemical reactions driven by sunlight.[76]

Most striking is the high salt proportion – 40 percent of the PM_{10} and 33 percent of the $PM_{2.5}$ particles come from sea-spray. The European Air Quality Directive allows salt and other particulate matter from natural sources to be subtracted from monitoring results when assessing compliance with the European Union standards.[77]



Source: GNS

Figure 4.1 Sources of PM_{10} at the Takapuna monitoring site in Auckland.



Source: GNS

Figure 4.2 Sources of $PM_{2.5}$ at the Takapuna monitoring site in Auckland.

4.2 Keeping homes warm and dry

In their efforts to comply with the PM_{10} rule, regional councils have taken a variety of actions to reduce the particulates from home heating. Such actions include the banning of open fires, the setting of standards for enclosed burners, and limits on the moisture content of firewood.

The temperature inversions that form on still winter days in the most polluted cities and towns trap particulates from all sources, not just home heating. The source that regional councils have the most influence over is home heating, and they have understandably focused on this.[78] But in doing so, they have run into considerable resistance. In recent hearings on Environment Southland's Regional Policy Statement, the Mayor of Gore said that no other issue had raised such a high level of concern among residents during his three decades in politics.[79]

There are a number of reasons for resistance to the 'clean heat' initiatives in air quality plans, including the following:

- Switching from an existing form of heating is costly. The capital cost of clean heating appliances like heat pumps, flued gas heaters, and pellet burners is high, although some councils have provided subsidies.
- Many people love the radiant heat and 'ambience' of a fire.
- The security of a 'non-electric' heater is valued where winters are cold; this is especially so in post-quake Christchurch where people are aware of how long power cuts can last. Also some have experienced heat pumps 'cutting out' in cold temperatures.[80]

While poor air quality is a health issue in New Zealand, the state of the housing stock is another. New Zealand homes are famously cold and damp, and this takes a toll on the health of many.[81] The most effective way of keeping many houses in cold parts of the country warm and dry is an enclosed solid fuel burner.[82] Retrofitting insulation to old draughty houses makes a big difference to their thermal integrity, but they will never be as 'tight' as a new house with the ceiling, walls, and floor insulated and the windows double-glazed.

It is difficult to see compliance with the PM_{10} rule being achieved in towns like Masterton and Alexandra without removing most, if not all, of the solid fuel burners. The Chairman of Otago Regional Council commented recently *"We need to have a fundamental look at the standard, now we are getting to the hard end of things."* [83]

While regional councils are held accountable for compliance with air pollutant rules, they have little influence over sources other than home heating and industry (through conditions in resource consents). But they have no influence over *indoor* air pollution.

On cold winter days particularly at night when pollutant levels are highest, people spend most of their time indoors. While outdoor air pollution contributes to indoor air pollution particularly in old draughty houses, there are also sources of air pollutants inside homes.

One such source is unflued gas heaters. Because these heaters emit pollutants into inside air, not outside air, they are 'clean' from a regional council perspective. Unflued gas heaters emit carbon monoxide (if not properly maintained), nitrogen dioxide, and water vapour, and are considered to be particularly bad for asthmatics. They are cheap to buy, but expensive to run, and have been dubbed 'the poor person's heater'.[84] There could be significant health gains from replacing unflued gas heaters in households where they are used regularly.[85]

Figure 4.3 Many New Zealand houses were built with no insulation, and with open fires and coal ranges for heating. Even when retrofitted with insulation, old draughty houses are much more difficult to heat than new houses that must comply with modern building standards.

4.3 The other 'air problem' - greenhouse gases

Under the Resource Management Act 1991, councils must have regard to the *effects* of climate change, but have no legal obligation to consider *mitigation* of climate change – that is, whether their actions increase or decrease emissions of greenhouse gases.[86]

The main greenhouse gas causing climate change is carbon dioxide. As trees grow, they take carbon dioxide out of the atmosphere; as they decay or are burned the carbon dioxide is returned to the atmosphere. For this reason, firewood is close to 'carbon-neutral'. Yet this is not a consideration in council air quality plans. Neither is the National Environmental Standard (NES) on Air Quality (which includes the PM_{10} rule) concerned with limiting emissions of carbon dioxide.

Coal versus wood

The regulations governing emissions from solid fuel burners make no distinction between coal and wood. Yet coal is the most carbon-intensive of the fossil fuels, and this is particularly so for the lignite used as a fuel by some households in the south of the country. When it comes to air quality also, the emissions from burning coal are worse than those from burning wood. Particulate emission factors are considerably higher for small coal burners than for wood burners, even for bituminous coal, which burns more hotly than lignite.[87] Coal combustion also emits more sulphur dioxide than wood combustion – this is the reason for the acrid odour of coal smoke.

Gas heaters and heat pumps

When solid fuel burners are replaced because they do not produce 'clean heat', they are generally replaced by heat pumps and, increasingly, flued gas heaters that run on LPG in areas where reticulated natural gas is not available. Both LPG – liquefied petroleum gas – and natural gas are fossil fuels that produce carbon dioxide when burned.

Heat pumps and resistance heaters both use electricity, but heat pumps are more efficient. The demand for electricity in New Zealand peaks in winter, and this peak is largely caused by households using electricity for space heating and water heating. Gas power plants supply much of this winter peak. Thus, electric heating contributes to carbon dioxide emissions. One analysis shows the carbon dioxide emissions intensity of heat pumps to be only a little less than that of gas heaters.[88]

Figure 4.4 Unflued gas heaters release water vapour and nitrogen dioxide (and, if not maintained well, carbon monoxide) directly into the room. Public health experts have called for the use of unflued gas heaters to be phased out.

Source: Shutterstock

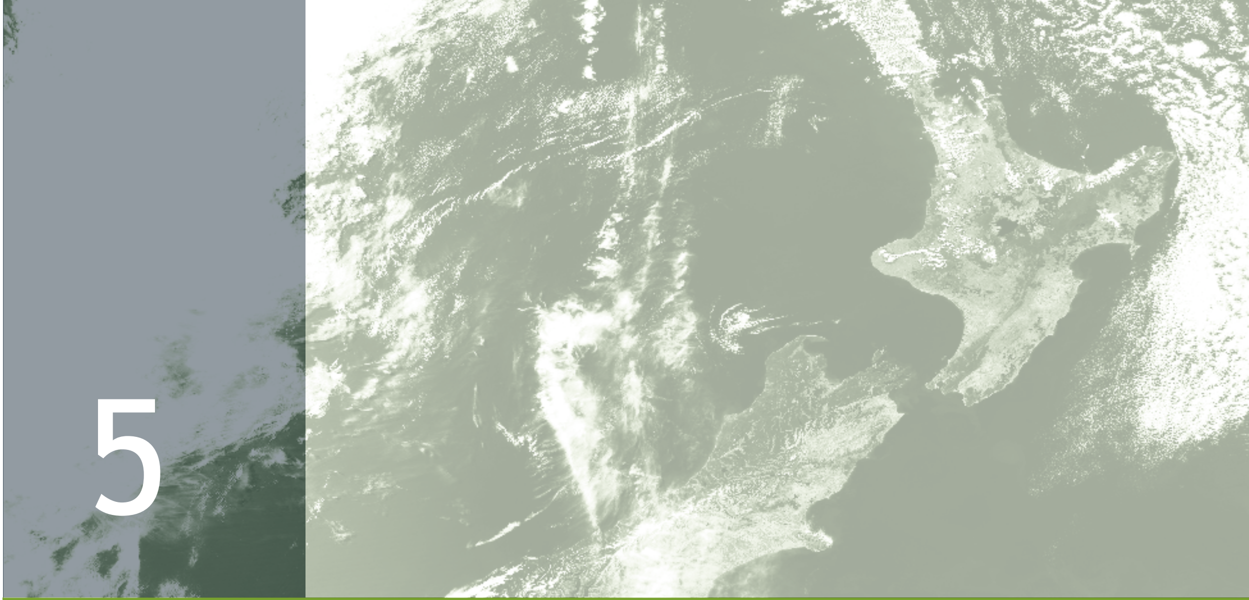
Source: PCE archives

Figure 4.5 There has been widespread uptake of heat pumps in New Zealand.

Diesel versus petrol

As described in section 3.4, pollutants from diesel vehicles are a far greater concern than pollutants from petrol vehicles. The source apportionment for Auckland in section 4.1 shows how great the difference is for particulates. But it is not just particulates – diesel vehicles emit far more NO_X than petrol vehicles.

When it comes to emissions of the greenhouse gas carbon dioxide, diesel vehicles have been much better than petrol vehicles (of the same engine size) for a long time.[89] However, new petrol vehicles are now so efficient, their carbon dioxide emissions are only slightly higher than those from diesel engines.[90]



5

Conclusions and recommendations

This report is a commentary by the Commissioner on the first state of the environment report prepared jointly by the Secretary for the Environment and the Government Statistician. The Environmental Reporting Bill is expected to become law in 2015. This will make the preparation of regular state of the environment reports mandatory, as it is in other developed countries.

This commentary began with an assessment of the *2014 Air Domain Report*. The need for a clear conclusion on the state of air quality in New Zealand led to an examination of the air pollutant of most concern – the tiny airborne particles called particulate matter. The scientific understanding of particulate pollution has developed since New Zealand's PM_{10} rule was first established. This rule may no longer be the best way to ensure ongoing incremental improvement of air quality.

What then is the state of air quality in New Zealand? It is generally good as we would expect in a windswept, maritime country, with a small population and little heavy industry. Air quality is significantly poorer in winter in many towns and cities, and particularly so where temperature inversions form trapping wood smoke and other pollutants. However, even in towns such as Masterton and Alexandra, air quality is high on most days.

Particulate matter is not the only pollutant. In particular, increasing nitrogen oxide emissions from transport could become an issue, particularly in Auckland.

Air quality in New Zealand is an environmental good news story. The shift from heating homes with wood or coal to heating homes with electricity and the introduction of efficient wood burners has had a notable impact. Uninsulated houses heated with open fires are no longer the norm. Emissions from industry must meet limits in resource consents. New vehicles have to comply with increasingly stringent emission standards.

This chapter contains two recommendations from the Commissioner.

The first, following from the assessment of the *2014 Air Domain Report* in Chapter 2, identifies aspects in need of improvement in future state of the environment reports.

The second, following from the analysis in Chapters 3 and 4, is concerned with the regulation of particulate matter – the PM_{10} rule.

5.1 Improve environmental reporting

The Government Statistician and the Secretary for the Environment are to be commended for producing the *2014 Air Domain Report* – the first state of the environment report produced under the new system.

There will never be a perfect state of the environment report – the task is too wide-ranging and the data sets that are available will always be inadequate in some way. The challenge is one of incremental improvement.

In Chapter 2 of this commentary, seven aspects for improvement in future reports were identified. The last is specific to future reporting on the air domain, but the others are applicable to reports on all domains. They are:

1) Clear conclusions on the *state* of the environmental domain are essential.
2) The development of national indicators should be treated as a 'work-in-progress', and the indicators chosen not given undue weight. All relevant information should be considered when drawing final conclusions.
3) Location matters. It is important to make it clear where an environmental issue is significant and where it is not.
4) Indicating the degree of uncertainty in major results is important. This should include statistical testing of observed differences.
5) Modelled results should always be 'ground-truthed' wherever possible.
6) The limitations of models should be explained.
7) Future air domain reports would benefit from more analysis of natural sources of air pollution.

I recommend that:

The Government Statistician and the Secretary for the Environment publish a code of practice for preparing environmental reports that incorporates the improvements listed above.

5.2 Review the PM_{10} rule

The 'PM_{10} rule' is the limit on particulate matter in ambient air that has been set in the National Environmental Standard for Air Quality. The rule requires that the average PM_{10} concentration exceed 50 µg/m^3 on no more than one day a year. Most regional councils are to achieve this by 2016, but those responsible for airsheds where exceedances occur on ten days a year or more, have until 2020 to comply.

A number of issues related to the PM_{10} rule have been raised in this report. Most importantly, New Zealand's limit on particulates in ambient air has been based on the *least* important of the WHO's four guidelines for particulate matter – that governing short-term exposure to PM_{10}.

The *most* important of these guidelines is that governing long-term exposure to $PM_{2.5}$.

The smaller airborne particles are, the greater is the risk to those who inhale them. Similarly, it has been discovered over time that the health impacts of long-term exposure to particulates are much greater at a population level than the impacts of short-term exposure.

Thus, there is a strong case for a rule aimed at long-term exposure to fine particles – a limit on the annual average concentration of $PM_{2.5}$. A necessary first step would be a requirement to monitor $PM_{2.5}$.

There are other reasons for a focus on long-term exposure to fine particles. For instance, the particulates from natural sources, primarily wind-blown soil and seaspray, tend to be relatively large, so $PM_{2.5}$ is 'more anthropogenic' than PM_{10}.

Some might question the value of mandatory limits on pollutants in ambient air, and suggest that it would be preferable to rely on guidelines and on emission standards such as those on woodburners and vehicles. However, the argument for a mandatory ambient air limit is that it incentivises regional councils to take action. Indeed, despite the limitations of the PM_{10} rule raised in this report, it has achieved a great deal.

On the other hand, a council might be deterred from taking much action at all if it will clearly be unable to comply with a rule, reasoning that it might as well be hanged for a sheep as a lamb. Hypothetically at least, a council responsible for airsheds with the double whammy of very cold winters and temperature inversions might be tempted to take this stance.

There is no 'safe' level of air pollution, and air quality in New Zealand is generally good and likely to continue improving. The policy goal should be to ensure progressive improvement, and a rule could be designed in such a way as to incentivise this.

Air quality is, of course, not the only thing that matters. In its latest update of its air quality guidelines, the WHO states that standards for particulate matter should be set "*to achieve the lowest concentrations possible in the context of local constraints, capabilities and public health priorities.*" It would be counterproductive if, for instance, actions to reduce emissions from wood burners resulted in more cold damp homes.

I recommend that:

The Minister for the Environment initiate a review of how particulate matter is managed that determines:

a. **Whether $PM_{2.5}$ should be measured across the country in airsheds where there is likely to be a problem;**

b. **The value of setting rules for $PM_{2.5}$ and for long-term exposure;**

c. **Whether the PM_{10} short-term rule still has value;**

d. **The impact of air quality rules on other public health issues, such as cold damp homes; and**

e. **How air quality policies might be designed so as to achieve progressive improvement.**

Notes

[1] See Bell et al., 2004.

[2] Ozone at ground level is harmful to humans, animals, and plants. Naturally occurring ozone in the stratosphere is beneficial because it reduces the amount of ultraviolet light from the sun reaching the surface of the earth – its preservation is important for life on earth.

[3] Gush, 2003.

[4] Hughey et al., 2013, p. 11.

[5] There are of course other sources of pollutants. Industrial air pollutants such as exhaust fumes from chemical reactions are localised and generally controlled through resource consents.

[6] Pope and Dockery, 2006. Small particles also tend to adsorb more contaminants on to their surface than large particles.

[7] Maynard, 2009.

[8] There are 1000 microns in a millimeter. PM_{10} particles have a diameter less than one-fifth of the diameter of a human hair. $PM_{2.5}$ particles have a diameter less than one-twentieth of the diameter of a human hair. (Particles greater than 10 microns in diameter are generally not considered to be a threat to human health as they cannot get past the body's natural defences.)

[9] Otago Regional Council, 2007.

[10] Pope, 2000, p.719.

[11] WHO, 2013, pp.11-12.

[12] WHO, 2006a. The guidelines for the daily averages state that only values in the 99th percentile are to be used. This means that the three highest daily averages are not counted, effectively allowing three exceedances per year.

[13] The *2014 Air Domain Report* and its associated spreadsheets are available on the Ministry for the Environment's website.

[14] Short 'commentaries'– topics where the data available is very limited – are also included.

[15] Environmental Reporting Bill 2014 (189-1), cl 17. Note that the Commissioner is not obliged to produce commentaries; he or she must always assess the value that would be added by such a commentary *vis-à-vis* the value of undertaking investigations or providing advice under Section 16 of the Environment Act 1986.

[16] Ministry for the Environment, 2014, p.5.

[17] Australia State of the Environment Committee, 2011, p.128.

[18] The Ministry for the Environment website lists six criteria for selecting national indicators – relevance, accuracy, timeliness, accessibility, coherence/consistency, and interpretability, with national representativeness a "*significant consideration*". These criteria are based on Statistics New Zealand's Principles and Protocols for Tier One Statistics. Only the first two criteria are mandatory.

[19] The report on the Commissioner's investigation into longfin eels, though far from air quality, provides an example of the importance of using all relevant data. It is only relatively recently that concern has arisen about the sustainability of this iconic species. The focus in the past has been on the management of the eel fishery, so 'economic' data such as catch per unit effort and the size of processed fish has been collected for many years. However, the data needed for assessing the sustainability of the longfin eel population is very different – the age distribution of the population and the number of females that successfully migrate out to sea to breed.

[20] The locations are identified in the supporting information and spreadsheets published on the Ministry for the Environment's website.

[21] Because this national indicator is weighted by population, it will be dominated by measurements at sites within large cities. Thus, part of the difference between 2006 and 2012 could have been caused by a particularly cold and windless winter in Auckland in 2006 and a mild and windy winter in Auckland in 2012.

[22] In the process of preparing this commentary, a non-parametric Mann-Kendall trend analysis was performed using the data in Figure 12. The results showed statistically significant declines in annual average PM_{10} levels for the St Albans and Upper Hutt sites, but not for the other three sites.

[23] This approach was used to assess the condition of Australia's marine environment for the *2011 State of the Environment Report*. See Ward, 2014.

[24] The Vehicle Emission Prediction Model uses a range of information to predict vehicle emissions of pollutants, including CO, NO_X, and CO_2. The data required to run the model covers vehicle type, fuel type and specification, engine capacity, and engine technology; and is applied to a range of driving conditions, to estimate total vehicle emissions for the New Zealand fleet. (New Zealand Transport Agency, 2013, p.6).

[25] Most emitted NO_X is NO, but this is oxidised to NO_2, so the impact of NO_X emissions in air is measured in terms of concentrations of NO_2. Nitrous oxide (N_2O) is a greenhouse gas and not a component of NO_X.

[26] Between 2003 and 2011, mean emissions of NO_X from light diesel vehicles rose, despite the Vehicle Emission Prediction Model predicting the opposite (Metcalfe et al., 2013, p.2).

[27] While NO_X emissions from petrol vehicles have fallen significantly in recent years, this has not been the case for the on-road performance of diesel vehicles. Carslaw et al., 2011, p.4.

[28] Hannaby and Kuschel, 2013, p.29. The 15 percent reduction is an average for all of the monitoring sites with complete data records.

[29] Hales et al., 2012. In this study, the additional risk of death across the population due to long-term exposure to PM_{10} was found to be seven percent for every 10 $\mu g/m^3$ in the average annual level. The seven percent estimate has a 95 percent confidence interval of three percent to 10 percent. This relationship is similar to that observed in overseas studies (eg WHO, 2013).

[30] All epidemiological studies of this kind must assume that measurements of outdoor air quality reflect the exposure of the population. The actual exposure of individuals is very variable. For instance, PM_{10} levels in winter are generally considerably greater at night than during the day, and at night in winter most people are indoors. Depending on how draughty the house is, and what sources of indoor air pollution there are, the PM_{10} concentrations indoors can be very different to those outdoors. A draughty house with an old fire may well have higher levels of PM_{10} inside than outside.

[31] In epidemiological studies in New Zealand PM_{10} is used as a proxy for a mix of different air pollutants. However PM_{10} does not always correlate well with smaller particles or other pollutants such as NO_X.

[32] Begg et al., 2007, p.234. The estimates of health impacts from air pollution are very sensitive to model assumptions.

[33] This is why the number of annual premature deaths in the *2014 Air Domain Report* is 1,000, not the 2,000 mentioned above.

[34] Source apportionment of PM_{10} has only been done where regional councils have contracted GNS Science to do the work.

[35] Paraphrasing from the summary in the *2014 Air Domain Report* for greater clarity, in 2012:

- 86 percent of $PM_{2.5}$ monitoring sites met the WHO long-term guideline for $PM_{2.5}$.
- 43 percent of $PM_{2.5}$ monitoring sites met the WHO short-term guideline for $PM_{2.5}$.

[36] Airsheds are areas identified by regional councils for the management of air quality. Gazetted airsheds do not cover the whole country or even all urban areas. For example, the West Coast has only one gazetted airshed covering the inland town of Reefton.

[37] The airshed labelled Alexandra on Figure 3.1 and 3.2 is actually Otago Regional Council Airshed 1, and encompasses Arrowtown, Clyde, and Cromwell, as well as Alexandra – data is consolidated from monitoring sites in all four towns. Similarly, the airshed labelled Dunedin also represents and gathers data from Balclutha and Oamaru as well as Dunedin. Masterton refers to the Wairarapa airshed.

[38] Monitoring stations are commonly situated at sites where air pollution is expected to be worst. Therefore, measurements of pollutants tend to overstate, rather be representative of, overall air quality within an airshed.

[39] This standard is stricter than the WHO guideline (which allows three exceedances) since all regional councils must achieve only one exceedance per year by 2020, and some by 2016. The standard is 'strict' in another sense also. Stations measuring PM are typically placed at sites within an airshed where concentrations of pollutants are likely to be highest. Moreover, in airsheds where there are multiple sites the daily average PM_{10} concentration in these air sheds is taken to be that at the site with the highest measurements on any given day.

[40] In Canada, only $PM_{2.5}$ is regulated. The health impacts of ultrafine particles – $PM_{0.1}$ – are now studied by some scientists.

[41] Figure 3.4 contains data for two more sites than Figure 3.3 – Queen St in Auckland, and Nelson A (the Nelson A airshed, where about a quarter of city's the population live, has historically had the poorest air quality in the city.) This data has been provided by Geological and Nuclear Sciences (GNS Science). GNS Science has been contracted by some councils to undertake 'source apportionment' of $PM_{2.5}$ – identifying how much comes from combustion, how much from diesel, and so on. Annual average concentrations of $PM_{2.5}$ can be taken from these GNS reports, but daily average concentrations cannot because measurements were not taken every day.

[42] WHO, 2006b, p.12. See also WHO 2013, pp.11-12.

[43] WHO, 2006a, pp.154-155. See also United States Environmental Protection Agency, 2012, p.3.

[44] In Figure 3.6, there are no results for $PM_{2.5}$ for part of August, because the instrument was measuring PM_{10} for comparison. However, the highest average concentration of PM_{10} on any day in this period is 28 μg/m^3, so it is extremely unlikely that the average $PM_{2.5}$ concentration on the missing days would exceed the WHO guideline of 25 μg/m^3.

[45] There is no threshold in the dose-response curve for long-term exposure to particulates.

[46] A number of air quality indicators have been developed around the world. The UK Air Quality Index is described in *Committee on the Medical Effects of Air Pollutants (2011). Review of the UK Air Quality Index*. Produced by the Health Protection Agency for the Committee on the Medical Effects of Air Pollutants. The European Union Common Air Quality Index is described in van den Elshout et al. (2012). Following New Zealand's first state of the environment report in 1997, the Ministry for the Environment proposed a series of air quality indicators. The basic approach was similar to the Australian method where air quality was categorised depending on how close levels were to the guideline levels for each pollutant.

[47] TSP is an old way of measuring particulate concentrations. Because it includes particles up to 50 microns in diameter, it can be dominated by relatively harmless wind-blown soil. Nevertheless, it is a valuable indicator of change over this long time period.

[48] Data supplied by Auckland Council. One of the major factors for the decline was the piping of natural gas to Auckland as a fuel for industry, commercial buildings and homes.

[49] Data supplied by Environment Canterbury. The measurements have been taken from three monitoring sites – two in St Albans and one in Victoria Street. Mean concentrations are used when measurements were available from more than one site.

[50] Over the same period, a greater decline in the number of homes heated with coal has occurred – from 12 percent in 1996 to four percent in 2013. Statistics New Zealand, Census data.

[51] Buckett, 2007, pp 6-7.

[52] Some councils have set up 'clean heat' schemes that provide subsidies for insulation and, in some cases, heat pumps, for example, the Canterbury Clean Heat Project, and the Warm Dunedin programme. About 235,000 homes were insulated between 2009 and 2013 under a central government subsidy scheme called *Warm Up New Zealand: Heat Smart*.

[53] Howden-Chapman et al., 2005. In 2013, the Government launched a second insulation programme called *Warm Up New Zealand: Healthy Homes*. $100 million has been allocated over three years for subsidising the insulation of low-income homes.

[54] The combustion processes inside diesel engines generally operate with a high degree of excess air, and burn hotter than in petrol engines. This means they also produce more nitrous oxides than petrol engines, as the nitrogen and oxygen in the air react to produce NO and NO_2. In addition, the fuel to air ratio in diesel engines is less well controlled than in petrol engines, so partial combustion of the diesel can occur when oxygen levels in the engine have dropped. This process, called pyrolysis, is a major reason for the high levels of soot and other particulates produced by diesel engines.

[55] In 2000, 12 percent of the vehicles in the 'light fleet' were powered by diesel; that has now grown to 17 percent. (Ministry of Transport, 2014). A 'light' vehicle is defined as weighing less than 3.5 tonnes. Over the same time period, the 'heavy' fleet has also grown and now carries 43 percent more freight (measured in tonne-kilometre) than in 2000. (New Zealand Transport Agency indicator FT004).

[56] Approximately 50-90 percent of diesel exhaust particles are ultrafine (United States Environmental Protection Agency, 2002, p. 79).

[57] The allowable level of sulphur in diesel fuel in New Zealand is now 10 parts per million. In the past the allowable level of sulphur has been as high as 2,500 parts per million (Fisher et al., 2002, p.4). Sulphur dioxide causes respiratory problems.

[58] Particulates from diesel exhaust can do this in several ways, including: by damaging pollen grains and causing the release of smaller and more harmful particles; by inducing inflammation that then allows pollen particles to more easily permeate airways; and by directly transporting pollen particles into human airways (D'Amato et al., 2002).

[59] Studies in Auckland have shown measured emissions of carbon monoxide and hydrocarbons from petrol cars have dropped by 44 percent and 63 percent respectively between 2003 and 2011 (Metcalfe et al., 2013). Even more strikingly, studies from the UK have shown a new petrol car that meets current emission standards can produce 95 percent less NO_X than an older engine with no emission controls (Carslaw et al., 2011).

[60] Kuschel et al., 2012.

[61] Metcalfe et al., 2013.

[62] Source apportionment analysis has been done by GNS Science for particulates collected at the Takapuna monitoring site between 2006 and 2013. The analysis shows that on average diesel is the source of 19 percent of particulate matter and petrol is the source of 1-3 percent of particulate matter at this site. The Auckland Council considers the Takapuna site to be the most representative of the city's air quality.

[63] Calculated from Ministry of Economic Development data – Energy Sector Projections: Energy Supply and Demand, Ministry of Economic Development 2010. Much of this increase is predicted to be used for long-haul transport.

[64] In Europe, where in 2011 diesel vehicles accounted for almost 37 percent of the fleet, growing concern about the health effects of diesel exhaust pollution has led some cities to consider penalising polluting diesel vehicles. The Mayor of Paris said recently that she would like to see diesel cars banned from that city by 2020, and the Mayor of London is considering increasing the congestion charge for diesel vehicles that do not meet stringent new Euro 6 emissions standards. (*Journal du Dimanche*, 7 December 2014, *"Hidalgo: La fin du diesel à Paris",* and Office of the Mayor of London, July 2014, *"Mayor calls on EU and Government to do more to help improve air quality"*.)

[65] *"Warming is expected to be associated with …. less frequent cold extremes (high confidence)…"* Intergovernmental Panel on Climate Change (IPCC), 2014, Chapter 25: Australasia, p. 1374

[66] J. Salinger, unpublished data. This data comes from sites in the New Zealand climate database held by the National Institute of Water and Atmospheric Research (NIWA), where there have been no changes to the site location over the period.

[67] WHO, 2006a, p.181.

[68] National environmental standards are regulations promulated under s43 of the Resource Management Act 1991. The National Environmental Standard on Air Quality was promulgated in 2004 and amended in 2010. It contains a variety of compulsory rules that regional councils must comply with. These rules include bans on burning tyres and oil, restriction on the granting of resource consents, and design standards for wood burners. Limits are set on the allowable concentrations of five pollutants in ambient air – carbon monoxide, nitrogen dioxide, ozone, PM_{10}, and sulphur dioxide. An airshed is deemed noncompliant when these limits are exceeded.

[69] Councils that manage airsheds with high numbers of exceedances are to reduce their exceedances to three per year by 2016 and one per year by 2020.

[70] WHO, 2006a, p 276. "*Current scientific evidence indicates that guidelines cannot be proposed that will lead to complete protection against adverse health effects of PM, as thresholds have not been identified.*"

[71] Annual and daily concentrations are correlated, but the relationship is not linear. Emissions Impossible, 2013, p.6.

[72] National Environmental Protection Council, 2014, p.4.

[73] Some of the rules use three year averages for assessing compliance – all three of the United States' rules, and the long term exposure rules for $PM_{2.5}$ in the European Union and Canada. In the short-term exposure rules that allow three or seven exceedances of a limit, the rules are expressed in terms of the 99th and 98th percentile of the distribution of daily averages respectively.

[74] Auckland Council, October 2014, p.4.

[75] Based on samples taken every third day beween 2006 and 2013.

[76] In Auckland, the emissions from ships' engines are a major source of sulphur dioxide, which then reacts to form sulphate. The emissions from diesel vehicles are another source.

[77] European Council, 2008, cl 15.

[78] Councils are also responsible for consenting air discharges from industry, although in most airsheds industry emissions are only a small proportion of the particulate emissions.

[79] *Southland Times*, 17 December, 2014, *"Hicks fears for health of Gore elderly if air plans proceed."*

[80] A heat pump will stop heating a house if ice forms on the evaporator coils; the heat pump reverses and starts taking heat out of the house to melt the ice.

[81] In recent years a landmark research project has quantified the health benefits of making homes warmer and drier. Howden-Chapman et al., 2005.

[82] Houses heated with enclosed solid fuel burners reach the highest temperatures and stay warm for longer. Isaacs et. al., 2010, pp.84-85.

[83] *The Press*, 2 January 2015, *"South dominates bad air statistics"*.

[84] Howden-Chapman, 2012.

[85] About 25 percent of renting households and 17 percent of owner-occupied households have unflued gas heaters (Buckett et al., 2011). In Australia, cabinet LPG heaters that have the LPG cylinder inside the heater casing are prohibited because they do not meet safety requirements (Clough, 2010, p.5).

[86] Resource Management Act 1991, s7.

[87] Butcher and Ellenbecker, 1982, p. 34. The particulate emission factors for wood do vary with the moisture content of the wood – dry wood is much better than wet wood.

[88] Concept Consulting Group, 2012, p. 50.

[89] In Europe people have been encouraged to buy diesel vehicles through measures such as lower taxation of diesel fuel and alignment of vehicle tax with CO_2 emissions.

[90] For example, a Ford Fiesta with a 1 litre turbocharged petrol engine has been tested as producing 99 g CO_2/km, while the same car with a 1.6 litre diesel engine produces 95 g CO_2/km. (Data Ford Europe). In some real-world tests, measured CO_2 emissions from small petrol vehicles were lower than comparable diesel ones (Hagman and Amundsen, 2013).

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